Kingdom of Cambodia: Study of the Influence of Built Structures on the Fisheries of the Tonle Sap
(Financed by the Government of Finland)

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For Cambodia National Mekong Committee

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Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

FINAL REPORT

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KNOWLEDGE SUMMARY

At the Mekong Basin scale, the most significant built structure type evaluated by the TA was large-scale dams and associated reservoirs. The hydrological modeling analysis shows that upstream damming in "intensive" and "extreme" development scenarios could reduce inflows to the Tonle Sap Lake by 10 to 25% in dry years. The annual flood could also be delayed for up to a month and end two weeks earlier than normal.

Upstream damming would increase river discharge in the dry season, and expand the surface area of the Tonle Sap Lake by 300 to 900km². These rising water levels would result in permanently inundating some flooded forests, ultimately killing the trees. It would also have ecological impacts on the floodplain by trapping massive amounts of sediment, likely resulting in reduced fish productivity and soil fertility in some areas.

Dams would have a major impact on fisheries by disrupting migration patterns and routes, since 87% of Mekong fish species for which information is available are migratory. Because these migratory species make up a dominant part of Cambodia's fisheries, dams could seriously impact the country’s economy. The loss of even a small percentage of this fishery represents tens of thousands of tons and millions of dollars worth of fish. While the reservoirs created by dams are sometimes considered a way to create new fisheries upstream, a literature review worldwide shows that this typically would not compensate for the loss of fisheries downstream. In the Mekong, only 9 species are known to breed in reservoirs. Other mitigation measures such as fish passes have not proven effective in the Mekong region, as the intensity of fish migration is so high that it cannot be accommodated by conventional fish passes.

At the Tonle Sap Basin scale, the TA assessed localized influences of roads, irrigation schemes, and large fishing gears. The case study shows that the roads there do not significantly affect water flows in the floodplains thanks to culverts. However, the location and design of roads is key in determining their impact on fish habitat and migration, as well as their management and operation. The road management committee in the study area, for example, prohibits culverts on the road from being blocked by fishing gears, a commendable practice that should be encouraged elsewhere in the country.

Small-scale irrigation reservoirs in the Tonle Sap floodplain so far have had a limited impact on water flows and quality due to the relatively small volume of water they trap. However, the cumulative effect of these reservoirs might be significant if their number continues to increase. The case study shows that irrigation schemes can offer a range of economic opportunities to some villages that directly benefit from them, while villages downstream may suffer a reduction of fish in the river and the rice fields.

Large-scale fishing fences made of bamboo and nylon nets are unique to the Tonle Sap Lake and its floodplain, with the total length of 409km. Experiments show that these fishing fences do not significantly slow the water flows. However, they clearly block fish movements, even more so when nylon nets are attached. A better understanding of fish ecology, including migration corridors, is essential to determine the optimal design of large-scale fishing fences to ensure a sustainable level of harvest.

Overall, the case studies found that negative impacts of built structures do not depend solely on technical and engineering factors; they also depend significantly on the way structures are managed and operated. It is clear that management and social issues associated with built structures, such as access to benefits, use rights and regulations, and operations, can be perceived at the local level as more crucial than the technical design of the structure itself.
A Overview of the project

1. The fishery resources of Cambodia, originating mainly from the Tonle Sap Lake, rank first in the world for their productivity and fourth for their total catch despite the small size of the country. The floodplains contribution to income, employment, and food security is higher than in any other country. However the natural productivity of the Tonle Sap's floodplains is threatened if the flood pulse, the temporarily submerged habitats, and the migration routes of the Tonle Sap are not given attention. In relation to this, the influence of Built Structures, that modify the hydrology of the system, needs to be better assessed at the ecological and socioeconomic levels.

2. Built structures primarily influence hydrology, but they also influence, directly and indirectly, the environment, fisheries and the livelihoods of people who depend on aquatic resources [Kummu et al. 2005]. Figure 1 illustrates a process in which built structures trigger a string of impacts. A given built structure—a small embankment for example—leads to some form of floodplain modification. The flood plain modification then causes direct effects on hydrology and fish, and in turn catalyse changes in the way that people use resources through increased or reduced access to fisheries or opportunities to develop other livelihood aspects. Some of these changes may induce further modifications to the floodplain, such as extension of the embankment or development of paddy fields around it. These modifications will then generate their own impacts on hydrology that can be considered as the “unintended” impacts of the original built structure, i.e. small embankment. The combination of technical, bio-physical and social interactions that result from the introduction of a built structure require a multidisciplinary approach if the impacts, cumulative effects and trade-offs of the new constructions are to be understood.

Figure 1: Process by which built structures achieve impacts
3. In October 2005, the Asian Development Bank proposed a Technical Assistance to the Kingdom of Cambodia for the study of the influence of Built Structures on the fisheries of the Tonle Sap. This 10-months technical assistance was accepted by the Cambodian Government on 26th December 2005, and has started officially on May 1st 2006. The closing date of TA was originally scheduled at the end of February 2007, however, it was later extended for 3 months to 30th May, 2007, in order to allow for sufficient time to incorporate the results of field work in December and January into publication outputs, and for a more thorough review of draft materials by relevant government agencies.

B  Project Administration

4. The project office was established at the Tonle Sap Biosphere Reserve Secretariat (TSBRS), equipped with eight desks, five computers, five backup disks, a printer and with an Internet connection. Initially there were minor problems in setting up the project office as the space provided by TSBRS was not in functional order, and the existing Internet connection was already saturated. However with some additional expenses, the office became operational by the second month of the TA implementation, with the Internet access of the whole TSBR Secretariat being upgraded. The project office was primarily used as the regular work space by the CNMC counterparts, the WUP-FIN consultants, and the domestic consultants.

5. WorldFish Center’s Mekong regional office in Phnom Penh provided financial, administrative, and logistical support to all the TA consultants for implementing their activities in Cambodia throughout the duration of the project. A TA coordinator was added to the project team in order to assist the team leader in setting up administrative and financial arrangements among partners, negotiating subcontracts and oversee their execution, facilitating implementation of field activities, organizing meetings and workshops, and overseeing publication production processes. The additional involvement of the TA coordinator has allowed the team leader to delegate administration tasks, and to focus on research coordination. Three national counterparts respectively from the TSBR Secretariat, from the Fisheries Administration and from the Ministry of Environment were also hired to assist the national project director and facilitate the coordination with these line agencies.

C  Scientific Approach

6. Streamlining the approach of all thematic research components. Having to strike a balance between comprehensiveness and feasibility in implementing the planned activities, and for cross-disciplinary integration of the results, the team resolved a number of issues regarding the scope and emphasis of research: 1) selecting focus built structures; 2) selecting geographic scales of analysis; and 3) selecting sites within each study area.
7. Focus built structures. The Database component identified at least 46 types of built structures\(^1\), which necessitated that a few major types of structures be selected for in-depth study. After extensive discussions between components and an assessment of major existing structures prevalent within the Tonle Sap catchment basin, it was decided that the TA focuses on four main types of structures: dams, irrigation schemes, floodplain roads/dykes, and large-scale fishing gear. Dams are a type of construction whose negative impacts on the environment and fisheries are relatively well known, as well as their benefits for hydropower or irrigation. Irrigation schemes (including canals) combine water retention and land use changes, with subsequent modification of environmental and socioeconomic patterns. Roads in floodplains are almost always associated with dykes; they result in floodplain fragmentation and loss of habitat for fish, while facilitating social exchanges and trade. Lastly, large-scale fishing gear is unique to Cambodia, where fences made of bamboo and nets are set up in the floodplain to concentrate fish into the net; fenced fishing lots now cover 3140 km\(^2\) and each of the current 81 lots uses on average 20 to 40 km of fence. In addition, the influence of these large-scale fishing structures on the lake’s hydrodynamics was previously unknown. Influence of dams was considered through integration into hydrological modelling, mainly at the Mekong level; irrigation schemes and canals were examined through a case study of Stung Chinit; floodplain roads/dykes were studied in Pursat province; and large-scale fishing gears were assessed in the area around Prek Toal.

8. Geographic scales of analysis. The review of existing studies showed that the productivity of Tonle Sap fisheries is a function of extensive local floodplains, fishing effort, sub-basin tributaries—which contribute 30% of the Tonle Sap water, and the hydrological and ecological influence of the Mekong river mainstream. Thus it was necessary to address three scales of influence in the TA: i) Tonle Sap floodplains; ii) Tonle Sap tributaries, and iii) Mekong catchment basin (Figure 2). The contribution of each component to each scale is detailed in Table I. The scale of the Mekong catchment basin has been addressed by the Hydrology and Fisheries components. The scale of Tonle Sap tributaries as well as the local scale were addressed by almost all components.

\[\text{Figure 2: Geographic scales covered by this study}\]

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\(^1\) Created water bodies (ponds, reservoirs, irrigation schemes, irrigation canals, transportation canals, pipes, irrigated areas, stilling basins), constructions (bridges, culverts, tunnels, road embankments, railroad embankments, reservoir dikes, polders, dikes, levees, flood control embankments, ripraps, reinforced banks, flood, gates, sluice, gates, navigation, locks, weirs, docks, dykes, breakwaters, piers, pumping, stations, hydropower, stations, run-of-the-river dams, irrigation dams, diversion dams, check dams, drop structures, spillways, fishways) and large scale fisheries (bag net fishery, river barrage, lake fenced lots, lift nets)
### Table 1: Geographic scales covered by each component

<table>
<thead>
<tr>
<th>Component</th>
<th>Local</th>
<th>Scale</th>
<th>Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Database</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
</tr>
<tr>
<td>Hydrology</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Environment</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fisheries</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Livelihoods</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Policy outreach</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

9. **Selected sites within each study area.** Resolving the issue of selecting specific locations for field data collection was a major coordination challenge faced by the TA. Hydrology, fisheries, and livelihoods components had different requirements in order to successfully detect and document the influence of built structures from a water, fish or social perspective. Much discussion was held among the team members to devise a set of criteria that could accommodate the essential needs of all components. The assessment methods were tailored by component detecting either the difference before/after the construction of a structure, or a spatial contrast, i.e. inside/outside the zone of influence of a built structure and upstream/downstream contrast in terms of the hydrology of streams. A combination of both was used at the Stung Chinit irrigation site. The structures itself had already existed since the Khmer Rouge era and had been influencing local hydrology and fish ecology, while the irrigation scheme was only recently rehabilitated and had just started operating in July 2006, hence too soon to observe significant effects on livelihoods. One overarching criterion was that the sampling locations should be very contrasted in order to better sort out entangled factors inherent to the presence of built structures and to allow generic lessons to be drawn.

10. Existing background information on candidate sites was compiled and reviewed, and pre-survey scoping visits were made to each of the selected study areas in order to determine specific sites that meet the criteria. The tables below list the sites selected for detailed data collection for each thematic component. Each component chose to sample slightly different set of villages/locations to survey because of the nature of the information that was required was different from component and component. In addition to these sites listed below, the Database component and Hydrology component conducted extensive field data collection around Tonle Sap Lake for calibrating the built structure database and the hydrological modelling, which was part of sub-basin and basin scale analysis, and not part of local-scale studies.
11. In Pursat, following locations were identified based upon their position a) in front of or behind a road acting as embankment; b) distance from road access; and c) away form influence of embankment or road.

Table 2: Selected sites around the floodplain roads in Pursat

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Village</th>
<th>Hydrology component</th>
<th>Fish component</th>
<th>Livelihoods component</th>
<th>Socioeconomics</th>
<th>Perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside of influence</td>
<td>Doung Chua</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Krang Veng</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Along the road</td>
<td>Ou Ta Prok Main</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chong Khlong</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kampong Lor</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upland from the road</td>
<td>Ou Ta Prok Up</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moat Prey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Figure 3: Map of the Pursat study site and sampling locations
In Stung Chinit, following sampling locations were selected according to a combination of criteria and of requirements between components (Table 2).

**Table 3: Selected sites around the Stung Chinit irrigation scheme**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Village</th>
<th>Inside/outside</th>
<th>Hydrology component</th>
<th>Fish component</th>
<th>Livelihoods component</th>
<th>Socioeconomics</th>
<th>Perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>La’ak</td>
<td>outside the scheme; loses livelihoods opportunities</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prey Dom</td>
<td>outside the scheme; might benefit from it</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-stream</td>
<td>Sao</td>
<td>inside the scheme; benefits from it</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Sa’ang</td>
<td>outside the scheme; might benefit from it</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Downstream</td>
<td>Thnot Chrum</td>
<td>outside the scheme; loses livelihoods opportunities</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 4: Map of the Stung Chinit study site and sampling locations*
13. In the study area near Prek Toal, following sampling locations were selected based upon their location with regards to the fishing lot number 2, and the lake. Thvang was selected as it is located on the northern bank of the Sangke River, formerly within the fishing lot number 3 which was abolished in 2000. The distance to the Prek Toal conservation area and the livelihood opportunities derived from it was an additional element of stratification among the villages.

**Table 4: Selected sites around the fishing lots number 2**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Village</th>
<th>Hydrology component</th>
<th>Fish component</th>
<th>Livelihoods component</th>
<th>Socioeconomics</th>
<th>Perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influence of fishing lot #2, near the lake</td>
<td>Peak Kantiel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>(no community fisheries area)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influence of fishing lot #2, near the lake</td>
<td>Prek Toal</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>(with community fisheries area)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Far from fishing lot #2 and the lake</td>
<td>Thvang</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>(with community fisheries area)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Prek Toal and Thvang</td>
<td>Anlung Ta Or</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kampong Prahok</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5: Map of the Prek Toal study site and sampling locations**

14.
Integrating the results of all thematic research components. Part of the scientific coordination consisted in making sure that the various components would be clear about the issue they would contribute to or share about, and would have a language in common so that they can ultimately be articulated and integrated. At the local scale, the Sustainable Livelihoods Framework was seen as the one best accommodating inputs from all components, as well as a standardized basis allowing comparisons with other Tonle Sap Initiative projects. At the scale of the Tonle Sap basin, three basic thrusts were identified (hydrology, fish, livelihoods) as the components simple enough to allow for integration of the results. At the scale of the Mekong Basin, focus is on hydrology, water management rules and scenarios, as previously adopted by the Mekong River Commission\(^2\). Figure 6 summarizes the approach for integration between components.

\[\text{Figure 6: A conceptual framework for integrating components at different scales.}\]
15. On the practical ground, the interactions between components were worked out, particularly through the identification of variables specific to each component (e.g. road height, water level, fish abundance, income, access rights) and some variables that can be shared among more than one components. This exercise helped each component understand what information the other components need, and assured that each component generated and documented results in a way that could be easily linked with the results of other components, at least logically if not quantitatively.

16. A shared template was developed for preparing the technical report of each component, in order to assure that each component produces the necessary outputs consistent with other components. The concept of integration by the 3 geographic scales was developed into an outline of the synthesis report, and information need for each section was identified through a writing workshop among key IRS and DRS. This process facilitated integration of multiple components results into a consistent framework.
## II TA ACCOMPLISHMENTS

### A Summary of the TA accomplishments

**Table 5: Summary of the project accomplishments**

<table>
<thead>
<tr>
<th>OUTPUTS</th>
<th>ACTIVITIES</th>
<th>MILESTONES ACHIEVED</th>
<th>PROBLEMS FACED</th>
<th>MEASURES TAKEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Creating a database of built structures (Database Output)</td>
<td>1.1 Categories of built structures, focus structures, and the scope of the study are determined</td>
<td>• Report on classification scheme of built structures was prepared</td>
<td>• Determining the scope of built structures for inclusion in the database was difficult, as there are countless small to medium-scale structures that may have cumulative impacts but are difficult to characterize by remote sensing.</td>
<td>• Built structures that are particularly relevant for the hydrological modeling were prioritized.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Focus structures for the TA were determined</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2 Existing information on Built Structures of concern is gathered</td>
<td>• Existing data from line agencies were secured.</td>
<td>• Very little data was available from line agencies. Almost all existing data are outdated because many new structures have been built in recent years.</td>
<td>• Supplemental data were obtained from alternative sources, including conservation NGOs and consultants in other projects.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Supplemental data from alternative data sources were obtained</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Data from JICA and MRC were secured</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In focus study sites road networks, canals, a irrigation scheme, and fishing fences were digitized using orthophotomaps and ground validation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.3 Ground validation of built structures is conducted in selected locations</td>
<td>• Hi-resolution satellite data sources were evaluated for usefulness for the database.</td>
<td>• Ground validation progressed slowly as road condition deteriorated during the rainy season.</td>
<td>• Additional ground-truthing visits to strategic and selective locations were made in order to improve the overall accuracy of the database. This required additional inputs of field consultant.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Ground validation exercises were conducted in Kampong Thom, Siem Reap, Pursat, and Kampong Chhnang provinces</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4 A database of built structures and the data documentation are prepared</td>
<td>• Database of built structures in the Tonle Sap basin was developed, with over 14,000 records, and was refined for faster access and flexible use for the public. Available for public access at: <a href="http://www.eia.fi/bs/">http://www.eia.fi/bs/</a></td>
<td>• It was difficult to identify an appropriate host server that allows free online access to the final database.</td>
<td>• Open Source servers (in commercial sites) were explored as alternative site for setting up the built structure database</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Users’ manual for the database was prepared</td>
<td>• It took longer than expected to populate the database with built structure information, as the data gathering and validation took longer than expected.</td>
<td>• Online access to the database was established through TSBR Environmental Database, which became available towards the end of the TA.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Summary statistics were generated from the database and presented in an additional report.</td>
<td></td>
<td>• The time allocation of the DRS was extended from 4 to 7 months.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Online access to the database was established through TSBR Environmental Database, which became the final repository.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5 Field survey data from other research components are integrated</td>
<td>• Databases with field survey data, reports, and other reference materials were transferred to TSBR Environmental Database.</td>
<td>• Ensuring compatibility with the TSBR-ED web site and interactivity for users of this web site has been challenging</td>
<td>• Programming solutions have been found by the team</td>
</tr>
</tbody>
</table>
## 2. Modeling the impact of built structures on hydrodynamics and water quality

### 2.1 Hydrodynamic model of the Tonle Sap is updated integrating large-scale built structures basinwide
- Detailed hydrological models for the sub-catchments that cover the 3 study areas were prepared.
- Simplified hydrological models for all Tonle Sap sub-catchments were prepared.
- The Tonle Sap water balance model was improved with the MRCS modeling team.
- It was difficult to obtain updated data and information from line agencies.
- Delay in the database component delayed the incorporation of built structures data in modeling.
- While waiting for the built structure data, the emphasis of modeling work was placed on refining, validating, and analyzing the input data other than built structures.
- Tools were developed to facilitate speedy integration of built structure information into the models.

### 2.2 Hydrodynamic model of the Tonle Sap is updated integrating small-scale built structures at selected sites
- Fields surveys were conducted to collect hydrological and water quality data at selected sites in Kampong Thom, Pursat, Siem Reap, and Battambang.
- Model was developed for small scale embankments and channels.
- A scaled-down version of Tonle Sap model was developed for faster analysis of built structures.
- A model of the Stung Chinit irrigation system including DEM, channels, gates and embankments was prepared.
- Existing large-scale model was not able to reproduce in detail the functioning of small scale structures.
- Description of small scale structures was difficult to achieve with reasonable level of accuracy and computation time.
- To achieve reasonable computation time with the built structure data, a simplified version of hydrological models was created for all sub-catchments.
- High-resolution models were developed for selected small/large scale built structures.
- Alternative approaches were tested for improved accuracy and decreased computer time.

### 2.3 Influence of major fishing gears on hydrodynamics is assessed
- Laboratory experiments of the influence of fishing fences on flood retention was conducted.
- Field measurements were taken in Prek Toal area at two different time periods, with and without fishing fences.
- The fishing gears were not in place during the flood season that was covered in the original workplan.
- Impacts of fishing fences are difficult to detect and study especially at large scale.
- Laboratory experiments were conducted to complement the field-based data.
- The time coverage of the field surveys was extended to January, allowing the *in-situ* measurements to be taken when fishing fences were in place.

### 2.4 Baseline and other scenarios with built structures are evaluated
- Four water development scenarios were developed and the results were compared.
- Report on the influence of built structures on hydrology and water quality was prepared.
- The scenario development was delayed due to the delay in the data input from the Database component.
- Identifying water development scenarios that are relevant for the Tonle Sap took a lot of time and efforts.
- Other TA components helped the hydrological modelers to define distinct scenarios that made sense for the Tonle Sap.

### 2.5 Maps and animations summarizing the modeling results are prepared
- Maps and other figures summarizing the results were prepared.
- Resulting quantitative information was complex, and the interpretation of the results into non-technical conclusions was a major challenge.
- Other TA components worked with the hydrological modelers and identified specific results that are easily interpreted and have clear environmental or fisheries implications.
## 3. Assessing the environmental impact of built structures

### 3.1 A literature review on the main consequences of built structures on tropical floodplains worldwide is conducted
- Over 200 publications were reviewed, and over 30 experts worldwide were consulted.
- The final review report was completed, with policy recommendations.
- Too much information of varying quality was available, but not enough time to screen everything.
- Much information was available in grey literature but unpublished and thus difficult to access.
- Expert questionnaire that was meant to capture unpublished knowledge did not generate much response.
- The focus of literature review was redefined, and the criteria to screen out some information were set.
- The questionnaire was re-sent to a fewer number of selected experts.

### 3.2 EIAs and IEEs on the projects within Tonle Sap basin are reviewed and findings and recommendations are synthesized
- Evaluation criteria for the review of EIA reports were set.
- Report on the evaluation of EIAs/IEEs was prepared.
- Recommendations for enhancing the EIA process, impact assessment method and support to the decision-making were identified.
- Significant difficulty in accessing EIAs and IEEs that are scattered across numerous line agencies.
- Delay in finalizing the EIAs review report, in order to incorporate additional references and strengthen the results.
- Collecting EIAs continued throughout the duration of the experts inputs And not only at the beginning of the task as initially planned
- The emphasis of the review was shifted to constraints in implementing EIAs.

### 3.3 Contributions, flaws and gaps of Tonle Sap based environmental impact assessments are identified
- Identified and held consultations with key stakeholders in Phnom Penh
- Knowledge gaps were identified with reference to existing information worldwide
- The coverage of existing EIAs for Built Structures and for floodplain environment was insufficient for the purpose of the review.
- The scope of review was expanded to include a broader range of Environmental Assessments, not just EIAs.
### 4. Assessing the impact of built structures on fishery resources

#### 4.1. Field surveys on the influence of Built Structures on fish production and species ecology are conducted in three study areas

- Numerous reference materials with regards to built structure and fisheries were reviewed and shared with other components.
- Local fish species were comprehensively reviewed for their ecological characteristics.
- The survey methodology using a semi-open questionnaire was developed, tested, and finalized.
- Experienced fishers at each target site were identified, and full surveys were completed at study areas in Pursat, Kampong Thom, and Battambang provinces.
- Fish larval drift surveys were conducted in 4 sites, and the analyses were conducted.
- Existing information on Tonle Sap fish ecology was found insufficient.
- Difficulty in identifying the survey sites that accommodate the data need for all components.
- Difficulty in developing a methodology that has a suitable balance between practicality and details, and that is flexible enough to accommodate the diversity of the selected sites.
- The large amount of time needed for testing questionnaires commanded a slight delay of the full surveys.
- Larval migrations consist of intense peaks that last only 1 to 2 days in each tributary and are unpredictable, which made their monitoring almost impossible and results insignificant.
- Stronger emphasis on collecting traditional knowledge from experienced/knowledgeable fishers.
- Involvement of a specialist in traditional knowledge.
- The criteria for selecting field sites and target built structures were discussed in details with the other components.
- The survey methodology was tested at all three study areas and revised so as to ensure its relevance to the local conditions.

#### 4.2 Fish ecology data and changes in hydrology and water quality predicted by the Tonle Sap hydrodynamic and water quality model are integrated

- A model of Tonle Sap fish production was updated with additional fish bioecology information.
- A report on the relationship between fish bioecology and hydrology was prepared.
- A report on the updated BayFish model of the Tonle Sap fish production was prepared.
- Hydrological modeling was delayed and the fish production model was subsequently delayed until February 2007.
- Coordination between hydrology and fisheries components was enhanced through additional meetings and other direct interaction among the experts, on how to integrate the data smoothly once hydrological model results become available.

#### 4.3 Based on best available information, the influence of built structures on Tonle Sap fish productivity is quantitatively assessed

- Potential influence of built structures on the Tonle Sap fish species that are vulnerable to hydrological changes was assessed.
- Influence of built structures on local fisheries was assessed at the selected study areas based on traditional knowledge.
- Report on the influence of Built Structures on fisheries was prepared.
- Difficulty in isolating the influence of built structures from other factors that affect fisheries in the specific study areas.
- Effects of structures on fish have been quantified as much as possible, but knowledge available basinwide does not allow extensive quantification.
- All documents and studies allowing a quantification of impacts have been used and combined, and emphasis has been put on dominant commercial species.
5. Assessing the impact of built structures on livelihoods

<table>
<thead>
<tr>
<th>5.1 A literature review on the main consequences of built structures on the livelihoods of fish-dependant communities in tropical floodplains worldwide is conducted</th>
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</thead>
<tbody>
<tr>
<td>• A large number of documents was compiled, of which 25-30 key references were used to inform local-scale surveys.</td>
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<tr>
<td>• Consultations were conducted with key informants and experts, including local government line agencies, NGOs, donor projects, and consultants.</td>
</tr>
<tr>
<td>• Difficulty in obtaining unpublished project reports relevant to the Tonle Sap study areas.</td>
</tr>
<tr>
<td>• Contacted relevant agencies and consultants for other TSI projects for unpublished information.</td>
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<tr>
<th>5.2 A field-based assessment of the impacts of local built structures on livelihood of fish-dependent communities is conducted</th>
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<tbody>
<tr>
<td>• Pre-survey site visits and key informant interviews were conducted in Pursat, K. Thom, and Prek Toal sites.</td>
</tr>
<tr>
<td>• Participatory survey methods, questionnaires, and materials were developed and tested in all study sites.</td>
</tr>
<tr>
<td>• Field surveys were conducted at the selected sites.</td>
</tr>
<tr>
<td>• Report summarizing the methods, analyses, the results, the policy recommendations was prepared.</td>
</tr>
<tr>
<td>• Difficulty in identifying the survey sites that accommodate the data need for all components, particularly in Pursat province where a variety of water development schemes are ongoing, including both irrigation structures and floodplain roads.</td>
</tr>
<tr>
<td>• The TA team selected a site with floodplain road, based on local diversity of the sites and relevance to all the components.</td>
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<tr>
<th>5.3 Availability of alternative livelihood is probed</th>
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<tr>
<td>• Focus group discussions were conducted in each of the sites at the Pursat, Kampong Thom, and Prek Toal study areas.</td>
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<tr>
<td>• Report on alternative livelihoods was prepared.</td>
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<tr>
<td>• No major problems encountered.</td>
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</table>
### 6. Informing policy makers and decision makers

#### 6.1 Dissemination strategy and plan are prepared
- Communications Strategy for the TA, including a detailed plan for dissemination of publication outputs, was prepared.
- Completion was delayed in order to incorporate the results of the stakeholder workshop in August.
- An experienced consultant was hired to strengthen the communication and dissemination strategy.

#### 6.2 Consultation and dissemination meetings with relevant agencies are conducted
- First Information Workshop held in Phnom Penh, August 2006 with 48 external participants.
- Stakeholder Review Workshop was held in January 2007 with 50 external participants.
- Final Workshop was held in May 2007 with 98 external participants.
- Identifying relevant agencies to invite was a challenge as they are scattered across numerous Ministries.
- Scheduling the workshop dates that accommodate the CNMC’s busy schedule in attending/organizing MRC-related meetings was difficult.
- CNMC’s membership network was used effectively to secure attendance.
- Planning of workshops started well in advance in order to fully engage CNMC and its member agency.

#### 6.3 Publication outputs are produced in English and translated into Khmer as appropriate
- Synthesis report was prepared both in English and Khmer and endorsed by CNMC.
- Policy brief was prepared both in English and Khmer and endorsed by CNMC.
- 7 short educational video clips were prepared in English, Khmer, and French.
- Scientific background documents (technical reports) were made available as PDF.
- More than 300 PDF files of bibliography have been uploaded in the TSBR-Environmental Database for public access on Internet.
- Securing good quality English-Khmer translation has proven very challenging.
- Thorough review process took time and careful coordination.
- The translated manuscripts and the video clips went through several rounds of reviews and revisions, in particular by CNMC and the Fisheries Administration staff.

#### 6.4 A series of dissemination events (i.e. workshop, briefing) are held
- Press release on the launch of TA was quoted in major Cambodian newspapers, including *Cambodge Soir* and *Rasmei Kampuchea*.
- Project information and updates were published in *Tonle Sap Bulletin*, *Cambodia Weekly*, and *South Eastern GLOBE*, a regional business magazine in English.
- Information on the TA was displayed at an exhibit booth at the Tonle Sap Initiative Forum in March 2007.
- Some video clips developed for the TA were shown at a World Wetlands Day event.
- All the publication outputs were physically delivered to the target audience identified in the Communication Strategy of the TA.
- No major problems encountered.
B Details of the TA accomplishments

1 Creating a database of Built Structures

17. The “Database component” of this project identified and catalogued the built structures of the Tonle Sap Basin, based on existing information from numerous sources such as line agencies and donor projects, validated by extensive ground-truthing exercises around the local study areas. The information compiled in a database was used at first for internal purposes by other research components of the project, facilitating the selection of sites and locations for pre-survey field visits, and later for surveys. The database was then refined further for public access through Internet. More specifically, its objective was to make updated information on built structures available to technicians, managers and decision makers. Key activities carried out include: (i) conducting a scoping study on Built Structure types, identifying the types that are relevant for hydrological modelling and for Tonle Sap, and determining focus Built Structures for the TA; (ii) gathering existing information on Built Structures in the Tonle Sap basin; (iii) ground-truthing the information on Built Structures of concern in selected locations; and (iv) producing a database of the characteristics of Built Structures of concern.

18. Conducting a scoping study on Built Structures. Spatial emphasis was set on the catchment areas through which water flows to the Tonle Sap, and more generally on areas that become inundated during the flood season. The Tonle Sap flooded area shown (in pale blue color) in Figure 4 is mostly confined between national roads nº 5 and 6. The Stung Chinit irrigation project, the project study area in Kampong Thom, is not in the floodplain itself but on the Chinit river, a major tributary flowing into the Tonle Sap.

19. As the first task of the component, The IRS Database Specialist, with support of the DRS, reviewed existing classification schemes of hydraulic structures and prepared a classification scheme for the TA, which groups built structures into a number of broad categories.
categories and rank them based on how they influence water flow and fish movements. An attempt was made to set criteria for identifying built structures that potentially have the most significant influence on fisheries and the environment, for inclusion in the database.

20. Structures in the target area were divided roughly to three categories, large, midsize and small structure. Large structures may have catchment-wide impacts, while midsize structures typically have only regional scale impacts, and small scale structures have only local impacts. A hydrological limit for large structure was defined as a structure that can store or transport 2.5 million m$^3$ water (in a year), or modify existing flows for at least 1 m$^3$/s on the average, or 4 m$^3$/s during peak flow time. A limit for midsize structure was here defined as a structure that can store or transports 0.5 million m$^3$ water (in a year), or modify existing flows for at least 0.5 m$^3$/s on the average, or 2 m$^3$/s during peak flow time.

21. Properties for each structure type was defined and incorporated in the database design. Main characteristics of a structure included in the database are: geographical location, physical dimensions of the structure, flow and volume of water affected, validation information. Additional information such as field video footage and photos of the structures, name of owner or management authority, was also included in the database as available.

22. The final database mainly contains large and mid-size structures. Structures classified into the small category may also be included to database in some cases, for example, if the impact of structure is not known or attributes required for assessing the structure size are not available. The total number of records entered to the database is more than 14,000.

23. Gathering information on built structures of concern. Information on existing built structures was compiled from existing paper maps, databases, reports, inventories, and remote-sensing data from various sources. The information gathered was gradually entered into the database as they became available. The Database Specialists visited multiple government agencies and other organizations as potential data and information sources: Consequently, the five major data sets were secured.

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3 Embankments: 1) Any embankment potentially catching water for more than 2.5 million m$^3$; 2) Embankments higher than 1 m if longer than 2 km; 3) Embankments lower than 1 m are not mapped; 4) Flood water catching embankments with collected water depth 0-2 m, if area > 2.5 km$^2$.

Dams & reservoirs: 1) Dams with reservoir volume larger than 2.5 million m$^3$. For typical reservoir in the area with water depth of 0-2 meters, this would mean an area of at least 2.5 km$^2$ when 1 m average water depth is used in volume computation.

Channels: 1) Channels with average flow larger than 1m$^3$/s, or peak flow larger than 10m$^3$/s; 2) Channels with high water cross section larger than 10 m$^2$.

Irrigation areas: 1) Irrigated areas with field area larger than 2.5 km$^2$.

4 Namely:
   - Department of Hydrology and Rivers Work and Department of Potable Water Supply, MOWRAM
   - Department of Geology and Department of Hydropower, Ministry of Industry Mines and Energy
   - Ministry of Public Works and Transport
   - Department of Fisheries, Ministry of Agriculture, Forestry, and Fisheries
   - Basin Development Program, Cambodia National Mekong Committee
   - Japan International Cooperation Agency, Information Center in Phnom Penh
   - Regional Flood Center, Mekong River Commission
   - Seila Programme, Ministry of Interior
   - Stung Chinit irrigation project office, Kampong Thom
24. Most of the government agencies were reluctant to share the data, despite the official request to these agencies for support and provision of data and information to the TA, issued by CNMC. At the same time, much of the existing data from the government sources turned out to be practically outdated because of the recent developments of new small to medium-scale built structures in the focal areas. Additional data were secured from other data sources, such as NGOs, including Wildlife Conservation Society (WCS), and consultants of other donor projects around the Tonle Sap, to supplement the available data. In addition, built structures for which the information was not readily available, namely floodplain road networks, canals, and fishing fences, were manually digitized based on existing orthophoro maps and entered into the database.

25. **Ground-truthing Built Structures of concern.** The built structure information gathered was checked for accuracy through extensive field-based validation exercises in Kampong Thom, Siem Reap, Pursat, and Kampong Chhnang provinces, with an emphasis on selected study areas. Information on flood retention reservoirs prevalent in Kampong Thom province, and on Stung Chinit irrigation scheme was thoroughly validated in particular. Field-based ground-truthing became increasingly difficult especially in remote areas because of the heavy rain and poor road condition, and difficulty in obtaining GPS data points. In addition to field surveys, high-resolution satellite data from IKONOS was evaluated for its usefulness for the ground-truthing, however, no coverage by the satellite was available for the target study areas. Existing orthophotos were also evaluated, but its usefulness turned out to be limited in some areas. Alternatively, the possibility of an airplane fly-over survey was explored for taking new aerial photos for ground-truthing built structures. However, this option was decided to be unpractical due to the overall cost and the time required for photo analysis. Consequently, additional field-based ground-truthing at strategic and selective locations was conducted to improve the overall accuracy of the database.

26. **Producing a database of built structures.** The Database Specialists, with inputs from the Hydrological Modeling Specialist, designed and developed a database of the built structures, which is publicly available for online access at EIA Ltd. web site (http://www.eia.fi/bs/) and at the Tonle Sap Biosphere Reserve Environment Information Database (TSBR-ED) web site (http://www.tsbr-ed.org/en/ --- the database access currently limited to registered users of TSBR-ED only) (Figure 8). The database structure went through a few rounds of refinements for faster access and flexible use. The database is now populated with over 14,000 records of built structure information. Discussions were held with the team who are implementing TSBR-ED, and technical solutions were devised to allow easy integration of the built structure database into TSBR-ED. TSBR-ED has been designated as the host of the final database and other associated databases, publications, and reference materials, and its staff will be responsible for making the data publicly available after the life of this TA.

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5 Namely:

- JICA 1999. Land use map simplified for Tonle Sap floodplain
- MRC Basin Development Plan and recorded infrastructures in the Tonle Sap floodplains
- Ministry of Public Works and Transport, data about bridges and culverts
- Seila program data about construction project locations
- Stung Chinit irrigation scheme data
2 Modelling the influence of Built Structures on hydrodynamics and water quality

27. This component uses the Tonle Sap 3D hydrodynamic and water quality model previously developed by WUP-FIN in 2001-2003, supplemented by the Mekong model subsequently developed. The overall objectives of the modeling component was to a) integrate Tonle Sap built structures data into a functional hydrological modeling framework and b) produce information on the influence of built structures on hydrology and water quality. The integrated model framework encompasses topography, land use/vegetation, water bodies (river channels, lake proper), meteorology, hydrology, monitoring data and built structures. This framework integrates data in a way that corresponds to the naturally occurring functional relationships and thus enables dynamic analysis of the system. The modeling output data was generated for analysis by the Fisheries component of the TA, which included flow and flooding characteristics, sedimentation, water quality, fish larvae drift (particles representing larvae) and habitat conditions. Not only local effects but also influence of upstream developments was studied with the model and was compared to the local effects in terms of its relative significance.

28. Key activities carried out were: (i) integrating large-scale Built Structures, at the basin level, into the Tonle Sap hydrodynamic and water quality model; (ii) integrating relevant small-scale Built Structures into the WUP-FIN Tonle Sap model; (iii) assessing the impact of major fishing gears on hydrodynamics; (iv) conducting quantitative analysis of
hydrodynamic and water quality differences with and without Built Structures; and (v) producing maps of the differences and illustrative animations of the effects.

29. Integrating large-scale built structures into the Tonle Sap model. The Hydrological Modeling Specialists worked with the Database Specialists to specify the attributes and formats of the built structure data so as to facilitate the use of database outputs for the hydrological modeling. Methods for converting the information on large-scale embankment and channel structure into inputs to hydrological models was developed. Time-series hydrological data were evaluated and formatted for input to the Tonle Sap model. The Modeling Specialists prepared detailed hydrological models for the sub-catchments that cover the 3 study areas. However, developing and including built structure data for the detailed models would take so much time that it is neither practical nor necessary for the project purposes. Instead simplified version of hydrological models were developed and used together with MRC Secretariat development scenario data. Because of the delay in populating the built structure database, the hydrodynamic and water quality model implementation with actual built structures was delayed. However, while waiting for the built structure data, the emphasis of modeling work was placed on refining, validating, and analyzing the model data other than built structures. Tools were also developed to facilitate speedy integration of built structure information into the models. Carrying out these exercises compensated for the delays. The built structure information was fully integrated into the large-scale model before the scenarios were evaluated. (See paragraphs below on scenarios).

30. Integrating relevant small-scale built structures into the Tonle Sap model. The small-scale structures that are relevant to the hydrodynamics of the selected study sites were integrated into the Tonle Sap model. To parameterize the influence of those small structures in the large-scale model, high resolution models of local small structures were prepared. A model for Stung Chinit irrigation system, including DEM, channels, gates and embankments, was prepared with, and without the structures for comparison. In addition, models were also prepared for small scale embankments and channels, and a floodplain irrigation structure in Kompong Thom province.

31. Field surveys were conducted to collect hydrological and water quality data at selected locations in Kampong Thom, Pursat, Siem Reap, and Battambang, covering the early stage, peak, and end of the flood cycle. The data collection and laboratory analyses were designed to detect characteristics in different phases of the flood cycle. Hydrological modelling parameters were upgraded subsequently as new data became available. Data were collected on parameters that form the basis of the functioning of the fisheries in lake-floodplain ecosystems: water levels; currents and inundation; hydrodynamic connectivity of channels and ponds; sediment transport and sedimentation; and water quality (TSS, DO, inorganic nutrients). Standard sediment and water quality sample analyses were conducted in Ministry of Water Resources and Meteorology (MOWRAM) laboratory, complemented by analyses done by the laboratory of the Research Development International Cambodia (RDIC) for inorganic nutrients. Specialized sediment nutrient bioavailability analyses were also conducted in Finland from the Tonle Sap sediment samples.

32. Assessing the impact of major fishing gears on hydrodynamics. In the original plan, the effectiveness of this activity was constrained by the fact that the time period available for field-based data collection during the TA implementation did not cover the fishing season in Cambodia, when large-scale fishing fences are in place. The scope and duration of
the field work was later extended to assure that the field measurements were taken with the fishing fences, enabling on-site assessment of the influence of fishing gear on local hydrology. In addition, laboratory experiments were conducted using bamboo fences and nets typically found in Tonle Sap fisheries, to recreate the condition similar to that created by fishing gears in a controlled environment. The results of preliminary experiments tend to indicate contrary to the local belief that the fences play a significant role in the lake’s hydrology, i.e. slowing down the receding flood. Additional field work during the receding flood yielded results that are generally supportive of the laboratory-based work.

33. Analysis of the hydrodynamics and water quality differences with and without Built Structures. Four water development scenarios described below were developed, using the MRCS development scenario simulation outputs, and evaluated for their potential implications on a number of hydrological parameters for the Tonle Sap, including water level, flood regime, hydrodynamics, and water quality. The results of each scenario were compared for the relative importance at basin and sub-basin scales.

- **Baseline scenario**—represents the existing level of water storage based on the actual situation in 2000 when there was only one hydro-electric dam in the Upper Mekong Basin with a relatively small water-storage capacity of less than one cubic kilometer.

- **Intensive basin development scenario**—represents a combined water-storage capacity of 55 cubic kilometers, assuming that seven more hydro-electric dams are built across the mainstream by 2025 in the Upper Mekong Basin. This assumes that China and Lao PDR will each have a water-storage capacity of about 23 cubic kilometers, including almost five cubic kilometers for the Nam Ngum 1 reservoir alone. Thailand and Viet Nam would account for the remaining nine cubic kilometers.

- **Extreme basin development scenario**—adds to the second scenario seven more dams on the Mekong mainstream in Lao PDR, Cambodia and Thailand, boosting the total storage capacity to 140 cubic kilometers. The additional 85 cubic kilometers would come from dams in Lao PDR (Luang Prabang, Pa Mong, Thakek and Pa Mong), Cambodia (Stung Treng and Sambor) and Thailand (Sayabouri).

- **Limited development scenario for the Tonle Sap watershed**—assumes a combined storage capacity of 5.5 cubic kilometers. This adds to the baseline scenario the hydro-electric and irrigation dams on seven tributaries that flow into the lake, notably Stung Sen.

34. Producing maps and illustrative animations. A series of team meetings in October – November 2006, and a synthesis workshop among the TA components held in January 2007 resulted in guidance to each component in terms of how to summarize their results so that they can be integrated with the results from other components in meaningful way. Numerous maps, figures, and tables were prepared, summarizing the results of the scenarios in a simple manner. The figures below are some examples comparing the results of different water development scenarios for the Tonle Sap.
Figure 9: Tonle Sap water levels under Baseline, Intensive Development, and Extreme Development scenarios.

Figure 10: Upstream developments result in floods ending sooner. The legend indicates the change in the duration of flood between the Baseline and Intensive Development scenarios. Longer period of inundation near the lake edge (highlighted in graduation from red to blue) is caused by increased water levels during the dry season.

3 Assessing the influence of Built Structures on the environment

35. This component reviewed scientific literature and local impact assessments on the known effects of Built Structures of concern on the environment. The resulting recommendations were derived from information regarding experiences on a world-wide scale with specific findings from the Tonle Sap. Its specific objective was to analyze lessons learnt from tropical floodplain ecosystems worldwide and from Tonle Sap Environmental Impact Assessments to produce useful guidance for further development of built structures in the Tonle Sap basin.
36. Key activities conducted were: (i) reviewing the documented short-term and long-term influence of Built Structures in tropical floodplains worldwide; (ii) synthesizing the findings and recommendations from environmental impact assessments (EIAs) and initial environmental examinations (IEEs) conducted for development projects in the Tonle Sap basin, existing EIA guidelines, and other secondary literature on the EIA processes, from environmental and social safeguard perspectives; and (iii) providing recommendations about the approaches, methods, and processes followed by EIAs and IEEs in the Tonle Sap basin.

37. Reviewing the documented short-term and long-term influence of built structures in tropical floodplains worldwide. Lessons learnt worldwide on the consequences of built structures on the ecosystem as a whole was reviewed and the general conclusions and recommendations drawn from other tropical floodplains to the Tonle Sap were assessed. To screen the wide variety of information available on the subject and to filter out the information that are not well documented or substantiated, this assessment concentrated on information of quantitative nature, and on lessons learnt in other countries with environmental or social similarities to the Tonle Sap.

38. The Environment Impact IRS conducted literature search using internet as well as university library databases and resources; over three hundred documents were reviewed, including journal articles, reports, and books on the subject. In addition, over 60 key experts and institutions working on floodplain environment conservation/management issues were contacted to gather information that were not readily available in published literature. All the data and information collected were systematically reviewed and synthesized, including the creation of a table specifying, for each significant study, the location, references, type and size of structure, and the recorded impact. Key tropical floodplains reviewed include: the Amazon and the Parana River systems in South America, the Senegal and the Niger in Africa, the Brahmaputra and the Mekong in Asia, and Australian floodplains. Initial analyses highlighted the fact that there are a large number of papers vaguely addressing this issue, without providing any quantitative evidence of changes; hence the need to focus primarily on post-development studies including a quantified approach was identified. A technical report was prepared documenting the findings, list of literature reviewed and the experts consulted, and also with the policy recommendations which were integrated into the synthesis report summarizing the research results of the TA.

39. Main findings of the worldwide review are the following:

- Information on the influence of built structures on tropical floodplain ecosystems are very limited
- Little quantitative and published information is available on impacts of built structures other than large dams
- Large dams have caused hydrological alteration, changes in biogeochemical processes, impacts on biodiversity, and pollution, and can also affect downstream floodplain environments strongly
- Smaller, but numerous built structures such as embankments, channels and dykes, have more localised effects on flood plains, but most probably lead to significant cumulative impacts
- Regardless of continent, disruption of flood pulse and lateral and longitudinal connectivity of floodplains by built structure generally result in loss of ecological services of floodplains
Compensating for lost floodplain ecosystem services is hard, if not impossible, through conversion of the floodplains to other land use such as crop cultivation and livestock grazing.

It is possible to partially recover the lost floodplain ecosystem services through rehabilitation efforts, while restoring the complete variety of floodplain ecosystem services is extremely difficult and costly.

40. Synthesizing the findings and recommendations from Tonle Sap EIAs and IEEs. The Aquatic Impact IRS and the Environment Impact DRS conducted a review, from a fisheries perspective, of the environmental impact assessments of existing and planned built structure projects in the Tonle Sap area. After initial efforts in identifying and compiling the relevant Environmental Impact Assessments (EIA) and Initial Environmental Examinations (IEE) reports, the scope of the review was expanded to include CEA (Cumulative Effects Assessments) and SEA (Strategic Environmental Assessments), due to the general paucity of the EIA and IEE reports referring to the Tonle Sap area. Inclusion of SIA (Social Impact Assessments) was initially considered for the review, however, no SIA was found within the timeframe of the review. Difficulty in identifying and accessing EIAs and IEEs that are scattered across numerous line agencies at different levels of authority also resulted in some delay in securing the relevant documents in time.

41. The original focus of the review was to evaluate the quality of impact assessments in terms of its analytical and predictive capability of impacts of built structures on the fisheries of the Tonle Sap. In face of the paucity of the EIA reports, an adjustment was made to shift the emphasis from evaluating impact assessments per se to improving understanding of the reasons underlying this lack of EIA reports, namely, the EIA process. To this end, increased efforts were made to compile secondary information on EIAs with regards to its approaches, methods, and recommendations, and to review this information in order to define the best working alternatives for conducting effective EIAs for floodplain ecosystems in the future. Unpublished secondary literature was identified, and understanding of the transparency of EIA processes and the accessibility of the related information to civil society groups in general was enhanced through stakeholder consultations. The IRS and DRS identified 10 key stakeholders and conducted meetings with them, including Fisheries Action Coalition Team, NGO Forum on Cambodia, EIA Department of Ministry of Environment, Tonle Sap Initiative Coordination Unit of ADB, TSBR Secretariat, Public Works Research Center of Ministry of Public Works and Transport.

42. The EIA and IEE reports and relevant secondary information were collected from various institutions and organizations such as the Ministry of Environment, donor government agencies, and local NGOs. Key official documents and grey literature in Khmer language were translated and summarized in English. The key documents reviewed include:

43. Data and information from the available reports were analyzed for the evaluation of EIAs and IEEs, based on the following criteria:

- **scope**: consideration of fisheries (Y/N)
- **methodology for impact assessment**: rapid and/or detailed, before-after or impact-control assessment; quantitative and/or qualitative; participation of stakeholders (Y/N); interdisciplinary and/or inter-sectoral; use of precautionary approach (Y/N)
- **results**: quantitative and/or qualitative; support to management recommendations
- **recommendations**: adequacy of mitigation and/or enhancement measures, feasibility, cost-efficiency, monitoring of implemented measures.

44. The results on EIA review have been summarized into a technical report, highlighting key constraints (e.g. institutional arrangements, local resources), quality of impact assessment, adequacy of compensation measures, and lessons learnt.

Main findings of the EIA review are the following:

- Lack of coordination among relevant agencies with regards to EIA implementation, and limited influence of MOE in the process
- Insufficient coverage of EIAs – many large to medium-scale built structures have never gone through EIA
- Gap between the recommendations of EIA/IEE and actual implementation of the projects
- Quality of impact assessment widely varies in terms of scope, predictive capability, and adequacy of the recommendations
- Lack of monitoring and evaluation of implemented measures

45. Providing recommendations about the approaches, methods, and processes followed by EIAs and IEEs in the Tonle Sap basin. Based on the main lessons from the two reviews conducted, main strengths and limitations of Tonle Sap EIAs, and key recommendations for conducting environmental impact assessments of projects, including built structures, were identified. A particular emphasis was placed on the need for assessing cumulative impact and the way to overcome their absence in individual project-based impact assessments. The scope was broadened to include EIA implementation process in general, not just methods for built structure projects, drawing from the knowledge and experience of stakeholders gained through informal consultation and documented in secondary literature.
46. This component assessed the consequences of Built Structures on fishery resources, and their weight in relation to other environmental factors using a variety of tools (questionnaires, biological surveys, modelling). The study was three-fold: one sub-component identifies the changes in composition and abundance of the catch between sites under the influence of built structures or outside their influence. The second sub-component matched this ecological and historical information with the changes in hydrology and water quality derived from the work of the Hydrology component. In a third sub-component, the conclusions of the previous studies were integrated into the BayFish model of Tonle Sap fish production, previously produced during the TA projects “Capacity building of IFReDI”, Phases I and II\(^6\), so that the influence of hydrological changes resulting from built structures on fishery resources can be quantified and the influence of these structures compared to that of other environmental parameters can be weighted.

47. Key activities included (i) surveying local knowledge on the influence of built structures on fish production and species ecology in specific study sites; (ii) matching changes in fish resource to changes in hydrology; (iii) forecasting the influence of hydrological changes on fishery resources; and (iv) quantifying, based on available information, the influence of Built Structures on Tonle Sap fishery resources.

48. Influence of built structures on species and catch. Numerous reference materials with regards to built structure and fisheries were collected from a variety of sources and the information in these documents were reviewed for its usefulness for the TA. While much information is available for the Stung Chinit and Prek Toal areas, lack of information on built structures in Pursat presented considerable challenge in selecting specific sites. To overcome this problem, the team conducted extensive consultations with key local informants, including governments and NGOs.

49. Literature review was conducted for Tonle Sap fish species diversity and ecology. 192 local fish species were comprehensively reviewed for their ecological characteristics, such as length and trophic level, and selected into groups of indicator species for assessing specific element of the influence of built structures on fisheries:

- 30 fish species selected for documenting the change in fish catch and fishing effort;
- 9 species selected for studying migration patterns; and
- 20 species for collecting new ecological information.

50. During the process of the review, it was discovered that the Tonle Sap has almost 300 species, making it the third-richest lake in the world in terms of fish specie diversity. 296 fish species are actually found in the Tonle Sap, more than twice the number recorded before. That ranks the Tonle Sap just after Lake Malawi (433 species) and Lake Tanganyika (309 species). Overall, the Tonle Sap has 23 species whose annual migrations are triggered by changes in water levels, and another 3 species triggered by changes in water flows. These fishes, accounting for about 10 percent of the species documented for the Tonle Sap, are particularly sensitive to the hydrological changes.


ADB 2005 Technical Assistance to the Kingdom of Cambodia for capacity building of the Inland Fisheries Research and Development Institute Phase II (TA 36634-CAM)
consequences of infrastructure development such as delays in the arrival of floodwaters, increased water levels in the dry season and changes in the speed of the current. The impact of changing water levels on the remaining 90 percent of Tonle Sap species is still unknown.

51. Because existing information on fish ecology—particularly feeding, spawning, nursing habitats, and migration patterns of some local fish species—is generally poor, and the limited seasonal coverage of the TA period does not allow for effective field-based data collection on fish ecology, a stronger emphasis has been placed on collecting traditional knowledge from experienced/knowledgeable fishers.

52. The surveys of traditional knowledge on fisheries and fish ecology were designed to collect qualitative information from carefully selected knowledgeable informants, fishers, as opposed to the Livelihoods component's approach that covers all social groups present. A survey methodology using a semi-open questionnaire was developed and tested at all three of the study areas to ensure its relevance to the local conditions. Initially, the team encountered some challenges in developing a methodology that has a suitable balance between methods that engage the fishers, are easy to use and that can produce data with the necessary level of detail in the available time. The diversity of selected sites—in terms of biophysical environment and fish species compositions—also raised some issues relating to the identification of what type of impacts of built structures can be documented at each site and how. For example, at Stung Chinit the structure was very new and it was therefore difficult to identify the actual changes in the fishery that can be attributed to the structure itself; at Prek Toal many of the impacts were due less to the structure itself (i.e. the fencing) than to the associated institutional arrangements and it was hard to disentangle these in practice.

53. Acknowledging the importance of getting the survey method right, a few additional rounds of field testing of the questionnaire were conducted, including testing at each of all three study sites. Thanks to this additional effort it was ensured that the methodology was sufficiently flexible to be used in the three very different sites. The increase in the time needed for testing meant that the survey schedule was slightly delayed. However, the information generated during the testing was shared with other components, yielding some useful insights for their surveys and helping define the scope of each component more clearly. The survey methodology was finalized with the revised questionnaire and visual tools with which both the surveyors and the fishers were comfortable.

54. 60-80 experienced/knowledgeable fishers were selected at each target area (about 12 per village) based on a set of criteria, by provincial fisheries officers and village/commune heads. The selection criteria were: between the age of 40-60 years old; with 10-15 years experience fishing; currently active in fishing; well-known for fishing skills in the village; and the fishers selected from same village fish at different location from each other. Using the finalized survey tools, full surveys were completed at the sites in Pursat, Stung Chinit, and Prek Toal. The survey collected a variety of information, including fish catch by gear and species in each season, changes in catch—i.e. fish size and species composition—local fish migration, fish price, flooding areas, fish habitat and fishing location. All the survey data was entered into a database so that systematic analyses can be conducted.

55. In addition to collecting traditional knowledge of fishers, fish larval drift surveys were conducted in 5 locations—Stung (means river) Pursat, Stung Chinit, Stung Stoung, and
Stung Sangkae and the Prek Toal floodplain—to strengthen the bioecological information on Tonle Sap fishes. The sites were selected to compare the patterns of larval drift at locations where influence of built structure is present or absent. For example, the team collected fish larvae drifting down the river with a net at two sites (i.e. Stung Stoung and Stung Sangkae) where there is no apparent influence of a major built structure. Initial analysis of the larvae sampling indicate that significant amount of fish larvae drift from far upstream of Tonle Sap tributaries into the lake at the onset of rainy season, highlighting the importance of connectivity between the upper reach of tributaries and the lake proper. The larval field survey was completed in September and the laboratory analysis of specimens was conducted for species identification and calculating dry and wet weight. Overall the results of this survey have been quite disappointing; the lesson being i) fish larvae migrate during intense and very brief peaks of 1-2 days, the date of these peaks being unpredictable; ii) the expertise available in Cambodia does allow proper locally-driven surveys and studies of fish larvae.

56. Matching changes in fish resource to changes in hydrology. The information on changes in the fishery resources collected during the surveys was interpreted by comparing them to changes in hydrological regime, as synthesized and quantified by the work of the Hydrology component. A series of technical discussions about variables in common between both models were held for bridging hydrological and fisheries models together. Parameters such as water level, changes in flows, extent and length of flooding, were identified as having strong relevance to at least 26 species, which account for about 10 percent of the species documented for the Tonle Sap.

57. Forecasting the influence of hydrological changes on fishery resources. The above results were integrated into a broader framework encompassing other environmental and fishery parameters, and upgraded the model of fish production for the Tonle Sap. A technical documentation for this upgrade was prepared, in addition to the report summarizing the information linking fish bioecology and hydrology for the Tonle Sap.

58. Quantifying the influence of built structures on Tonle Sap fishery resources. An analysis of the literature and integration of results of previous projects demonstrated clearly the important impact of upstream dams on Tonle Sap fish resources. This impact was quantified as much as possible but overall the quantification remains limited and disappointing; this is due to the very limited number of scientific studies available despite significant awareness raised by the MRC and other players over the last decade. At the local level the relative importance of potential hydrological impacts and water quality impacts of Built Structures on Tonle Sap fisheries was compared, based on the existing literature as well as bioecological information collected for the TA. It was not possible to quantitatively weigh these different types of hydrological impacts on fisheries, as there is still large information gap in terms of potential habitat change caused by hydrological changes. Effect of change in hydrological triggers of fish migration on fisheries productivity are still unclear. For example, reduced sediment inputs to certain areas of the lake, prolonged inundation of areas with flooded forests, which may cause loss of flooded forests. Another uncertainty lies in the implication of changes in oxygen load to the lake’s water on survival rate of fish larvae and eggs. Further scientific investigation on these issues need to be explored to estimate true influence of hydrological changes on the lake’s fisheries.
5. **Assessing the influence of Built Structures on livelihoods**

59. The study conducted under the Livelihoods component was two-fold: i) assessing the influence of Built Structures on the livelihoods of Tonle Sap communities and ii) examining the availability of alternative livelihoods for aquatic resource-dependent communities. The first sub-component assessed changes in the people’s livelihood strategies and outputs derived from fisheries, in terms of changes in activity patterns, vulnerability, resource access, diet and food security, and income. It also captured people’s perception of the interconnectivity between hydrology, built structures, environment, fisheries and livelihoods, as well as their viewpoints on best practices for built structures. In absence of alternatives, loss of natural capital to the people living in and around Tonle Sap areas can hamper their ability to sustain their livelihood, thus increasing their vulnerability to poverty. In the second sub-component, alternative livelihood options and strategies as well as constraints were probed, and recommendations on enhancing other elements of livelihood assets were developed, such as human, physical, and financial capitals, and relevant transforming structures and processes that enable such enhancements.

60. **Assessing the influence of Built Structures on the livelihoods of Tonle Sap communities.**
A literature review was conducted to gather information on the consequences of built structures on fisheries-dependent livelihoods in tropical floodplains around the world and from the region, including reports from particular donor projects around Tonle Sap. The purpose of this activity was to identify key issues that need to be addressed in the assessment of potential influence on fisheries-dependent communities in the Tonle Sap area. A large number of existing reference materials were compiled, and of those, 25-30 were used to inform the development of survey methodologies. Obtaining unpublished project reports from the past was particularly difficult. Thus the information was also gathered through consultation with government agencies and consultants working on relevant donor projects around Tonle Sap, such as the Sustainable Livelihood Project, the Participatory Poverty Assessment, and the Lowland Stabilization Project of ADB, and the Tonle Sap Conservation Project of UNDP.

61. A series of pre-survey interviews and consultations were held at various locations in Kampong Thom, Pursat, and Battambang provinces, to identify specific field survey sites and to collect background information to guide the design of survey questionnaire. The key informants and stakeholders consulted during the pre-survey activities included: Provincial Departments of Agriculture, Fisheries, Rural Development, and Water Resources; District officials of Rural Development; GRET (a French NGO); Centre d'Etude et de Développement Agricole Cambodgien (CEDAC), Osmose, KNC, and FACT (Cambodian NGOs); and Leucaena (a Japanese NGO). All these NGOs implement projects locally in the three selected provinces.

62. Through extensive field visits and discussions with other research components of the TA, especially the Fisheries component, the team achieved a compromise where both components can generally meet their needs. In Kampong Thom, The Livelihoods team visited 8 places/villages and selected 2 villages, Snao and Sa’ang. In Battambang, the team visited 5 places/villages and selected 2 villages, namely Prek Toal and Thvang villages in Koh Chivang commune. In Pursat, the team visited 10 sites/villages and selected Chong Khlong and Ou Ta Prok.
63. The main compromise made during the site selection was the new Stung Chinit irrigation scheme, as the irrigation scheme had been operational only for a few months and the benefit was unlikely to be reflected in the survey results. However, this challenge was addressed by some modifications to the survey methods. For the survey areas with relatively new built structures, the Livelihood component included ex-ante analysis and assessment of anticipated benefits/negative change caused by the structure based on the local perceptions and operational plans for the built structure.

64. The sites were selected with an aim of capturing diversity of experiences with regards to built structures, which inevitably lead to difficulty in developing a standardized survey format that was flexible enough to collect site-specific information. Another challenge faced by the team was the difficulty in crafting the questions so that they can isolate the influence of built structures among many other factors that affect livelihoods. Draft questionnaires and checklist for interviews and surveys were tested in Pursat and Kampong Thom by the socioeconomic survey team. It took several rounds of testing and revisions to refine the tools so that they were easily used by the enumerators, easily understood by the interviewees, and focused enough to gather information specific to the influence of built structures.

65. Full set of data collection activities—community surveys, household surveys, and participatory village surveys, including group discussions and in-depth interviews of key stakeholders—were conducted at the selected sites in K. Thom, Pursat, and Prek Toal study areas. The results of household surveys were entered into the database and quantitatively analyzed using stratified grouping of households by the main income generating activity and wealth status, with emphasis on changes in livelihood activities, income, income sources and income portfolio, and the role of assets endowments. Inconsistencies in the results of quantitative and qualitative assessments were identified for and possible explanations for the inconsistencies were explored during the process of synthesizing the results from all the research components. The data interpretation and entry into the database was particularly time-consuming, and required additional support personnel to be hired to speed up the process.

66. Examining the availability of alternative livelihoods for aquatic resource-dependent communities. The data collected through the field surveys were analyzed specifically to identify issues for focus group discussions among selected survey participants, with regards to alternative livelihoods strategies. Focus group discussions were organized in two villages in each of the three study sites, with participants selected to have a balance in gender, wealth groups (poorer, medium, and richer). The village chief and vice-chief were also included in each focus group, for a total of 10-12 people per group. Existing and alternative livelihoods scenarios were discussed and evaluated by the focus group participants. Constraints to livelihood diversification were identified and ranked, as well as suggestions about addressing these constraints. The results of these discussions have been integrated into recommendations of the main technical report documenting the overall results of the Livelihoods component. A supplemental report on alternative livelihoods was also prepared, detailing the results of this particular activity.
6. **Informing policy makers and decision makers**

67. The purpose of this TA was to improve the awareness and understanding of Government agencies and policy makers regarding the influence of built structures on the lake’s hydrological regime, fisheries, and livelihoods. This required that key findings were translated into products appropriate for target audiences and readily accessible. As the other components of the TA were primarily about generation of new knowledge, the sixth output of this TA focused on the dissemination of research results in a form that was accessible to decision-makers in particular\(^7\).

68. Key activities included: (i) A synthesis of lessons learned culminating in a policy brief; ii) preparing a set of guidelines about approaches and methods that would minimize the negative influence of built structures while maximizing their beneficial outcome; and (iii) disseminating the policy brief and guidelines.

69. A communication strategy was developed to guide the overall approach of this component, in close collaboration with CNMC. This strategy characterizes the different stakeholders, defines the format and content of the appropriate communication products, and evaluates the possible delivery systems or communication channels. The completion of the communication strategy was slightly delayed from the end of July to mid August, in order to reflect the results of the first stakeholder workshop on August 2\(^{nd}\). CNMC took a lead in implementing the plans outlined in the strategy, with support from the TA consultants. The main role CNMC played during the TA implementation was to communicate to relevant government agencies about the plans and activities of the TA and seek their feedback and support. An official letter of request for support signed by the Chairman of CNMC was issued to relevant government agencies, in terms of facilitating access to information and documents, as well as supporting the field work in provinces.

70. As identified in the Communication Strategy, a number of publication products were developed toward the end of the TA, in order to communicate the results and the recommendations of the TA to different set of target audiences. Two main publications are: a Synthesis Report, which integrates the key scientific findings of the thematic studies described above, into a coherent narrative with conclusions and recommendations; and a Policy Brief, which presents the conclusions and recommendations in a much shorter, less technical narrative. The contents of these reports were informed by the stakeholder feedbacks during the two consultation workshops organized by the CNMC and WorldFish, as described below. The original draft contained a set of “guidelines” aiming to inform decision-makers for planning built structures that potentially affect Tonle Sap fisheries. The draft was officially reviewed by the CNMC, and upon CNMC’s request, the term “guideline” was replaced with “recommendation”, which does not have connotation of a binding agreement. After full endorsement by CNMC, both documents were translated into Khmer language, and went through another round of thorough editing and review by WorldFish scientist and CNMC in order to assure the accuracy of translation. (See Section III: Communication Products for more details. Also see Table 6: Products and Dissemination Targets Achieved in Section VI: Dissemination of Publication Outputs).

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\(^7\) Advice on linking research to practice is provided at http://www.adb.org/Projects/Tonle_Sap/.
71. The progress of the TA was presented to key stakeholders at different phases of the implementation, as planned in the communication strategy. The First Information Workshop was held on August 2nd in Phnom Penh, to introduce the TA to key stakeholders and to seek their support and feedback. It was organized jointly by WorldFish and CNMC, and chaired by H.E. Sin Niny, the Vice Chairman of CNMC. About 48 external participants—27 representing government agencies in Phnom Penh, 7 from provincial departments of agriculture, fisheries, or water resources, and 14 NGOs—attended the workshop. Presentations were given on the overview and the objectives of the TA and the on-going and planned activities under each research component, followed by Q&A and open discussion. In his opening address, H.E. Sin Niny highlighted the importance of addressing the issues associated with built structures and the needs for a clear legal framework and collective efforts among all parties concerned, including government institutions, local authorities, international organizations as well as civil society organizations. His contribution was instrumental in setting a positive tone for the presentations that followed. In his closing remark, H.E. also gave a strong endorsement to the TA and urged all the participants for assistance and close cooperation during the course of the TA implementation.

72. There was active participation and strong interests from the participants, especially from those who were representing provincial line agencies. This was very encouraging because these provincial officials are the ones dealing with day-to-day decisions associated with built structures. Emphasizing the scientific nature of the TA and its balanced, inter-disciplinary approach to look at both negative and positive influence of the built structures, generally ensured that the feedback was positive and constructive. The key comments repeatedly expressed by the participants during the Q&A and discussion were the following:

- A study of the influence of built structures is appropriate and timely, and its results would be useful to policy-makers as new privately-owned built structures (i.e. irrigation reservoirs) are mushrooming in Kampong Thom and Pursat provinces in particular. These structures have become a concern for several line agencies because they are constructed and operated out of any formal regulatory framework;
- The TA, with its emphasis on trade-offs between positive and negative aspects of built structures, is much welcome;
- Results of the study should be made widely available, particularly at the provincial level, since province agencies typically never get any information back from projects they contribute to;
- Scientific rigor of the TA is compromised because the duration of the study does not cover a full one-year cycle despite the seasonal variability in fishing activities and livelihoods that is characteristic in Cambodia; and
- A follow-up study or at least an extension of the current study will be desirable in order to cover the full fishing season.

73. The Stakeholder Review Workshop was held in January 2007, in Phnom Penh, to present the preliminary results of the TA to key stakeholders and to seek their feedback and suggestions. It was organized jointly by WorldFish and CNMC, and chaired by H.E. Sin Niny, the Vice Chairman of CNMC. Approximately 50 external participants—30 representing government agencies in Phnom Penh, 5 from provincial departments of agriculture, fisheries, or water resources, and 15 NGOs and donor agencies—attended the workshop. Each research component gave a presentation on the activities and the preliminary results, and draft recommendations, followed by Q&A and open discussion.
Level of participation was active, but was relatively concentrated on a few individuals, mostly from the government agencies. Key comments expressed by the participants include:

- Clear action guidelines are needed rather than vague and unrealistic recommendations that are typically found in other similar studies;
- Specific recommendations need to be made for different stakeholders and decision-makers;
- Scope and limitations of the study need to be clearly stated;
- Use extra caution in generalizing the conclusions and messages based on the limited scope of the study;
- Need for follow-up studies or related studies should be identified; and
- Dissemination of final results is important, especially at provincial level.

74. The Final TA Workshop was held on 2 May 2007 in Phnom Penh. The purpose of the workshop was to present the final conclusions and recommendations of the study and seek the participants’ endorsement and suggestions on implementation, especially from the representatives of 10 Ministries under the CNMC, and their line agencies in the provinces. As were the previous two stakeholder workshops, the final workshop was chaired by H.E. Sin Niny, Vice-Chairman of CNMC. 98 participants attended the workshop: 43 from government agencies in Phnom Penh; 29 government officials from 10 provinces around the Tonle Sap lake and the Mekong river downstream; and 26 representing NGOs and development partners.

75. A pre-publication draft of the Policy Brief with the TA findings and recommendations was disseminated to the participants in advance of the workshop, allowing them enough time to consider these recommendations. The pre-publication draft of the Synthesis Report, which contains more details on the scientific results of the TA, was also distributed to the participants at the workshop. The participation to the Q&A and open discussions were active, and many comments were made by representatives of provincial agriculture departments and NGOs in particular. Key points that came across from the questions and comments raised by the participants are:

- There is high demand from provincial-level stakeholders for more specific guidance on how to implement the TA recommendations into practice at local scale
- Many stakeholders want to know more precise quantitative information on the impacts of dams upstream in the Mekong river on the Tonle Sap fisheries, so that the information can be used for future planning of built structures
- More detailed, follow-up studies are needed in order to address the two points above
- The participants are concerned about how Cambodia can address the potential impact of water development projects in upstream countries within the Mekong river basin
- Dissemination of the recommendations not only in Cambodia but also in other Mekong countries are needed
- Dissemination of the reports and implementation of the principles outlined in the reports to provinces are needed

76. In response to some of the questions raised, H.E. Sin Niny expressed his strong intention to disseminate the findings at regional fora, particularly the impact of upstream infrastructure development on Tonle Sap fisheries. Ms Mio Oka, the ADB representative,
also assured that the results of the TA will be shared with other relevant ADB projects in the region, which will help some of the recommendations to be put into practice. H.E. Sin Niny and the WorldFish research team members also responded to some of the more technical comments, pointing out that the scope and timeframe of the TA was limited for producing the kind of detailed guidelines needed at local scale, and that instead, the TA identified many areas that require further studies. H.E. added that CNMC cannot endorse specific guidelines aimed at local scale decision-making, however, will explore opportunities for conducting follow-up studies on the issue with ADB and other potential donor agencies. The workshop concluded with an endorsement from the chairperson to officially publish both publication outputs of the TA (i.e. Synthesis Report and Policy Brief) under CNMC. (See Section VI Dissemination of Results for details on distributing the final publication outputs.)

77. Other opportunities to disseminate information from the TA were actively pursued throughout the TA implementation, as outlined in the communication strategy. Reporters from major news papers were invited to the stakeholder workshops, which resulted in the following coverage:

- **Cambodge Soir**, 3-08-2006 --- “The ADB finances a study of the impact of the infrastructures on the fisheries” (in French)
- **Rasmei Kampuchea**, 4-08-2006 --- “Three sites is selected for a new research project on fishery resources of Tone Sap basin” (in Khmer)
- **Cambodge Soir**, 10-01-2007 --- “Tonle Sap - effects of development on the fisheries” (in French)

78. A short, non-technical article introducing the TA activities was also published in news letters in Khmer language, one issued by Save Cambodia’s Wildlife and another by Tonle Sap Environmental Management Project, and was distributed in provinces. Similar article was also published in Cambodia Weekly, a newly established English-language news paper, and in South Eastern GLOBE, a regional business magazine in English (March 2007). Posters on the TA approach and video clips on built structures that were prepared as the TA product were also displayed at a joint CNMC/WorldFish exhibit booth at the Tonle Sap Initiative Forum organized by ADB and CARD in March 2007. Over 300 people attended this event, and the exhibit area also received much attention from the participants.

79. In addition, technical papers describing the research approach of the TA or built structures were presented in two international meetings: **The 2nd International Symposium on Sustainable Development in the Mekong River Basin**, organized by the National Institute for Rural Engineering of Japan and the Institute of Technology of Cambodia, with participants from four Mekong countries as well as Japanese researchers; and **the Southeast Asia Regional Meeting on Integrated Water Resources Management**, organised by the United Nations Development Program, in Thailand. The titles of the papers are:


80. Khmer-language translation of the first paper on the approach of the study was made available to the Deputy Chairman of the National Assembly Commission on Economy, Planning, Investment, Agriculture, Rural Development, Environment and Water Resources. Some of the TA team helped him prepare the National Assembly delegation for the upcoming Asia-Pacific Parliamentarians Conference on Environment and Development by providing copies of several relevant documents.

81. As part of dissemination activity, the reference materials and maps gathered by the various components from partners (e.g. EIA reports, site-specific studies, etc.) were scanned and catalogued as PDF files so that they can be shared electronically. Thus more than 300 documents have been posted as pdf files at the TSBR bibliographic database, and are accessible through the TSBR-ED web site.
III COMMUNICATION PRODUCTS

A Technical Reports

82. Thirteen technical reports documenting specific aspect of the project activity and the results were prepared, which serve to substantiate the conclusions and recommendations summarized in the Synthesis Report, and Policy Brief (see Section III-B and C below). The titles of the reports are as below:

- J. Koponen, S. Tes, and J. Mykkänen. *Impact of built structures on Tonle Sap hydrology and related parameters.*
- E. Baran E., N. So, R. Arthur, S.V. Leng, and Y. Kura. *Bioecology of 296 fish species of the Tonle Sap Great Lake (Cambodia).*
- T. Jantunen. *Integration of databases to the BayFish – Tonle Sap fish production model*

These reports are published as PDF documents, made available online at the WorldFish Center web site, and as CD-ROM.

B Synthesis Report (Guidelines)

83. A "Synthesis" report was prepared as the main publication output of the TA. The report is based on the results of technical reports listed above, and combines the hydrological, ecological, fisheries, and livelihood consequences of built structures into a coherent narrative, including recommendations to decision-makers at national and sub-national levels. The full reference is:


The hard copy report is published jointly by CNMC and WorldFish Center in English and Khmer languages.
C Policy Brief

84. This report summarizes conclusions and recommendations of the overall study as described in the Synthesis Report into a comprehensive, short narrative, and integrates elements of the policy context in Cambodia. The full reference is:


The hard copy report is published jointly by CNMC and WorldFish Center in English and Khmer languages.

D Scientific and Academic Articles


E Newspapers and Magazine Articles

- *Cambodge Soir*, 3 August 2006 --- “The ADB finances a study of the impact of the infrastructures on the fisheries” (in French)
- *Rasmei Kampuchea*, 4 August 2006--- “Three sites is selected for a new research project on fishery resources of Tone Sap basin” (in Khmer)
- *Cambodge Soir*, 10 January 2007 --- “Tonle Sap - effects of development on the fisheries” (in French)
- *Cambodia Weekly*, 4 March 2007 --- “Tonle Sap in Focus: Heart of Cambodia” (in English)
- *SE Globe*, March 2007 --- “Net values – a study to be released underscores the economic importance and vulnerability of fisheries of the Mekong” (in English)
- *Tonle Sap Biosphere Reserve Bulletin*, December 2006 --- “Three sites chosen for important new study on Tonle Sap fisheries” (in English and Khmer)

F Multimedia products

85. WorldFish commissioned the production of seven short video clips (8 minute-long each). These clips are for educational purposes, aiming to increase awareness of general, non-technical audience about natural resources, fisheries, fishing communities, and influence of infrastructure development around the Tonle Sap and in Cambodia in general. The themes covered by the video clips include: livelihoods of fishing communities on the lake; Cambodian fisheries; and Built Structures around the Tonle Sap. All clips are packaged as *Lands of the Lake*, a single VCD/DVD including English, Khmer and French versions.
IV KEY FINDINGS

The main findings of the four research components of the TA are listed below.

A Modelling the influence of Built Structures on hydrodynamics and water quality

Based on the Mekong basin-scale modelling of water development scenarios:

- Upstream developments in the Mekong basin will delay the onset of the annual flood in the Tonle Sap and shorten its duration. Under the intensive scenario in a dry year, the flood would be delayed by up to 12 days depending upon the location and altitude, and its duration would be a week shorter. Under the extreme development scenario, the flood would be delayed by one month and its duration would be two weeks shorter.

- Upstream developments will also decrease the height and surface area of the flood. Under the intensive development scenario in a dry year, the maximum height will be about half a meter lower and the surface area about 10 percent smaller. The main losses will occur in very high areas that are flooded for short periods.

- Dams upstream will also sharply reduce the input of sediments into the Tonle Sap, adversely affecting the recycling of nutrients and possibly threatening dry-season habitats, especially in areas with high fish productivity. The Upper Mekong Basin is the source of more than 50 percent of the suspended sediments in downstream areas in the Lower Basin. The planned cascade of eight dams in the extreme development scenario has the potential to trap nearly all of these sediments. Loss of sediments in flood water would result in a loss of natural soil fertility.

Based on the small-scale modelling of study areas and the field-based assessment:

- The velocity of water flows on the floodplain is generally very slow compared to the lake so the impact of roads depends on where they are placed, and whether they have culverts and gates as mitigation measures.

- Small-scale private reservoirs in the floodplain so far have had a relatively limited influence on the flow and quality of water around the Tonle Sap. The overall storage capacity of existing private irrigation structures on the floodplain is quite limited as the depth of water trapped is only about one and a half meters. Existing reservoirs in the Tonle Sap floodplain have a surface area of less than 100 square kilometers with a storage capacity of about one-tenth of a cubic kilometer, a small fraction of the annual inflows into the Tonle Sap ranging from 44 to 107 cubic kilometers.

- Laboratory experiments demonstrated that fishing fences made of bamboo and nets typical used on the Tonle Sap cause only minimal resistance to water flows and do not slow down water recession, whereas it is clear that the fences and the attached nets obstruct fish movements.
B Assessing the influence of Built Structures on the environment

Findings based on the worldwide literature review of the built structures in floodplain environment:

- In terms of ecological and social benefits, floodplains are among the most valuable landscapes in the world. A global review of tropical floodplains completed during the study found that fish and other natural resources are the primary benefits, followed by the replenishment of nutrients and fertile soils for farmlands and pastures. However, much is still unknown about the ecological functions of floodplains and how to value them properly.

- Modifying water flows and flood patterns are the biggest threats to the ecology of floodplains. Once lost, the costs of rehabilitating the ecological functions of floodplains are very high. Any structure affecting water within a floodplain or in rivers upstream is assumed to have some influence on the floodplain environment and should be treated with caution. Most declines in fisheries production in tropical floodplains are either directly or indirectly related to changes in water flows. Seasonal flooding and connectivity are essential for maintaining the ecology of floodplains.

- Large infrastructure projects increasingly require cumulative-impact and strategic-environmental assessments. Most structures are not isolated from the surrounding environment. The cumulative impact of many structures can be assessed, although this is complicated as it is more than simply adding up the individual impacts of each structure. In general, impact assessments rarely quantify benefits that might be lost. Existing guidelines and recommendations on how to implement EIAs typically do not include instructions on how to consider specific environmental characteristics of floodplain and how to assess impacts of a project on floodplain ecosystems, or how to include economic valuation of lost benefits of floodplains.

Findings based on the review of the Environmental Assessment reports and the EIA processes around the Tonle Sap:

- Environmental Impact Assessments (EIAs) for Tonle Sap infrastructure projects that may have a significant impact on water resources and fish are not systematically implemented. Access to Environmental Impact Assessments of Tonle Sap development projects is difficult, reports being scattered across various ministries and provincial and district government offices or with project developers. Very few are available at the Ministry of Environment or other relevant ministries. Assessments are not systematically recorded or classified.

- The quality of the Environmental Impact Assessments (EIAs) of Tonle Sap projects that might have a significant impact on water resources and fish is insufficient. The EIA process refers to the overall mechanism in place to request, submit, accept and monitor project EIA. Increased awareness of the importance of EIA practice should be supported.

- Stakeholder participation in planning of built structure development and environmental impact assessments is generally very limited. There is no systematic
mechanism for involving local communities, provincial and district authorities, and non-governmental organizations. This raises issues of transparency and the need to allocate resources to communications at the local and national levels.

C Assessing the influence of Built Structures on fishery resources

Findings at the Mekong basin scale include:

- Dams are the main type of structure having an impact on fisheries production in the Mekong river systems, through their negative impact on fish migrations. In the Mekong Basin, 87 percent of fish species, for which the information is available, are migrant species. Sixteen percent of these species are known to be sensitive to hydrological migrations triggers that will be modified by dam construction. Since the bulk of the catch is actually due to a small number of species groups that are in majority sensitive to hydrological migration triggers, a very large proportion of the total catch is likely to be affected by river modifications (for example, 96% of the catch in Khone Falls, Southern Laos).

- The study found no examples of positive long-term impacts of dams on fisheries, nor any effective mitigation measures. Reservoirs are sometimes presented as a way to create new fisheries upstream, but this usually does not compensate for the loss of downstream fisheries. Similarly, fish passes are often proposed to help fish migrate. However, there are no examples of fish passes that work in the Mekong Basin. This is mainly due to ecological factors and the intensity of migrations which fish passes cannot accommodate. Out of the hundreds of species in the Mekong Basin, only nine are known to breed in reservoirs. The effectiveness of the new fish pass at Stung Chinit completed in 2006 has not yet been assessed.

- The Tonle Sap has almost 300 species, making it the third-richest lake in the world in terms of fish diversity. A review of scientific literature identified 296 species, more than twice the number recorded before. That makes the lake the richest in the world only after Lake Malawi (433 species) and Lake Tanganyika (309 species), both in Africa.

- Changes in water levels affect the annual migrations of some sensitive species which account for 13 percent of the Tonle Sap catch, or between 38,000 tonnes and 56,000 tonnes a year. In addition, if the two species of trey riel (Henicorhynchus genus)---that are also suspected to be sensitive---are included, the proportion of the catch whose migration is triggered by changing water levels jumps to 38 percent, amounting to between 110,000 tonnes and 164,000 tonnes a year. How this effect on migration translates to fish productivity is still unclear.

Findings at the Local study sites include:

- Road-management committees have an important role to play in fisheries protection by instituting rules that prohibit road culverts from being blocked by fishing gear. This is a commendable practice at the Pursat study site that should be encouraged
elsewhere in the country. But these rules are not always followed and more intensive fishing gear is being deployed.

- Maintaining downstream flows and migration upstream is important to the sustainability of fish catches. Villages downstream seem to have borne several costs and received fewer benefits from the irrigation scheme. All people interviewed downstream blamed flow changes for reduced fish abundance and smaller catches from the river. Rice-field fisheries also seem to have suffered. Respondents mentioned that local fish abundance was closely linked to the seasonal flooding of the lake with bigger floods leading to more fish.

- Both fisheries management systems (fishing lots and community fisheries) suffer from a prevalence of highly destructive fishing practices, such as electro fishing, damming and pumping water out of streams. But there are trade-offs between productivity, equity and possibly sustainability between the two management systems in operation at the site.

D Assessing the influence of Built Structures on livelihoods

Findings at the Local study sites include:

- In both planning and maintaining roads, commune councils have a natural coordinating role to play with local bodies, such as community-fishery and road-maintenance committees as well as Buddhist and Islamic institutions that can mobilize collective action.

- Getting villagers to take part in infrastructure planning is a key factor in shaping their perceptions of a scheme's suitability and their willingness to invest in its long-term maintenance.

- All the case studies show clearly that management and social issues associated with built structures, such as access to benefits, use rights and regulations, and operations, can be perceived at the local level as much more crucial than the technical design of the structure itself.

- The case studies found that coordination between fishing communities, local authorities, management committees and fisheries officers was either limited or absent at all three study sites.

- The study found that most people's livelihoods were diversifying as new opportunities and risks arose from new infrastructure. However all case studies showed that fishing and related activities were still the main source of income.

- Infrastructure development is generally benefiting richer households. Many poor households are also benefiting but not at the same rate. The three case studies found that rural households had different capacities to benefit from opportunities arising from infrastructure development.
The three case studies showed strong ties between household assets, especially education, and the ability to take advantage of new opportunities. After education, the next most significant asset explaining the ability of households to get out of poverty was livestock, a form of savings.
V RECOMMENDATIONS TO DECISION MAKERS

86. A set of recommendations were drawn from the results of the TA research components. The recommendations below point to key principles and actions needed that are meant to help decision-makers in maximizing the economic and social returns from investments in infrastructure while minimizing adverse impacts on the environmental sustainability of the Tonle Sap or the people who live around the lake.

1. When planning infrastructure development, avoid irreversible changes to water flows, especially those affecting seasonal flooding or breaking the natural "connectivity" between various water bodies around the Tonle Sap.

2. In assessing plans for dams and other water developments upstream on the Mekong mainstream, highlight the significant impacts on flooding in the Tonle Sap Lake.

3. In addition to considering the seasonal impact on water flows, planning of upstream water developments should specifically take into account possible ecological consequences of the changes in flooding, including loss of flooded forests, reduced inflows of sediments, lower oxygen levels, and changes in the drift of fish larvae and juvenile fish.

4. The livelihood benefits of floodplains should be properly evaluated and integrated into basin-wide water development planning, with particular focus on the impact of dams on fisheries.

5. Adopt regional guidelines such as the Strategic Environmental Framework for the Greater Mekong Sub-region (GMS), which promote strategic environmental assessments addressing the cumulative impacts of multiple development projects in order to improve EIA processes.

6. Give special attention to infrastructure developments within the Tonle Sap basin, because these have direct impacts on fisheries, and because they can magnify the influence of upstream changes in water flows.

7. Improve the Environmental Impact Assessment process, particularly the coverage of fisheries, coupled with capacity-building for EIA practitioners.

8. Impact assessments and regional negotiations over water allocation should take into account the unique importance of the Tonle Sap Lake for fisheries productivity and fish diversity not only in Cambodia but throughout the Mekong system.

9. When assessing the impact of infrastructure development on Tonle Sap fisheries, focus on species that are both economically important and which depend on hydrological triggers for migration. In particular, prioritize trey sleuk russey (Paralaubuca typus), trey chhkok and trey sraka kdam (two species from the Cyclocheilichthys genus) and trey pra (species from the Pangasius genus) as indicator species.
10. In designing fisheries management strategies and conducting impact assessments, consider three – rather than the traditional two – major ecological groups of fish. This highlights the importance of species which rely on tributaries as dry season refuges.

11. Explicitly take water flows and fish-migration routes into account when planning and building roads in floodplains, using culverts and bridges to avoid blocking complex networks of channels. Also ensure that planning addresses how these structures will be managed and maintained.

12. Coordinate road development among ministries and also with local institutions, particularly Commune Councils, to ensure proper planning and maintenance.

13. Ensure that road planning takes into account the poorest groups by clarifying who will benefit and how. Provide alternative livelihoods support services targeted to poorer families to help them accumulate household assets, such as education, cattle and savings.

14. Assess the ecological impacts of dams and reservoirs at the planning stage. Determine the pros and cons in the long run so that informed decisions can be made and mitigation measures taken.

15. Analyze the social and economic costs and benefits of irrigation projects for different social groups at the planning stage. Make complementary investments to make sure poorer households can take advantage of new opportunities.

16. Provide training to commune councils to build effective communication channels between local officials, engineers and villagers. Support the establishment of water-user committees to promote equitable distribution of water and avoid conflicts over operating and maintaining the system.

17. Promote future studies on how large-scale fishing fences affect the movement of fish and longer-term fish recruitment, and appropriate mitigation measures.

18. Decisions on where and how large-scale lot systems are implemented should take into account economic, social, and ecological trade-offs as compared to other management options such as community fisheries.

19. When fishing lots are released and access opened to local communities, there are high incentives for relatively wealthier households to capture more of the benefits. Pay specific attention to institutional mechanisms to ensure equity and manage conflicts.

20. Ensure that negative impacts of built structures are addressed through management and operational aspects of the projects, in addition to technical and engineering measures.

21. Improve management of fisheries around built structures adapted to the newly created social dynamics and fishing environment, through better enforcement of regulations and coordination of stakeholders, including community fisheries, government agencies, donors, and non-governmental organizations.
22. Hold systematic consultations between national and local stakeholders throughout project development and help local people articulate their needs and concerns. Evaluate and publicly debate the social, economic and ecological trade-offs arising from different development scenarios before deciding on a specific option.

23. Link infrastructure planning to the decentralized institutions for rural development and natural resource management (commune, district, and provincial councils).

24. Analyze how the costs and benefits of a project affect different social groups, taking the role of local institutions and differences in household assets into account. Considering the importance of poverty alleviation in Cambodia’s development agenda, make special provisions to involve the poorest groups in project planning.

25. Complement infrastructure projects with investments in basic education, training and technical support.

VI DISSEMINATION OF PUBLICATION OUTPUTS

87. After the Final Workshop of TA, the Synthesis Report and the Policy Brief were published both in English and Khmer languages. The set of video clips was reproduced as DVD and also as VCD, which is more popular in provinces (see Table 6 below). The full set of publication products was packaged and distributed to relevant line agencies under CNMC, as well as key national decision-makers in the National Assembly, Senate, Council for the Development of Cambodia, as identified in the Communication Strategy. At provincial level, provincial departments of relevant line agencies, provincial governors, district governors, Chamber of Commerce are the main target for dissemination of the publication products in Khmer version. Over 900 sets of publications were manually couriered to provincial line agency offices and the offices of key decision-makers. Similarly, around 700 sets were distributed to key target audience in Phnom Penh through CNMC’s dissemination channels at member Ministries, and also through courier services hired by WorldFish.
Table 6: Products and Dissemination Targets Achieved

<table>
<thead>
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<th>Product</th>
<th>No</th>
<th>Medium</th>
<th>Content</th>
<th>Lang</th>
<th>Copies</th>
<th>No</th>
<th>Copies</th>
<th>Note</th>
<th>Achieved</th>
</tr>
</thead>
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<td>Synthesis Report</td>
<td>1</td>
<td>Print</td>
<td>Hydrological, ecological, fishery and livelihood impacts (10 to 30 pages, 5,000-15,000 words)</td>
<td>Eng. Khmer</td>
<td>600</td>
<td>1</td>
<td>Eng. 1,000 Khmer 2,000</td>
<td>Number of copies increased for wider distribution in provinces</td>
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</tr>
<tr>
<td>Policy brief</td>
<td>1</td>
<td>Print</td>
<td>National issues relating to hydrological, ecological, fishery impact of built structures (8 to 12 pages, 4,000-6,000 words)</td>
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<td>2,000</td>
<td>1</td>
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<td>Number of copies increased for wider distribution in provinces</td>
<td>Yes</td>
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<tr>
<td>Guidelines*</td>
<td>1</td>
<td>Print</td>
<td>Design, number and operation of built structures (4-8 pages, 2,000-4,000 words)</td>
<td>Eng. Khmer</td>
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<td>0</td>
<td>-</td>
<td>Included as general recommendations in both Synthesis Report and Policy Brief</td>
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<tr>
<td>Meetings</td>
<td>2</td>
<td>DVD, PDF</td>
<td>Project activities, results</td>
<td>Eng. Khmer</td>
<td>x</td>
<td>5</td>
<td>x</td>
<td>Includes stakeholder workshops and external conferences</td>
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<tr>
<td>News releases</td>
<td>4</td>
<td>Print media</td>
<td>Newsworthy developments and findings as they emerge including background material from inception and mid-term reports</td>
<td>K (E)</td>
<td>x</td>
<td>6</td>
<td>(4 press releases, 2 magazine articles)</td>
<td>x</td>
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</tr>
<tr>
<td>Multimedia</td>
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<td>CD/DVD</td>
<td>Multimedia CD/DVD including i) 40 mn of video clips on Built structures, BS and water, BS and fisheries, BS and livelihoods; ii) 4 audio interviews of scientists, and iii) 3D didactic animations</td>
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<td>x</td>
<td>Available online as PDF at WorldFish and IFReDI web sites</td>
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* It was agreed by CNMC and ADB during the TA implementation stage that guidelines are no longer required as their elements are already included in the Synthesis Report.
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

*Database Component*

**BUILT STRUCTURES DATABASE**
**TONLE SAP BUILT STRUCTURES STATISTICS**

Prepared by

Hannu LAURI

Environmental Impact Assessment Center of Finland Ltd

April 2007
INTRODUCTION

This document contains summary statistics of the Tonle Sap Basin built structures database. Data sets used to identify structures are detailed in the database documentation. In short this census is based on the best available GIS information covering the whole basin, with a specific focus on floodplains and the three project study areas: Stung Chinit, Prek Toal and Pursat. For these study areas, more detailed information has been sought, maps of higher resolution have been used and details of these maps have been digitized (e.g. fishing gear in Prek Toal) to be better quantified.

More than fourteen thousand built structures have been identified during the studying the Tonle Sap Basin. However counting all existing structures in the Tonle Sap Basin (i.e. over 44 percent of the whole country) is a titanic undertaking; during this project only 3 study areas could be covered in detail. Roads cannot be easily counted (their length, width or design might be more important than their number). Counting structures also relies on automatic mapping (e.g. to identify rice fields), with subsequent uncertainties. Categorizing them into simple, distinct groups is often tricky (e.g. difference between weirs, dykes and embankments). Fishing fences can be identified as long as they are not under vegetation cover nor underwater (which is often the case with extensive nylon barriers). Canals are many but include a large majority of canals from the Khmer Rouge period that are not actually operational. Major pollution sources (mines, factories, etc.) can be counted, but not diffuse pollution sources due to agriculture or human settlements. Last, the influence of many structures depends on how they are designed and operated. For instance a sluice gate in an irrigation scheme counts as one structure, but its role depends whether it is open or closed, and when; similarly a floodplain road that counts as one structure will have a different influence depending upon the number and size of its culverts.
### 1. STATISTICS BY SUB-CATCHMENT

![Tonle Sap subcatchments](image)

**Figure 1: Tonle Sap subcatchments**

**Tonle Sap subcatchment statistics**

<table>
<thead>
<tr>
<th>Subcatchment</th>
<th>Area (km²)</th>
<th>Flooded (km²) in medium flood</th>
<th>Flooded (%) in medium flood</th>
</tr>
</thead>
<tbody>
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<td>Siem Bok</td>
<td>8851.22</td>
<td>2171.99</td>
<td>24.54</td>
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<tr>
<td>St. Baribo</td>
<td>7153.78</td>
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<td>94701.70</td>
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Lake dry season and medium flood (year 2001) statistics

Dry season lake from MRC shoreline data (50m resolution):
Lake shoreline length 1059 km
Main islands shoreline length 1309 km
Together 2368 km
Lake area (islands subtracted) 2767 km²

Medium flood lake shoreline length from MRC 2001 flood level data (50m resolution):
Total shoreline length 7007.8 km
Area under flood 19718.7 km²

Dry season and medium flood shoreline lengths by catchment area

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Dry season (km)</th>
<th>Flooded (km)</th>
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Figure 2: Data used in shoreline length and area computation, dry season lake area in blue, medium flood area in light blue, and catchment boundaries in red.
Dry season lake shoreline length during low water level, computed from subcatchment boundary data:

<table>
<thead>
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<th>Catchment</th>
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2. STATISTICS BY PROVINCE

![Figure 3: Cambodian provinces intersecting Tonle Sap catchment area](image-url)
Area data for provinces in the Tonle Sap catchment, including flooded area of provinces within the Tonle Sap catchment boundary (see Figure 4).

<table>
<thead>
<tr>
<th>Province</th>
<th>Area (km²)</th>
<th>Flooded (km²) in medium flood and within Tonle Sap catchment</th>
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*Figure 4: Medium flood area with provinces and Tonle Sap catchment boundary (wide blue line).*
3. NUMBER OF STRUCTURES BY CLASS

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4. STRUCTURE STATISTICS BY SUBCATCHMENT

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### Length of railroad embankments (km)

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### Length of embankments (km)

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**Length of irrigation channels (km)**

Channels selected for a catchment if the channel mid-point is within the catchment.

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**Length of reservoir dikes (km)**

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**Length of fish fences (km)**

Data was available from Preak Toal area only, see figure 5.
Figure 5: Area from where fishing fences, pens and traps data have been digitized.

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<tr>
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**Number of traps (km)**

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## Number of pens (km)

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## Area of reservoirs (km²)

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## Area of paddy fields (km²)

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### Number of dams

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### Number of bridges

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**Number of culverts**
Includes only bridges on primary roads (no data on culvers elsewhere)

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5. STRUCTURE STATISTICS BY PROVINCE

In that section, statistics about built structures are detailed by province. Two special cases are to be mentioned:
- the tables below include a “Tonle Sap” category, that corresponds to the permanent water body that includes structures but does not pertain to any province in particular;
- the tables also include a “Thailand” category; as a matter of fact a small fraction of the Tonle Sap basin lies in Thailand, and this area includes built structures that have also been recorded in the database.

**Length of primary roads (km)**

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**Length of other roads (km)**

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### Length of irrigation channels (km)

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<td>34</td>
<td>334.23</td>
</tr>
<tr>
<td>Kampong Chhnang</td>
<td>10</td>
<td>63.58</td>
</tr>
<tr>
<td>Kampong Cham</td>
<td>12</td>
<td>192.95</td>
</tr>
<tr>
<td>Kampong Spe</td>
<td>7</td>
<td>24.43</td>
</tr>
<tr>
<td>Kandal</td>
<td>6</td>
<td>60.05</td>
</tr>
<tr>
<td>Sum</td>
<td>159</td>
<td>3526.08</td>
</tr>
</tbody>
</table>

## Number of bridges

<table>
<thead>
<tr>
<th>Province</th>
<th>All bridges</th>
<th>Bridges on primary roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stung Treng</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Oddar Meancheay</td>
<td>106</td>
<td>0</td>
</tr>
<tr>
<td>Preah Vihear</td>
<td>138</td>
<td>0</td>
</tr>
<tr>
<td>Banteay Meanchey</td>
<td>118</td>
<td>42</td>
</tr>
<tr>
<td>Siem Reap</td>
<td>158</td>
<td>51</td>
</tr>
<tr>
<td>Thailand</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Battambang</td>
<td>187</td>
<td>77</td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>99</td>
<td>40</td>
</tr>
<tr>
<td>Kratie</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>Tonle Sap</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pailin</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Pursat</td>
<td>242</td>
<td>52</td>
</tr>
<tr>
<td>Kampong Chhnang</td>
<td>87</td>
<td>39</td>
</tr>
<tr>
<td>Kampong Cham</td>
<td>53</td>
<td>16</td>
</tr>
<tr>
<td>Kampong Spe</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Kandal</td>
<td>50</td>
<td>37</td>
</tr>
<tr>
<td>Sum</td>
<td>1311</td>
<td>317</td>
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</tbody>
</table>
### Number of culverts

<table>
<thead>
<tr>
<th>Province</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stung Treng</td>
<td>0</td>
</tr>
<tr>
<td>Oddar Meanchey</td>
<td>0</td>
</tr>
<tr>
<td>Preah Vihear</td>
<td>0</td>
</tr>
<tr>
<td>Banteay Meancheay</td>
<td>34</td>
</tr>
<tr>
<td>Siem Reap</td>
<td>126</td>
</tr>
<tr>
<td>Thailand</td>
<td>0</td>
</tr>
<tr>
<td>Battambang</td>
<td>42</td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>58</td>
</tr>
<tr>
<td>Kratie</td>
<td>0</td>
</tr>
<tr>
<td>Tonle Sap</td>
<td>0</td>
</tr>
<tr>
<td>Pailin</td>
<td>0</td>
</tr>
<tr>
<td>Pursat</td>
<td>17</td>
</tr>
<tr>
<td>Kampong Chhnang</td>
<td>20</td>
</tr>
<tr>
<td>Kampong Cham</td>
<td>9</td>
</tr>
<tr>
<td>Kampong Spe</td>
<td>4</td>
</tr>
<tr>
<td>Kandal</td>
<td>13</td>
</tr>
<tr>
<td>Sum</td>
<td>323</td>
</tr>
</tbody>
</table>

### Number of dams

<table>
<thead>
<tr>
<th>Province</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stung Treng</td>
<td>0</td>
</tr>
<tr>
<td>Oddar Meanchey</td>
<td>2</td>
</tr>
<tr>
<td>Preah Vihear</td>
<td>10</td>
</tr>
<tr>
<td>Banteay Meancheay</td>
<td>23</td>
</tr>
<tr>
<td>Siem Reap</td>
<td>0</td>
</tr>
<tr>
<td>Thailand</td>
<td>0</td>
</tr>
<tr>
<td>Battambang</td>
<td>0</td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>2</td>
</tr>
<tr>
<td>Kratie</td>
<td>1</td>
</tr>
<tr>
<td>Tonle Sap</td>
<td>0</td>
</tr>
<tr>
<td>Pailin</td>
<td>0</td>
</tr>
<tr>
<td>Pursat</td>
<td>0</td>
</tr>
<tr>
<td>Kampong Chhnang</td>
<td>0</td>
</tr>
<tr>
<td>Kampong Cham</td>
<td>0</td>
</tr>
<tr>
<td>Kampong Spe</td>
<td>0</td>
</tr>
<tr>
<td>Kandal</td>
<td>0</td>
</tr>
<tr>
<td>Sum</td>
<td>38</td>
</tr>
</tbody>
</table>
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Database Component

DATABASE DOCUMENTATION

Prepared by:

Hannu LAURI
EIA Ltd, Finland

April 2007
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PURPOSE OF THE DATABASE COMPONENT OF THE PROJECT

The main task of the database component of the Built Structures project is to prepare a database of existing surface water and surface water quality related structural works in the Tonle Sap Basin. The database should contain the geographic extent and characteristics of these structures.

The database will be used in the assessment of the consequences of built structures on the environmental and human components of the lake ecosystem.

A built structure is defined here as a structure that
(i) opposes water outflow (e.g. dams, weirs, irrigation schemes, levees, embankments);
(ii) prevents water inflow (e.g. roads, railways, flood control works, polders, dykes, wharves and quays);
(iii) alters water inflow or outflow (e.g. drainage canals, diversion structures, agricultural works, and flow modifications);
(iv) may degrade water quality (e.g. plants with aqueous effluents, mining and mineral processing facilities, petroleum storage facilities, sewerage systems, and dredges); and
(v) Fishing gears that can alter hydrological flows and obstruct fish movement.

The main emphasis of the database is on structures of type (i), (ii) and (v).

CLASSIFICATION OF BUILT STRUCTURES

The structures are grouped in the database using structure type classification, derived from structure type and usage. The type classification
1. Assigns exactly one type class for each existing structure in the target area,
2. Determines what characteristics of a given structure are stored in the database,
3. Aids database users in searching for structures that have specific impacts,
4. Is easy to understand for the database user.

STRUCTURE TYPE CLASSIFICATION

1 Storage
   110 Reservoir
   120 Floodwater storage

2 Flow route
   210 Canal
   211 Irrigation canal
   210 Bridge
   230 Culvert
   240 Spillway
3 Flow control
310 Dam
320 Embankment
321 Road embankment primary road
322 Road embankment other
323 Railroad embankment
324 Reservoir dike
330 Gate
340 Weir
350 Pumping station
360 Hydropower station
370 Measurement station
371 Hydrological station
372 Meteorological station

4 Fish and aquaculture
410 Fishing gear
411 Dai fishery
412 River barrage with bagnet or trap
413 Fence system fence
414 Fence system trap
415 Fence system pen
420 Fishway
430 Aquaculture
431 Fish pond
432 Fish cage
440 Fishing lot
450 Fish sanctuary

5 Erosion prevention
510 Reinforced bank
520 RipRap

6 Agriculture
610 Rice field
620 Field crops
630 Plantation
640 Other agriculture
650 Irrigated area

7 Transportation
710 Docks/Harbour
720 Breakwater
730 Ferry

8 Discharge
810 Point source
811 Sewage treatment plant
812 Sewage outlet
813 Industrial sewage outlet
814 Mine
820 Diffuse source
821 Scattered population
**STRUCTURE ATTRIBUTES**
Structure attributes are values that describe a given structure and are stored in the database. The following data is stored:

- Structure name
- Structure position (mid-point position), UTM (Universal Transverse Mercator, zone 48N with false easting of 500000, and WGS84 datum)
- Structure outline, mid-line or point location, coordinate system as above
- Structure creation (and demolition) date
- Database diary data; entry date and user ID
- Main physical dimensions of the structure
- Main hydrological characteristics of the structure
- Photographs of the structure

Below is a table of attributes based on the above structure classification.

**Attributes for all classes**

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Structure identifier</td>
</tr>
<tr>
<td>class_id</td>
<td>Int</td>
<td>-</td>
<td>Structure class identifier</td>
</tr>
<tr>
<td>name</td>
<td>String</td>
<td>-</td>
<td>Name of structure</td>
</tr>
<tr>
<td>info</td>
<td>String</td>
<td>-</td>
<td>Additional information in text format</td>
</tr>
<tr>
<td>xpos</td>
<td>Real</td>
<td>m</td>
<td>X-coordinate of mid-point (UTM)</td>
</tr>
<tr>
<td>ypos</td>
<td>Real</td>
<td>m</td>
<td>Y-coordinate of mid-point (UTM)</td>
</tr>
<tr>
<td>boundary</td>
<td>Geom</td>
<td>-</td>
<td>Boundary/mid-line/mid-point data</td>
</tr>
<tr>
<td>constructed</td>
<td>Date</td>
<td>-</td>
<td>Construction date (when taken to use)</td>
</tr>
<tr>
<td>demolished</td>
<td>Date</td>
<td>-</td>
<td>Demolition date (when taken out of use)</td>
</tr>
<tr>
<td>entrydate</td>
<td>Date</td>
<td>-</td>
<td>Date when entered into database</td>
</tr>
<tr>
<td>entryby</td>
<td>String</td>
<td>-</td>
<td>Userid of user who created this entry</td>
</tr>
<tr>
<td>datasource</td>
<td>String</td>
<td>-</td>
<td>Datasource acronym</td>
</tr>
<tr>
<td>srid</td>
<td>Int</td>
<td>-</td>
<td>Coordinate system identifier</td>
</tr>
<tr>
<td>boundary</td>
<td>Geom</td>
<td>-</td>
<td>Mid-point/boundary/mid-line geometry data</td>
</tr>
</tbody>
</table>

**Class-dependent attributes**

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Height of structure</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of structure</td>
</tr>
<tr>
<td>area</td>
<td>Real</td>
<td>m²</td>
<td>Area or structure (at the maximum water level)</td>
</tr>
<tr>
<td>activestorage</td>
<td>Real</td>
<td>m³</td>
<td>Storage volume between minimum and maximum water levels</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Water level at which flow out or through a structure stops</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Maximum water level for a structure</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>maxflow</td>
<td>Real</td>
<td>m³/s</td>
<td>Maximum flow on maximum water level</td>
</tr>
<tr>
<td>crsection</td>
<td>Real</td>
<td>m²</td>
<td>Channel/opening cross section area at maximum water level</td>
</tr>
<tr>
<td>wldrop</td>
<td>Real</td>
<td>m</td>
<td>Water level drop over structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Construction material, material, e.g. timber/earth/stones/concrete/metal</td>
</tr>
</tbody>
</table>
SELECTION CRITERIA FOR STRUCTURES

SPATIAL EXTENT
The database contains structures in the Tonle Sap Basin as defined by the watershed boundary. Spatial emphasis is on the areas through which water flows to the Tonle Sap, and more generally on areas that are or have been under water during the flood season. The Tonle Sap flooded area is shown in Figure 1 and is mostly limited by National Roads nº 5 and 6. The project target sites in Preak Toal, Pursat and Chinit are included in the database with some more detail.

FLOW IMPACT CLASSIFICATION
Structures in the area are divided roughly into three categories according the impact of the structure on water flow. The classes are large, mid-size and small structure. Large structures may have catchment scale impacts, mid-size structures have regional scale impacts, and small-scale structures have only local impacts.

A limit for large structures is here defined as a structure that can store at least 2.5 million m$^3$ water (in a year), or modify existing flows for at least 1 m$^3$/s on average, or 4 m$^3$/s during peak flow time.

A limit for mid-size structures is defined as a structure that can store at least 0.5 million m$^3$ water (in a year), or modify existing flows for at least 0.5 m$^3$/s on average, or 2 m$^3$/s during peak flow time.

Structures that store water modify flows less than mid-size structures that belong to the small category.

The database mainly contains large and mid-size structures. Structures classified as small may also be included in the database in some cases, for example, if the impact of a structure is not known or the attributes required for assessing the structure size are not available.
DATABASE
The data is put into a relational database with the capability to store geometry types. MySQL database version 5.0.21 is used here. The MySQL database is free, and contains user friendly tools for installation, database management, and queries. Also, tools for data import from shapefile to the database are available.

A map-based data viewer Java applet was constructed to allow remote access to the database data using an Internet browser.

Export of data to and from the database to GIS programs can be done by writing selected database contents to an ESRI shapefile. The shapefile attribute table will contain selected structure properties.

DATABASE TABLES
The database contains the following tables:
- Structure table – table for storing structure attributes
- Class table – table for storing structure classification data
- Photo table – table for storing photographs of structures
- Contact table – table for storing contact information for structure managers, database users and data sources
- Validation table – table for storing validation data
- Discharge table – table for storing point load data
- Area table – geographic data that can be used to geographically select structure data, for example, catchment boundaries, main rivers, districts and province boundaries, and main settlement locations.

Structure table
Since many types of structures have common attributes, all structures are put in to a single table that has a set of attributes shown below. The list of attributes can be extended if required. Not all attributes are relevant to all structures, so only the relevant attributes, defined by the structure class, will be set for each structure. The irrelevant attributes will have undefined (null) values.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Structure identifier</td>
</tr>
<tr>
<td>class_id</td>
<td>Int</td>
<td>-</td>
<td>Structure class identifier</td>
</tr>
<tr>
<td>name</td>
<td>String</td>
<td>-</td>
<td>Name of structure</td>
</tr>
<tr>
<td>info</td>
<td>String</td>
<td>-</td>
<td>Additional information in text format</td>
</tr>
<tr>
<td>xpos</td>
<td>Real</td>
<td>m</td>
<td>x-coordinate of mid-point (UTM)</td>
</tr>
<tr>
<td>ypos</td>
<td>Real</td>
<td>m</td>
<td>y-coordinate of mid-point (UTM)</td>
</tr>
<tr>
<td>boundary</td>
<td>Geom</td>
<td>-</td>
<td>Boundary/mid-line/mid-point data</td>
</tr>
<tr>
<td>constructed</td>
<td>Date</td>
<td>-</td>
<td>Construction date (when put into use)</td>
</tr>
<tr>
<td>demolished</td>
<td>Date</td>
<td>-</td>
<td>Demolition date (when taken out of use)</td>
</tr>
<tr>
<td>entrydate</td>
<td>Date</td>
<td>-</td>
<td>Date when entered into database</td>
</tr>
<tr>
<td>entryby</td>
<td>String</td>
<td>-</td>
<td>Userid of user who created this entry</td>
</tr>
<tr>
<td>datasource</td>
<td>String</td>
<td>-</td>
<td>Datasource acronym</td>
</tr>
<tr>
<td>srid</td>
<td>Int</td>
<td>-</td>
<td>Coordinate system identifier</td>
</tr>
<tr>
<td>boundary</td>
<td>Geom</td>
<td>-</td>
<td>Mid-point/boundary/mid-line geometry data</td>
</tr>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Height of structure</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of structure</td>
</tr>
</tbody>
</table>
### area Real m² Area of structure (at the maximum water level)

### activestorage Real m³ Storage volume between minimum and maximum water levels

### minlevel Real m Water level at which flow out or through a structure stops

### maxdepth Real m Maximum water level for a structure

### crestlevel Real m Minimum water level for flow to occur over structure

### maxflow Real m³/s Maximum flow on maximum water level

### crsection Real m² Channel/opening cross section area at maximum water level

### wldrop Real m Water level drop over structure

### material String - Construction material, e.g. timber/earth/stone/concrete/metal

### production Real kg/a Approximate production per year

#### Class table
The class table contains data on structure classes.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Structure class identifier</td>
</tr>
<tr>
<td>name</td>
<td>String</td>
<td>-</td>
<td>Name of class</td>
</tr>
<tr>
<td>parent</td>
<td>Int</td>
<td>-</td>
<td>Identifier of parent class</td>
</tr>
<tr>
<td>description</td>
<td>String</td>
<td>-</td>
<td>Description of the class</td>
</tr>
<tr>
<td>shapetype</td>
<td>tinyint</td>
<td>-</td>
<td>Shape type point/polyline/polygone</td>
</tr>
<tr>
<td>linecolor</td>
<td>Integer</td>
<td>-</td>
<td>RGB linecolor (256<em>R+256</em>(G+B))</td>
</tr>
<tr>
<td>linestyle</td>
<td>tinyint</td>
<td>-</td>
<td>Line style: 0=thin, 1=medium, 2=thick, 3=dashed</td>
</tr>
<tr>
<td>fillcolor</td>
<td>integer</td>
<td>-</td>
<td>RGB fillcolor (256<em>R+256</em>(G+B))</td>
</tr>
<tr>
<td>fillstyle</td>
<td>tinyint</td>
<td>-</td>
<td>Fill style, 0=solid, 1-28 hatch: 1: \ ', 4: \ \ \ \ , 7: \ \ \ \ \ , 10: \ \ \ \ \ \ , 13: xx', 16: ++'; +0=dense, +1=medium, +2=sparse</td>
</tr>
</tbody>
</table>

#### Photo table
The photo table contains photos that can be added to structure descriptions. Photos are stored using a maximum size of 1600x1200 pixels and in .jpeg format.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Photo identifier</td>
</tr>
<tr>
<td>structure_id</td>
<td>Int</td>
<td>-</td>
<td>Structure identifier</td>
</tr>
<tr>
<td>image</td>
<td>BLOB</td>
<td>-</td>
<td>Photograph data (.jpeg 1600x1200)</td>
</tr>
<tr>
<td>description</td>
<td>String</td>
<td>-</td>
<td>Photo description</td>
</tr>
<tr>
<td>priority</td>
<td>Int</td>
<td>-</td>
<td>Photo presentation order, smaller first</td>
</tr>
<tr>
<td>date</td>
<td>date</td>
<td>-</td>
<td>Date photo was taken</td>
</tr>
<tr>
<td>ypos</td>
<td>Real</td>
<td>m</td>
<td>Photo position X-coordinate (UTM)</td>
</tr>
<tr>
<td>ypos</td>
<td>Real</td>
<td>m</td>
<td>Photo position Y-coordinate (UTM)</td>
</tr>
<tr>
<td>direction</td>
<td>Int</td>
<td>degr</td>
<td>Direction from structure to photographer, 0=from north, 90=from east side</td>
</tr>
<tr>
<td>distance</td>
<td>Real</td>
<td>m</td>
<td>Distance from structure to photographer</td>
</tr>
</tbody>
</table>
Contact table
Table for contact information of database users, data sources and structure managers.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Contact identifier</td>
</tr>
<tr>
<td>acronym</td>
<td>String</td>
<td>-</td>
<td>Acronym</td>
</tr>
<tr>
<td>firstname</td>
<td>String</td>
<td>-</td>
<td>Firstname</td>
</tr>
<tr>
<td>lastname</td>
<td>String</td>
<td>-</td>
<td>Lastname</td>
</tr>
<tr>
<td>userid</td>
<td>String</td>
<td>-</td>
<td>Database userid, if exist</td>
</tr>
<tr>
<td>institute</td>
<td>String</td>
<td>-</td>
<td>Institute</td>
</tr>
<tr>
<td>department</td>
<td>String</td>
<td>-</td>
<td>Department</td>
</tr>
<tr>
<td>address1</td>
<td>String</td>
<td>-</td>
<td>Street address</td>
</tr>
<tr>
<td>address2</td>
<td>String</td>
<td>-</td>
<td>Post number and city</td>
</tr>
<tr>
<td>phone1</td>
<td>String</td>
<td>-</td>
<td>Phone number</td>
</tr>
<tr>
<td>phone2</td>
<td>String</td>
<td>-</td>
<td>Mobile phone number</td>
</tr>
<tr>
<td>fax</td>
<td>String</td>
<td>-</td>
<td>Fax number</td>
</tr>
<tr>
<td>email</td>
<td>String</td>
<td>-</td>
<td>Email address</td>
</tr>
<tr>
<td>date</td>
<td>Date</td>
<td>-</td>
<td>Date of last update</td>
</tr>
</tbody>
</table>

Validation table
Table for structure validation data.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Validation identifier</td>
</tr>
<tr>
<td>structure_id</td>
<td>Int</td>
<td>-</td>
<td>Structure identifier</td>
</tr>
<tr>
<td>contact_id</td>
<td>Int</td>
<td>-</td>
<td>Validator identifier</td>
</tr>
<tr>
<td>validated</td>
<td>Date</td>
<td>-</td>
<td>Date of validation</td>
</tr>
<tr>
<td>method</td>
<td>String</td>
<td>-</td>
<td>Validation method; visit/indirect</td>
</tr>
<tr>
<td>description</td>
<td>String</td>
<td>-</td>
<td>If anything was changed</td>
</tr>
</tbody>
</table>

Discharge table
Table for discharge data.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Load identifier</td>
</tr>
<tr>
<td>structure_id</td>
<td>Int</td>
<td>-</td>
<td>Associated structure</td>
</tr>
<tr>
<td>substance</td>
<td>String</td>
<td>-</td>
<td>Load variable, e.g. PTOT, NTOT</td>
</tr>
<tr>
<td>amount</td>
<td>Real</td>
<td>kg/d</td>
<td>Amount of load per day</td>
</tr>
<tr>
<td>dyear</td>
<td>Int</td>
<td>-</td>
<td>Year for discharge</td>
</tr>
</tbody>
</table>

Area table
Table for selection data.

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>Int</td>
<td>-</td>
<td>Area identifier</td>
</tr>
<tr>
<td>name</td>
<td>String</td>
<td>-</td>
<td>Area name</td>
</tr>
<tr>
<td>type</td>
<td>String</td>
<td>-</td>
<td>Catchment/district/river/settlement/road</td>
</tr>
<tr>
<td>area</td>
<td>Double</td>
<td>m²</td>
<td>Area of boundary</td>
</tr>
<tr>
<td>boundary</td>
<td>Geometry</td>
<td>-</td>
<td>Area boundary</td>
</tr>
</tbody>
</table>
**CLASS DEPENDENT DATA**

110 Reservoir

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>String</td>
<td>-</td>
<td>Reservoir owner (owner: name)</td>
</tr>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Reservoir extent (bounding box width) in east-west direction</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Reservoir extent (bounding box height) in north-south direction</td>
</tr>
<tr>
<td>area</td>
<td>Real</td>
<td>km²</td>
<td>Area of reservoir at the maximum water level</td>
</tr>
<tr>
<td>activestorage</td>
<td>Real</td>
<td>m³</td>
<td>Active storage of the reservoir</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Water level at which outflow from the storage stops</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Difference from minlevel to activestorage level</td>
</tr>
</tbody>
</table>

Selection criteria

*Large*: Reservoirs with a volume larger than 2.5 million m³. For typical reservoirs in the area with a water depth of 0-2 meters, this would mean an area of at least 2.5 km² when 1 m average water depth is used in volume computation.

*Midsize*: Reservoirs with a volume 0.5-2.5 million m³. For typical reservoirs in the area with a water depth of 0-2 meters, this would mean an area of at least 0.5 km² when 1 m average active depth is used in volume computation.

Reservoirs that are next to each other are included in the database if the combined estimated volume exceeds the above criteria.

Source data

- source data JICA reservoirs (ts_reservoir2.shp),
  - attributes: boundary, name and area

Data processing

- reservoirs with area smaller than 0.5 km² dropped out
- selection criteria applied to original data
120 Floodwater_storage

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>String</td>
<td></td>
<td>Storage owner (owner: name)</td>
</tr>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Storage extent (bounding box width) in east-west direction</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Storage extent (bounding box height) in north-south direction</td>
</tr>
<tr>
<td>area</td>
<td>Real</td>
<td>km²</td>
<td>Area of storage at the maximum water level</td>
</tr>
<tr>
<td>activestorage</td>
<td>Real</td>
<td>m³</td>
<td>Active storage of the reservoir</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Water level at which flow to/from the storage stops</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Difference from minlevel to water level at activestorage volume</td>
</tr>
</tbody>
</table>

Selection criteria
- same as for reservoirs (class 110)

Source data
- source data Kampong Thom private reservoirs, Agriculture Office Kampong Thom Province (kt_reservoir.shp)
  - attributes: boundary, owner, area

Data processing
- no addition processing

210 Canal

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Channel/opening width perpendicular to flow direction</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Channel/opening length along flow</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Channel bottom level</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Channel depth from minlevel to bank level</td>
</tr>
<tr>
<td>crsection</td>
<td>Real</td>
<td>m²</td>
<td>Channel cross section area at maxlevel</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Selection criteria

- **Large**: Canals with an average flow larger than 1 m³/s, or a peak flow larger than 10 m³/s. Channels with high water cross section larger than 10 m²
- **Midsize**: All channels wider than 2 meters

Source data
- no data

Data processing
- no addition processing
211 Irrigation canal

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Channel width perpendicular to flow direction</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Channel length along flow</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Channel bottom level</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Channel depth from minlevel to bank level</td>
</tr>
<tr>
<td>csection</td>
<td>Real</td>
<td>m²</td>
<td>Channel cross section area at maxlevel</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td>Bank material, if not earth</td>
</tr>
</tbody>
</table>

Selection criteria
- same as canal (class 210)

Source data
- source data JICA irrigation channel data (ts_irr_canal2.shp)
  • all data included
  • attributes: mid-line, small/large size classification
- source data Chinit irrigation project channel data (added ts_reservoir2.shp)
  • all data included
  • attributes: mid-line, size: main/secondary/tertiary canal/drain

Data processing
- simplified data to 10 meter resolution
- split with catchment boundaries

220 Bridge

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Channel/opening width perpendicular to flow direction</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Height of bridge bottom from dry-season water level</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Channel/opening length along flow</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Bridge opening bottom level</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Typical maximum water depth under bridge</td>
</tr>
<tr>
<td>csection</td>
<td>Real</td>
<td>m²</td>
<td>Channel/opening cross section area at maxlevel</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td>Material</td>
</tr>
</tbody>
</table>

Selection criteria
- Large: Bridges longer than 30 meters
- Midsize: Bridges longer than 5 meters

Source data
- source data JICA map road bridges (ts_rd_bridge.shp)
  • all bridges included
  • attributes: location
source data JICA map railroad bridges (ts_rr_bridge.shp)
  - all bridges included
  - attributes: location

Data processing
  - no additional processing

230 Culvert

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>String</td>
<td></td>
<td>Culvert type, pipe/box</td>
</tr>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width perpendicular to flow direction</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Height of culvert opening</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length along flow</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Culvert bottom level</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Culvert maximum water depth</td>
</tr>
<tr>
<td>crsection</td>
<td>Real</td>
<td>m2</td>
<td>Cross section area at maxdepth</td>
</tr>
<tr>
<td>wldrop</td>
<td>Real</td>
<td>m</td>
<td>Difference of height from start to end of culvert</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td>Material, if not earth</td>
</tr>
</tbody>
</table>

Selection criteria
  - all culverts included

Source data
  - source data (ts_culvert2.shp)
    - attributes: location, culvert type box/pipe, construction year

Data processing
  - Culverts with no completion year dropped out

240 Spillway

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Channel/opening width perpendicular to flow direction</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Channel/opening length along flow</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m2</td>
<td>Typical maximum water depth</td>
</tr>
<tr>
<td>crsection</td>
<td>Real</td>
<td>m2</td>
<td>Cross-section area</td>
</tr>
<tr>
<td>wldrop</td>
<td>Real</td>
<td>m</td>
<td>Water level drop over the length of structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td>Bank material, if not earth</td>
</tr>
</tbody>
</table>

Selection criteria
  - all data included
Source data
- field visit data from Chinit
  - attributes: width, length, wldrop

Data processing
- no additional processing

310 Dam

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure/opening perpendicular to flow direction</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Largest height of dam</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of flow path in structure along flow direction</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Timber/earth/stone/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria

_Large_: Dams with active reservoir volume larger than 2.5 million m³
_Midsize_: Dams with active reservoir volume between 0.5-2.5 million m³

Source data
- source data JICA map (ts_dam_earth2.shp)
  - attributes: boundary, material

Data processing
- all data included
- joined lines
- simplified to 10 m resolution

320 Embankment

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Average height of embankment from ground level</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of embankment</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Timber/soil/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria

_Large_: Any embankment potentially catching water for more than 2.5 million m³, or, an embankment longer that 10 km.
_Midsize_: Embankments higher than 1 m if longer than 2 km. Also, other embankments that potentially trap more than 0.5 million m³ of water.
Source data
- source data JICA embankments (ts_levee3.shp)
  • attributes: boundary, material, length

Data processing
- joined lines
- dropped out embankments shorter than 0.8 km, and not within distance of 0.5 km of a selected embankment
- simplified to 10 m resolution
- split with catchment boundaries

321 Road embankment (primary)

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Average height of embankment from ground level</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of embankment</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Timber/soil/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria
- all data included

Source data
- source data JICA primary roads (ts_rdprimary2.shp)
  • attributes: boundary, length

Data processing
- split with catchment boundaries
- set the crestlevel to 12 meters (equal to above flood)

322 Road embankment (other)

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Average height of embankment from ground level</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of embankment</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Timber/soil/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria
- all data included (no knowledge on embankment heights available)
Source data
- source data JICA secondary roads (ts_rdsecondary2.shp)
  - attributes: boundary, length

Data processing
- simplified data to 25 meter resolution
- split with catchment boundaries

323 Railroad embankment

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Average height of embankment from ground level</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of embankment</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td>Timber/soil/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria
- all data included

Source data
- source data JICA railroads (ts_railway2.shp)
  - attributes: boundary, length

Data processing
- joined lines
- simplified data to 25 meter resolution
- split with catchment boundaries
- set crestlevel to 12 (above flood)

324 Reservoir dike

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of structure</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Largest height of dike from ground level</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of dike</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td>Timber/earth/stone/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria
- see reservoir

Source data
- source data Chinit irrigation project data (chinit_embankment.shp)
  - attribute: boundary, width, length
Data processing
- no additional processing

330 Gate

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of gate perpendicular to flow direction</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Height of gate from bottom to max water level</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of flow path in gate along flow direction</td>
</tr>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Min water level on which flow can occur through the gate</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Typical maximum water depth for gate</td>
</tr>
<tr>
<td>crsection</td>
<td>Real</td>
<td>m^2</td>
<td>Cross section though which water can flow at maxdepth</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Timber/earth/stone/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria

*Large*: Gate with width of at least 3.0 meters

*Midsize*: Gate with width of 1.0 to 3.0 meters

Source data
- field survey data

Data processing
- no additional processing

340 Weir

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of weir perpendicular to flow direction</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>m</td>
<td>Height of weir</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of weir flow path in flow direction</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur over structure</td>
</tr>
<tr>
<td>wldrop</td>
<td>Real</td>
<td>m</td>
<td>Water level drop (typical)</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Timber/earth/stone/concrete/metal</td>
</tr>
</tbody>
</table>

Selection criteria

*Large*: Weir with width of at least 30 meters

*Midsize*: Weir with width of 2.0 to 30 meters

Source data
- source data Chinit irrigation project data (chinit_weir.shp)
  - attributes: length, wldrop, material

Data processing
- no additional processing
350 Pumping station

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level where the station can work</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>m3/s</td>
<td>Maximum pumping capacity</td>
</tr>
</tbody>
</table>

Selection criteria

*Large*: Station with capacity of at least 2 m3/s
*Midsize*: Station with capacity over 0.5 m3/s

Source data

- no data

Data processing

- no additional processing

360 Hydropower station

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>minlevel</td>
<td>Real</td>
<td>m</td>
<td>Min water level on which flow can occur through the structure</td>
</tr>
<tr>
<td>maxdepth</td>
<td>Real</td>
<td>m</td>
<td>Typical maximum water depth from minlevel</td>
</tr>
<tr>
<td>maxflow</td>
<td>Real</td>
<td>m3</td>
<td>Maximum flow though structure on maximum water level</td>
</tr>
<tr>
<td>wldrop</td>
<td>Real</td>
<td>m</td>
<td>Water level drop (maxlevel to bottom of structure)</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>Gwh</td>
<td>Annual hydropower production</td>
</tr>
</tbody>
</table>

Selection criteria

*Large*: Station with production over 50 Gwh
*Midsize*: Station with production less than 50 Gwh

Data processing

- no additional processing

370 Measurement station

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>Real</td>
<td>m</td>
<td>Type of station: automatic/manual, measured variable(s)</td>
</tr>
</tbody>
</table>

Selection criteria

- all data stations included

Data processing

- no additional processing
371 Hydrological station

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>Real</td>
<td>m</td>
<td>Type of station: automatic/manual, measured variable(s)</td>
</tr>
</tbody>
</table>

Selection criteria
- all data stations included

Source data
- source data MOWRAM water level stations (river_station.shp)
  - attributes: location, station id code, measured variables

Data processing
- no additional processing

372 Meteorological station

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>Real</td>
<td>m</td>
<td>Type of station: automatic/manual, measured variable(s)</td>
</tr>
</tbody>
</table>

Selection criteria
- all data stations included

Source data
- source data MPWT rainfall stations (rainfall_st.shp)
  - attributes: location, station id, measured variables

Data processing
- no additional processing

410 Fishing gear

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in one year</td>
</tr>
</tbody>
</table>

Selection criteria
- stationary gears included

Data processing
- no additional processing
411 Dai fishery

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Number of nets</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in one year</td>
</tr>
</tbody>
</table>

Selection criteria
- all known dai fisheries included

Source data
- satellite picture from Google Earth
  - attributes: boundary, number of nets

Data processing
- no additional processing

412 River barrage with bagnet or trap

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width of barrage</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in one year</td>
</tr>
</tbody>
</table>

Selection criteria

Large: Barrages longer than 50 meters
Midsize: Barrages between 10-50 meters

Data processing
- no additional processing

413 Fence system fence

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of associated fence system (main fence part only)</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in one year</td>
</tr>
</tbody>
</table>

Selection criteria
- all fences, traps and pens

Source data
- digitized from aerial photos (fence_pen.shp, fence_trap.shp, fish_fence.shp), Preak Toal area only
  - attributes: boundary, length
Data processing
   - no additional processing

414 Fence system pen

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of associated fence system (main fence part only)</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in one year</td>
</tr>
</tbody>
</table>

Selection criteria
   - all fences, traps and pens

Source data
   - digitized from aerial photos (fence_pen.shp, fence_trap.shp, fish_fence.shp), Preak Toal area only
     • attributes: boundary, length

Data processing
   - no additional processing

413 Fence system rap

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of associated fence system (main fence part only)</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in one year</td>
</tr>
</tbody>
</table>

Selection criteria
   - all fences, traps and pens

Source data
   - digitized from aerial photos (fence_pen.shp, fence_trap.shp, fish_fence.shp), Preak Toal area only
     • attributes: boundary, length

Data processing
   - no additional processing

420 Fishway

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Channel width perpendicular to flow direction</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Channel length along flow (measured along bank)</td>
</tr>
<tr>
<td>Attribute</td>
<td>Type</td>
<td>Unit</td>
<td>Explanation</td>
</tr>
<tr>
<td>-------------</td>
<td>--------</td>
<td>------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>crestlevel</td>
<td>Real</td>
<td>m</td>
<td>Minimum water level for flow to occur</td>
</tr>
<tr>
<td>crsection</td>
<td>Real</td>
<td>m²</td>
<td>Channel cross section</td>
</tr>
<tr>
<td>wldrop</td>
<td>Real</td>
<td>m</td>
<td>Water level drop over the length of structure</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td></td>
<td>Bank material, if not earth</td>
</tr>
</tbody>
</table>

**Selection criteria**
- all fishways

**Source data**
- field trip data from Chinit area
  - attributes: boundary, width, length, wldrop

**Data processing**
- no additional processing

### 430 Aquaculture

**Class-dependent attributes**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>m²</td>
<td>Aquaculture area</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in year</td>
</tr>
</tbody>
</table>

**Selection criteria**
- farms with annual production more than 10 tons per year

**Source data**
- no data

**Data processing**
- no additional processing

### 431 Pond fish farm

**Class-dependent attributes**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>m²</td>
<td>Aquaculture area</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in year</td>
</tr>
</tbody>
</table>

**Selection criteria**
- same as for aquaculture (class 430)

**Source data**
- no data

**Data processing**
- no additional processing
432 Cage fish farm

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>m²</td>
<td>Aquaculture area</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in year</td>
</tr>
</tbody>
</table>

Selection criteria
- same as for aquaculture (class 430)

Source data
- no data

Data processing
- no additional processing

440 Fishing lot area

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>String</td>
<td></td>
<td>Province and number</td>
</tr>
<tr>
<td>area</td>
<td>Real</td>
<td>m²</td>
<td>Lot area</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>kg/a</td>
<td>Approximate production in year</td>
</tr>
</tbody>
</table>

Selection criteria
- all fishing lots included

Source data
- source data MRC fishing lots from year 2001 (c_lot2001_commercial_3.shp)
  - attributes: boundary, lot number, area code

Data processing
- extracted commercial lots (type 2) from c_lot2001.shp
- union of lots with same region code and lot number
- simplified to 50 m resolution
450 Fish sanctuary

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*name</td>
<td>String</td>
<td></td>
<td>Province and number</td>
</tr>
<tr>
<td>area</td>
<td>Real</td>
<td>m2</td>
<td>Lot area</td>
</tr>
</tbody>
</table>

Selection criteria
- all fish sanctuaries included

Source data
- source data MRC fish sanctuaries from year 2001 (c_lot2001_sanctuary.shp)
  - attributes: boundary

Data processing
- extracted sanctuaries (type 3) from c_lot2001.shp
- simplified to 50 m resolution

510 Reinforced bank

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Description of material used</td>
</tr>
</tbody>
</table>

Data processing
- no additional processing

520 RipRap

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>Real</td>
<td>m</td>
<td>Width across flow direction</td>
</tr>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length along flow direction</td>
</tr>
<tr>
<td>material</td>
<td>String</td>
<td>-</td>
<td>Description of material used</td>
</tr>
</tbody>
</table>

Selection criteria
- ripraps associated with a structure already in the database

Source data
- field trip data from Chinit area
  - attributes: boundary, width, length, wldrop

Data processing
- no additional processing
610 Rice field

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>km2</td>
<td>Area of structure</td>
</tr>
</tbody>
</table>

Source data
- source data JICA paddy field areas (ts_paddyfield5.shp)
  - attributes: boundary, area

Data processing
- simplified to 50 m resolution
- split to catchment areas
- areas smaller than 0.1 km2 removed

620 Field crops

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>km2</td>
<td>Area of structure</td>
</tr>
</tbody>
</table>

Source data
- source data JICA plantation areas (ts_fieldcrop2.shp)
  - attributes: boundary, area

Data processing
- simplified to 50 m resolution
- areas smaller than 0.1 km2 removed
- split to catchment areas

630 Plantation

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>km2</td>
<td>Area of structure</td>
</tr>
</tbody>
</table>

Source data
- source data JICA plantation areas (ts_plantation2.shp)
  - attributes: boundary, area

Data processing
- simplified to 50 m resolution
- areas smaller than 0.1 km2 removed
- split to catchment areas
640 Other agriculture

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>km²</td>
<td>Area of structure</td>
</tr>
</tbody>
</table>

Source data
- source data JICA agricultural areas (ts_otheragri2.shp)
  • attributes: boundary, area

Data processing
- simplified to 50 m resolution
- areas smaller than 0.1 km² removed
- split to catchment areas

650 Irrigated area

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>Real</td>
<td>km²</td>
<td>Area of structure</td>
</tr>
</tbody>
</table>

Selection criteria
- Irrigated areas with field area larger than 2.5 km²

Source data
- source data MRC irrigated areas (ts_irriarea.shp)
  • attributes: boundary, project name, area
- source data Kampong Thom private reservoir areas (kt_irriarea.shp)
  • attributes: boundary, area, owner name

Data processing
- no additional processing

710 Dock/Harbour

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of structure</td>
</tr>
</tbody>
</table>

Selection criteria
- all data included

Source data
- no data

Data processing
- no additional processing
720 Breakwater

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of structure</td>
</tr>
</tbody>
</table>

Selection criteria
- breakwaters with length of at least 100 meters

Source data
- no data

Data processing
- no additional processing

730 Ferry

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Real</td>
<td>m</td>
<td>Length of structure</td>
</tr>
</tbody>
</table>

Selection criteria
- all data included

Source data
- source data JICA ferry lines (ts_ferry_line.shp)

Data processing
- no additional processing

810 Point source

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>production</td>
<td>Real</td>
<td>m3/d</td>
<td>Volume of water coming from outlet</td>
</tr>
</tbody>
</table>

Selection criteria
- waste water flow of at least 100 m3/d, or P load of at least 0.1 kg/d, or N load of at least 1 kg/d, or otherwise non-negligible point source.

Source data
- no data

Data processing
- no additional processing
811 Sewage treatment plant

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>production</td>
<td>Real</td>
<td>m3/d</td>
<td>Volume of water coming from outlet</td>
</tr>
</tbody>
</table>

Selection criteria
- with waste water flow of at least 100 m3/d

Source data
- no data

Data processing
- no additional processing

812 Sewage outlet

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>production</td>
<td>Real</td>
<td>m3/d</td>
<td>Volume of water coming from outlet</td>
</tr>
</tbody>
</table>

Selection criteria
- with waste water flow of at least 50 m3/d

Source data
- no data

Data processing
- no additional processing

813 Industrial sewage outlet

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>production</td>
<td>Real</td>
<td>m3/d</td>
<td>Volume of water coming from outlet</td>
</tr>
</tbody>
</table>

Selection criteria
- with waste water flow of at least 50 m3/d

Source data
- no data

Data processing
- no additional processing
814 Mine

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>String</td>
<td></td>
<td>Mineral/material, type open-pit/placer/quarry/sub-surface</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>tn</td>
<td>Production of material processed/taken out yearly</td>
</tr>
</tbody>
</table>

Selection criteria
- all data included

Source data
- source data MIME mine data (mine_mime2.shp)

Data processing
- removed points outside Tonle Sap catchment areas

820 Diffuse source

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>String</td>
<td></td>
<td>Type of source</td>
</tr>
<tr>
<td>area</td>
<td>Real</td>
<td>km2</td>
<td>Area of source</td>
</tr>
<tr>
<td>width</td>
<td>Real</td>
<td>-</td>
<td>Number of units</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>kg</td>
<td>Production per unit per year</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>units</td>
<td>Total production per year</td>
</tr>
</tbody>
</table>

Source data
- no data

Data processing
- no additional processing

821 Scattered population

Class-dependent attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>*info</td>
<td>String</td>
<td>km2</td>
<td>Type of source, waste produced</td>
</tr>
<tr>
<td>area</td>
<td>Real</td>
<td>km2</td>
<td>Area of source</td>
</tr>
<tr>
<td>width</td>
<td>Real</td>
<td>-</td>
<td>Number of people</td>
</tr>
<tr>
<td>height</td>
<td>Real</td>
<td>kg</td>
<td>Production per person per year</td>
</tr>
<tr>
<td>production</td>
<td>Real</td>
<td>units</td>
<td>Total production per year</td>
</tr>
</tbody>
</table>

Selection criteria
- Village (“phum”) level division

Source data
- population data from year 1998 (ts_phum2.shp)
- attributes: village position, number of persons

Data processing
- no additional processing

AREA DATA
The area table contains the following data:
- Tonle Sap catchment and subcatchment boundaries
  - Data source: MRC (tls_catchments.shp)
  - Attributes: boundary, name, area
- Medium flood extent boundaries
  - Data source: MRC (tls_catchments.shp)
  - Attributes: boundary, name, area
- Cambodian province boundaries (the provinces intersecting Tonle Sap catchment area)
  - Data source: MRC (tls_provinces.shp)
  - Attributes: boundary, name, area

SYSTEM COMPONENTS AND SETUP
The database system is based on the following MySQL standard software components
- MySQL database server (version 5.0. community edition)
- MySQL Query browser (version 1.1.20)
- MySQL Administrator (version 1.1.9)

Additional tools were created in the project to enable transfer of GIS file data to and from the database server, and to allow data to be shared in internet. These are:
- BSViv tool to access database locally, and to import and export data from ESRI shapefile format
- BSMap tool (a java applet) to view data in internet
- BSConn program (a www-server cgi-program) to retrieve data from database server to BSMap applet

The MySQL database server stores the database data and provides database services to client applications. The MySQL Query browser is an interactive tool that can be used to view and modify the data in the database in the computer that contains the database. Use of the tool requires knowledge of SQL. The Administrator tool is used to manage the database server, for example, create new users and create data backups. The programs are available at the MySQL www-site www.mysql.com free of charge.

The Local database access tool "BSViv" can be used to view, add, and modify structure data on map-based windows application. Also import and export of data to ESRI shape file is possible. This feature can be used, for example, when larger amounts of structure data need to be moved to GIS system. The BSViv program utilizes an open-source GIS tool package called FWTools (version 1.0.7), which can be downloaded from http://fwtools.maptools.org.
The Internet access interface "BSApp" can be used to view database data remotely using an internet browser. To use BSApp a www-server with system html pages and bsconn-/cgi-program needs to be setup.

Installation of the system for local and internet access is described in the chapter 2 of the Built Structures Database User Manual.

Figure 1: System components and connections

BSViv application files
The BSViv application is implemented using a viv-language interpreter, that is developed in Elia Ltd. for simple graphical user interface implementation. The installation will setup the BSViv application under the installation directory to several subdirectories listed below with contents. Starting the program is done by running the "viv.exe" program with the "bs.ip"-file as a parameter.

The viv (=program) subdirectory contains following files:
- bs.ip        - program startup file
- bsmain.ip    - main program file
- common.ip, rl*.ip  - application program files
- viv.exe      - ip-file interpreter
- vivres.dll, vivbmp.dll - viv.exe resources and bitmaps, required by viv.exe
- rlgis.bmp    - about dialog bitmap file

The map-subdirectory contains following files:
- tls_lake.*   - lake and river data for BSViv application
- tls_subcatch_utm.* - subcatchment boundaries for BSViv application

The doc-subdirectory contains following files:
- BSApp-help.doc - BSApp help file
- BSDB_manual.doc - Built structure database system user manual
- bsdb_techdoc.doc - this document

The bsdb-subdirectory contains following files:
- bs0.sql        - sql macro to create bs-database tables
bs0create.sql - sql macro to create bs-database
bs0dump.sql - database dump file
bs0users.sql - sql macro to setup default database users
classdata.sql - sql macro to populate structure class data to database

WWW-SITE FILES

To access the bs-database using internet, the files listed below need to be setup in a www-server directory. The built structures – site contains BSApp java applet, composed of several jar-files, a bsconn – cgi-bin program, and some html pages. By default user authentication is setup using as in the Apache www-server basic authentication using .htaccess file. The bs-www site contains the following files

Main directory: www/bs
  .htaccess - Apache access control file
  index.html - startup page
  tlsstart.jpg - picture in the startup page
  bsapp.shtml - applet window
  bsapp.jar - applet code
  openmap.jar - applet code library
  swingset.jar - applet code library
  bsapp_help.html - help window
  exitwindow.html - file used to exit applet

Help pictures : www/bs/bsapp_help_files
  *.* - bsapp_help.html pictures

cgi-bin programs: www/bs/cgi-bin
  bsconn.exe - cgi-bin program to connect bsapp to MySQL database
  libmysql.dll - mysql dll-library, used by bsconn

Documentation: www/bs/doc
  bsdb_manual.doc - bsdb user manual
  bsdb_techdoc.doc - this documentation

Apache configuration: wwwconf
  .htpasswd - password file
  htpassword.exe - password generator program
  httpd.conf - example Apache configuration file

DATABASE AND WWW-SITE USER AUTHENTICATION

The user authentication is setup by default for the Apache www-server using basic authentication. Entering the www/bs directory requires giving a user identification and password, after this no more passwords are asked.

The "bsconn" cgi-bin program uses default username and password (see user manual/Installation) hard coded in the program for accessing MySQL database server. Therefore, it is necessary to setup the default user to the database server if it is to be used via BSApp – applet. If required, the username and password can be easily changed in the bsconn source code.
SOURCE CODE FILES
The bsconn C++ source files and BSApp java source files are included in the "BSSourceSetup.exe" installation package. The bsconn is compiled with Borland C++ builder 6, and the BsApp with Java 1.5.0_08.
APPENDIX A: GLOSSARY
(Reference: http://www.nalms.org/glossary/glossary.htm)

Channel
A course, such as a trench or aqueduct, through which water is moved or directed; the bed of a river or stream.

Conduit
Any channel or pipe used for conducting the flow of water.

Culvert
A hydraulically short conduit which conveys water e.g. through a roadway embankment or through some other type of flow obstruction below ground level.

Dam
A barrier built across a valley or river for storing water.

Detention basin
A basin or reservoir where water is stored for regulating a flood. It has outlets for releasing the flows during the floods.

Embankment
A man-made earth structure constructed for the purpose of impounding water and/or carrying a roadway.

Fish ladder
An inclined trough which carries water from above to below a dam so that fish can easily swim upstream.

Fishway
A structure allowing fish to pass over vertical impediments. It may include special attraction devices, entrances, collection and transportation channels, a fish ladder, and an exit.

Gauge (gauging station)
Specific locations on a stream where systematic observations of hydrologic data are obtained through mechanical or electrical means.

Intake
A hydraulic structure built at the upstream end of the diversion canal; a tunnel or power plant for controlling the flow and preventing silt and debris from entering the diversion.

Levee
A natural or man-made earthen barrier along the edge of a stream, river, or lake to prevent the flow of water out of its channel.

Reservoir
An artificial lake, pond, tank, or basin (natural or man-made) into which water flows and is stored for future use.

Riprap
A layer of large stones, broken rock, boulders, or precast blocks placed in random fashion on the upstream and downstream faces of embankment dams, on stream banks, on reservoir shores, on the sides of a channel, or on other land surfaces to protect them from erosion caused by current, wind, wave, and/or ice action.

Sluice
An artificial channel for conducting water, with a valve or gate to regulate the flow.

Sluice gate
A valve or gate used in a channel to regulate flow.
Spillway
Section of a dam designed to permit water to pass over its crest; a weir or channel taking overflow from the dam; serves as a safety channel to prevent erosion of the dam.

Weir
A dam, usually small, in a stream to raise the water level or divert its flow.

Weir (measurement)
A notch or depression in a levee, dam, embankment, or other barrier across or bordering a stream, through which the flow of water is measured or regulated.

Weir (fish)
A barrier constructed across a stream to divert fish into a trap.
APPENDIX B: TONLE SAP CATCHMENT STATISTICS

Catchment area ~ 95000 km$^2$
Dry season lake ~ volume 1-2 km$^3$, depth minimum 0.5 m, area 2500 km$^2$
Rainy season lake ~ volume 50-80 km$^3$, depth 6-9 m, area 13000-14500 km$^2$
Lake retention capacity ~ 80 km$^3$
80 % of sediments brought to lake by flood retained

Average leaching from lake catchment area ~ 30 km$^3$/a = 10 l/s/km$^2$
Average volume flowing to lake outside catchment 40 km$^3$/a

Outflow from lake 7.5-8.5 months, 70.4 km$^3$, or 3375 m$^3$/s average for 8 months

Inflow to lake from outside catchment area 40.7 km$^3$, starting mid-May to mid-June, duration 3.5-4.5 months, 3860 m$^3$/s average for 4 months

Precipitation ~ 1300 mm/a, typically no rain from December to February
For rainy season, peak precipitation per month is typically over 300 mm/a, or about $\frac{1}{4}$ of the total yearly precipitation, three times the average precipitation.

Pan evaporation ~ 2100 mm/a = 5.8 mm/d
1 cm water level change in dry season lake level is 2.5 km$^3$
APPENDIX C: DATA DIRECTORY

JICA data point data
- ts_rr_bridge.shp
- ts_rd_bridge.shp
- ts_culvert.shp
- mine_mime.shp
- ts_hystation.shp

JICA line data
- ts_ferry_line.shp
- ts_railway2.shp
- ts_canal.shp
- ts_levee.shp
- ts_rdprimary2.shp
- ts_dam_earth.shp
- ts_rdsecondary_aw.shp
- ts_rdsecondary_dw.shp

JICA polygon data
- ts_reservoir.shp

MRC data
- Tonle Sap catchment boundary
- Tonle Sap subcatchment boundaries
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Database Component

BUILT STRUCTURES DATABASE
USERS MANUAL

Prepared by
Hannu LAURI
EIA Ltd., Finland

April 2006
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   - Database access ..................................................................................................................... 3

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1. INTRODUCTION

The Built Structures database "BSData" contains data on man-made hydraulic structures on the Tonle Sap catchment. The structures are classified according to the intended use. For each structure position, extent and structure attributes such as structure height and construction material are stored.

Classification of structures

The structures are classified for eight higher level classes that may have one or more subclasses. The detailed classification can be found in the technical documentation. The main classes are:

1. Storages (e.g. reservoirs)
2. Flow routes (e.g. canals)
3. Flow controls (e.g. dams, gates)
4. Fish and aquaculture (e.g. dai fisheries)
5. Erosion prevention (e.g. ripraps)
6. Agriculture (e.g. irrigated areas)
7. Transportation (e.g. docs and harbours)
8. Discharge (e.g. sewage outlets, mines)

Database access

The database can be accessed using three methods (see Figure 1.1):

1. Standard SQL tools (MySQL)
2. Local database access
3. Internet access interface

The standard MySQL tools are:

a. MySQL database server (version 5.0. community edition)
b. MySQL Query browser (version 1.1.20)
c. MySQL Administrator (version 1.1.9)
The MySQL database server stores the database data and provides database services to client applications. The Query browser is an interactive tool that can be used to view and modify the data in the database in the computer that contains the database. Remote access is also possible. Use of the tool requires knowledge of SQL. The Administrator tool is used to manage the database server, for example, create new users and create data backups. The programs are available at the MySQL www-site www.mysql.com free of charge.

Please see the technical documentation on database structure. Chapter 1, "Setting up the database” explains how to set up the database and access it using Query Browser.

The Local database access tool "BSViv" can be used to view, add, and modify structure data on map-based windows applications. Also, importing and exporting to and from ESRI shape files is possible if larger amounts of structure data need to be moved to or from a GIS system. See Chapter 3 below on how to set up and use this application.

The Internet access interface "BSApp" can be used to view database data remotely using an Internet browser. In order to use this access method, a www-browser installation of the database system needs to be set up. See Chapter 4 below on how to setup and use this system.

Database management, such as adding users and backing up data, can be done using Database standard tools. Some tasks can be done using the "BSViv" applications. See Chapter 5 on database administration and updating.

2. SETTING UP THE BSDATA DATABASE

Running environment

The database system works on PC computers using Windows 2000/XP operating systems. About 150 Mb of disk space is needed to set up the system. Software installation packages can be found on the distribution CD.

Setting up database for local use

To set up the BSData database the following software needs to be installed:

1. MySQL database server (version 5.0.21)
2. MySQL Query Browser (version 1.1.20)
3. BSViv application (version 1.0)
4. FWTools toolset (version 1.1.0)

Detailed installation instructions for the MySQL database server can be found on the MySQL www-site (www.mysql.com). The following instance configuration options seem to work quite well:

- Developer machine
- Multifunctional database
- Tablespace in C: disk and "Installation Path"
- Number of concurrent connections 15 (Manual setting)
- Enable TCP/IP networking (also configure your Firewall, so that access to port 3306 is allowed from localhost ip-address 127.0.0.1 only)
- Standard character set
• Set password to 'tietoa'. If you change this the password in the BSViv application must be changed as well. See below.

To install the Query Browser, BSViv application and FWTTools just run the corresponding installation files "mysql-query-browser-1.1.20-win.msi", "BSVivSetup.exe" and "FWTools100.exe". Please use the default installation directories. The database data is in the BSViv setup.

After the database server is installed and working, the database data needs to be imported. This can be done using the BSViv application, or by using MySQL command line client.

If you are using the BSViv, do the following:
• Start the BSViv application (Windows “Start” menu)
• If you changed the database root password, select the Database/Connection setup from the main menu and type in the new password to dbpasswd-field.
• To create to database select the "Database/Create bs0 database" menu item. If the database already exists, this will return an error.
• To import data to the database select the "Database/Import dump file" menu item, then select "bs0dump.sql" from the file list, and click "Open". The dump file is located in "C:\Program Files\BS\bsdb directory".

If you like to use MySQL command line, do as follows:
• Start MySQL command line (from Windows “Start” menu)
• create the database by typing "create database bs0;", then press <Enter>
• import data by typing "source C:/Program Files/BS/bsdb/bs0dump.sql;".

Setting up database remote access
There are two possibilities for accessing the database remotely:
• Access through IP-port 3306, using BSViv and Query Browser.
• Access using www-browser and BSApp

First, access to the database server can be opened to selected remote computers, by configuring the firewall of the server computer to allow access to IP-port 3306 from the remote computers. Note that access to port 3306 should be allowed for friendly ip-addresses only. In this case the BSViv and Query Browser can be used to access the database. Just configure the database server to the remote server computer.

The second way is to set up remote access using a www-server and the BSApp data browsing program. This configuration allows access to anyone with an Internet browser, and knowledge of the correct userid and password.

To setup remote internet access the following software needs to be installed (in addition to the local database installation):
• Apache 2.2.2 www-server
• BSApp www-pages and cgi-program.


The BSApp system setup can be done by running the BSAppSetup program from the distribution disk. The setup program will put the BSApp www-pages to directory c:\bs\www by default. In addition to running the setup program following task need to be done:
Set up network access user id's for the MySQL database by running the "bsdb/bs0users.sql" macro using the BSViv "Run SQL macro" command.

Modify Apache configuration file so that it works with BSApp. After installing the BSApp, an example configuration file "httpd.conf" can be found from the wwwconf-directory. To setup the default configuration for Apache, with local www-server access only, copy the provided example configuration file to Apache configuration directory (typically "C:\Program files\Apache Group\Apache2\conf"). Note that Apache must be restarted after the configuration has been changed. To modify the file by hand, "Includes" must be allowed for bs directory, and "bs/cgi-bin" directory must be defined to contain script files. See the provided "httpd.conf" file for details.

3. USING BSVIV TO ACCESS BSDATA LOCALLY

The BSViv program is used to access BSData locally; that is, the database server containing the data is in the same computer. The program can be configured to access data in remote servers as well.

The BSViv can be used for the following tasks:

- querying database data by class, and showing the results on the map
- moving data from an ESRI shapefile to the BSData database
- exporting data from the BSData database to a shapefile
- modifying single structure attributes
- adding and removing single structures from the database
- importing photos to the database
- modifying class related database data
- creating a database dump file and importing all data from an existing dump file
- creating a database report of the number of structures in each class.

Installation and starting the program

To install the BSViv application, see chapter 2, Setting up the database for local use. The installation program creates a start-menu item "BSViv", that is used to start the program. To start the system from command line, move to the installation directory ("C:\Program Files\BS\viv") and give command "C:\Program Files\BS\viv\viv bs.ip".

Main window, tools and main menu

The BSViv main window displays a menu, toolbar, data layer list, and map window workspace typically containing a single map window.

The top part of the window holds the main menu and toolbar. Main menu commands are used to initiate actions such as querying of the database. Toolbar tools are used to zoom and pan the map window, and select, add and remove structures from the data layers.

The map window displays some base map data (catchment boundaries and main rivers) from which database structure data is drawn. The data in the map window is divided into layers that are listed in the layer list. The map window can be zoomed and panned using the toolbar tools. The UTM coordinates of the current mouse location are shown on the toolbar as well.

On the left side of the window is the layer list containing a list of data layers shown in the map window. A data layer can hold data for one class of structures only. Many
data layers can be shown at the same time. Some actions require selecting a data layer from the layer list. This can be done simply by clicking the layer name in the layer list. Clicking a layer name with the right mouse button causes a popup menu to appear. By using this menu the layers can be rearranged or completely removed.

![BSViv main window](image)

*Figure 3.1: BSViv main window*

The toolbar has the following tools:

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Zoom in" /></td>
<td>Zoom in by dragging a rectangle to a model window</td>
</tr>
<tr>
<td><img src="image" alt="Zoom out" /></td>
<td>Zoom back to previous zoom setting</td>
</tr>
<tr>
<td><img src="image" alt="Pan" /></td>
<td>Pan by dragging the mouse</td>
</tr>
<tr>
<td><img src="image" alt="Copy" /></td>
<td>Copy window contents to the clipboard as a Metafile</td>
</tr>
<tr>
<td><img src="image" alt="Zoom to layer" /></td>
<td>Zoom to selected layer boundaries</td>
</tr>
<tr>
<td><img src="image" alt="Add structure" /></td>
<td>Add a new structure to the selected data layer</td>
</tr>
<tr>
<td><img src="image" alt="Coordinates" /></td>
<td>Current mouse position coordinates: UTM-East, UTM-North, (latitude, longitude)</td>
</tr>
<tr>
<td><img src="image" alt="Units" /></td>
<td>Units: meters and decimal degrees</td>
</tr>
</tbody>
</table>

The main menu has the following commands:

<table>
<thead>
<tr>
<th>File menu</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>Create a new map window</td>
</tr>
<tr>
<td>Run SQL command</td>
<td>Run a SQL command</td>
</tr>
<tr>
<td>Run SQL macro</td>
<td>Select a SQL macro file and run it</td>
</tr>
<tr>
<td>Show cmd window</td>
<td>Display viv command window</td>
</tr>
<tr>
<td>Exit</td>
<td>Exit program</td>
</tr>
</tbody>
</table>
### LayerData menu

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>New layer</td>
<td>Create a new empty structure data layer</td>
</tr>
<tr>
<td>Query by class</td>
<td>Query data from the database and create a new data layer</td>
</tr>
<tr>
<td>Read shapefile</td>
<td>Import graphics and attributes from a shapefile to a structure data layer</td>
</tr>
<tr>
<td>Write to shapefile</td>
<td>Write structure graphics and attributes to a shapefile</td>
</tr>
<tr>
<td>Import to database</td>
<td>Write structure data from a structure data layer to the database</td>
</tr>
</tbody>
</table>

### Other data menu

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import photo</td>
<td>Read a .jpeg photo to database, convert to standard size and also create an icon file</td>
</tr>
<tr>
<td>Edit class data</td>
<td>Select class and edit related data, such as line and fill color</td>
</tr>
</tbody>
</table>

### Database menu

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection setup</td>
<td>Set database location and userid information</td>
</tr>
<tr>
<td>Program path setup</td>
<td>Set MySQL command line and FWTools paths</td>
</tr>
<tr>
<td>Report by class</td>
<td>Count and report the number of items in each class</td>
</tr>
<tr>
<td>Dump to file</td>
<td>Dump all database data to a SQL-script file</td>
</tr>
<tr>
<td>Create bs0 database</td>
<td>Create a database, used when setting up the database</td>
</tr>
<tr>
<td>Reset tables</td>
<td>Create database tables, used when setting up the database</td>
</tr>
<tr>
<td>Import dump file</td>
<td>Used to import all database data and tables from a SQL dump file</td>
</tr>
</tbody>
</table>

### Viewing and updating database data

To view and edit database data, a database query must first be made. The query will then fetch data from the database and create a new data layer in the map window. To perform a query use the "LayerData/Query by class" command from the main menu, select structure class and click OK. After the query is completed a new data layer is added to the layer list, and the structure data is drawn to the window.

To view or modify single structure attributes zoom in on the area of the map where the structure is located, and click the structure graphic with the mouse. This action will create a popup menu showing a list of nearby structures, where the preferred structure can be selected. A dialog box containing the structure data then opens in the window, shown in Figure 3.2 below.
Figure 3.2: Structure data dialog box

The dialog box allows editing of structure attribute data. Attribute fields visible in the window depend on the structure class. To modify and update the data to the database first modify the desired fields, and then click the "Update" button. To close the window with no update click "Close". To remove the structure from the database click "Remove".

Graphical structure data cannot for now be modified in the BSViv application. If graphical data needs to be modified, the old structure must be removed, and a new structure with the modified data must then be created.

Importing data from ESRI shapefile to the BSData database

To move data from the ESRI shapefile to the database, first the shapefile must be imported to BSViv, and then from BSViv to the database.

To import shapefile contents to BSViv, use the "LayerData/Read shapefile" menu command. After giving the command two things need to be selected. First the shapefile to import, and then the structure class for the objects in the shapefile. Each shapefile may contain only structures belonging to same structure class. After selecting these an attribute selection window opens, in which the shapefile attribute data can be mapped to BS database structure attributes. (See Figure 3.3 below).
Figure 3.3: Setting class attributes during shapefile import

For each structure attribute there are the following options: “set to given value”, “use attribute from shapefile”, or “compute from geographic data”. The dialog box "Action" column pull-down menus define how to set the field value. Items starting with “%” are values that are computed from geographical data ("%length", "%xpos", "%ypos"). The items starting with "#" are attributes from the shapefile. If the action column value is "set" then the value in the "Value" column is set for all imported structures.

After pressing OK the shapefile data is imported to BSVis and displayed on the map. The structures are, however, not yet in the database, (structure "id" values are set to zero to show that the structures are not yet in the database). To copy the data from the new shapefile layer to the database, first select the new layer from the layer list, and then use the "LayerData/Import to database" command.

Exporting data from BSData database to shapefile

To export data from the database to a shapefile, first query the preferred structure from the database using the "LayerData/Query by class" command. After the query is done and a new data layer is created in the map window, select the data layer from the layer list and select the "LayerData/Write to shapefile" command from the main menu. Select a new name for the new shapefile and press OK:

Adding and removing single structures from the database

Adding new structures to the database can be done by importing shapefile data as described above, or by creating new structures manually.

To create a new structure, a data layer for the structure data must first be created using the "LayerData/New Layer" command. The command asks for the structure class of the new layer, after which it creates a new empty layer in the layer list.

To add a new structure to the created data layer, click the "Add new structure" tool from the toolbar, and use the mouse to click a location on the map for the new structure. If the structure is a point, one mouse click is sufficient. If the structure is a line-type of polygon, draw the structure on the map with a sufficient number of mouse clicks, and finish the drawing by double clicking. After the geographic data is clicked to the map, a dialog box asking for structure attributes opens. Fill the structure data and press "Create" to create the structure in the database.
**Importing photos to the database**

Photos can be put into the database and associated with structures that are already in the database. The imported photos must be in .jpeg format. Photos can be imported using the "Other data/Import photo" command, which will open a dialog box asking for the photo file name, photo location and associated structure id. After the information is given, the command creates a 800x600 pixel size version of the photo and copies it to the database. Also, a 80x60 pixel size icon is made and put into the database as well. The www-interface is able to show the photos along with structure data. The BSViv cannot display photos.

**Modifying class related database data**

Class related data, such as drawing line color and fill color, can be modified using "Other data/Edit class data". After selecting the class to edit, a class data edit dialog box opens. The drawing attributes and class description can be changed. Class identifiers and shapetype cannot be changed, since other applications use the defined values.

**Creating database dump file and importing all data from an existing dump file**

Database dump files can be used to move the whole database to another computer, or to backup the database before making changes to the data content. To create a database dump use the menu command "Database/Dump to file", select a new name for the database dump, and click OK.

To restore the database from a dump file, use the menu command "Database/Import dump file", select the database dump file from the file window, and click OK.

**Creating a database report**

A simple report listing number of items in each structure class can be created using the menu command "Database/Report by Class". The command will create a new text window containing the generated report.

<table>
<thead>
<tr>
<th>class</th>
<th>items</th>
<th>class name</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>55</td>
<td>Reservoir</td>
</tr>
<tr>
<td>211</td>
<td>3732</td>
<td>Irrigation canal</td>
</tr>
<tr>
<td>220</td>
<td>1278</td>
<td>Bridge</td>
</tr>
<tr>
<td>230</td>
<td>323</td>
<td>Culvert</td>
</tr>
<tr>
<td>310</td>
<td>38</td>
<td>Dam</td>
</tr>
<tr>
<td>320</td>
<td>892</td>
<td>Embankment</td>
</tr>
<tr>
<td>321</td>
<td>28</td>
<td>Road embankment primary</td>
</tr>
<tr>
<td>322</td>
<td>1858</td>
<td>Road embankment other</td>
</tr>
<tr>
<td>323</td>
<td>14</td>
<td>Railroad embankment</td>
</tr>
<tr>
<td>324</td>
<td>3</td>
<td>Reservoir dike</td>
</tr>
<tr>
<td>340</td>
<td>2</td>
<td>Weir</td>
</tr>
<tr>
<td>371</td>
<td>44</td>
<td>Hydrological station</td>
</tr>
<tr>
<td>372</td>
<td>85</td>
<td>Meteorological station</td>
</tr>
<tr>
<td>411</td>
<td>11</td>
<td>Dai fishery</td>
</tr>
<tr>
<td>413</td>
<td>472</td>
<td>Fence system</td>
</tr>
<tr>
<td>440</td>
<td>41</td>
<td>Fishing lot</td>
</tr>
<tr>
<td>450</td>
<td>7</td>
<td>Fish sanctuary</td>
</tr>
<tr>
<td>610</td>
<td>1323</td>
<td>Rice field</td>
</tr>
<tr>
<td>620</td>
<td>372</td>
<td>Field crops</td>
</tr>
<tr>
<td>630</td>
<td>77</td>
<td>Plantation</td>
</tr>
<tr>
<td>640</td>
<td>2708</td>
<td>Other agriculture</td>
</tr>
<tr>
<td>650</td>
<td>157</td>
<td>Irrigated area</td>
</tr>
<tr>
<td>710</td>
<td>4</td>
<td>Docks/Harbour</td>
</tr>
<tr>
<td>730</td>
<td>4</td>
<td>Ferry</td>
</tr>
<tr>
<td>814</td>
<td>62</td>
<td>Mine</td>
</tr>
</tbody>
</table>

*Figure 3.4: Database Report by class*
4. USING BSAPP TO ACCESS BSDATA REMOTELY

The BSApp interface can be used to connect to the BSData database using an Internet browser, such as IE 6.0 or Firefox 1.5. The Internet server should have BSData database installed for remote access.

The BSApp can be used for the following tasks:
- querying database data by class and geographical area, and showing the results on the map
- Viewing structure attribute data for selected structures
- Viewing structure attribute data in table format

Installation and starting the program

The BSApp runs in any modern Internet browser that can run Java applets. To run the program an Internet browser should be installed. The BSApp also uses Java Runtime Environment 5 or later, which should be installed on the client computer (JRE download: http://java.sun.com/javase/downloads/index.jsp).

To start the BSApp, start your browser program and type the address of the BSData server into the address bar of the browser. A test version of the database is available during 2007 at http://www.eia.fi/bs, userid "bsclient" and password "gh4ntx89". On the welcome page there is a button where the BSApp can be started.

After clicking the start button the application downloads from the www-server, which can take some time, since a few megabytes of data program code need to be downloaded. The application code is cached to the accessing computer, so next time the program is started the start time will be shorter.

Main window, tools and main menu

The main window of the BSApp applet is shown in Figure 4.1. The window displays a base map with main rivers and catchment boundaries, a coordinate grid and a scale bar. On the right side of the window is a data layer list displaying all data layers shown in the window. The top part of the window contains the menu and toolbar.

The map window can be zoomed and panned using the toolbar tools. Also, the Zoom, Query, Classes and Areas commands are located on the toolbar for fast access. The geographic coordinates of the current mouse location are shown on the toolbar as well.

On the right side of the window the layer list containing a list of maps and data layers in shown in the window. A data layer holds data that results from one database query. Many data layers can be shown at the same time. Some actions require selecting data layers from the layer list. This is done simply by clicking the layer name in the layer list. By clicking a layer name with the right mouse button, a popup menu appears. Using this menu the layers can be rearranged or completely removed.
Figure 4.1: BSApp main window

The toolbar has the following tools and buttons:

- **Arrow tool**: Show structure data (point and click), Zoom (drag) and Pan (Shift+drag)
- **Zoom in** by dragging a rectangle to model window
- **Zoom back** to previous zoom setting
- **Pan** by dragging with the mouse
- **Zoom to preset area**
- **Lat N, Lon E** Mouse position geographical coordinates in degrees and decimal minutes
- **Query** Query data from the database
The window menu contains the following commands:

<table>
<thead>
<tr>
<th>File menu</th>
<th>Help menu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Print</td>
<td>Help</td>
</tr>
<tr>
<td>Print window contents</td>
<td>Open up a help window</td>
</tr>
<tr>
<td>Exit</td>
<td>About</td>
</tr>
<tr>
<td>Exit program</td>
<td>Application version etc. info.</td>
</tr>
</tbody>
</table>

**Querying database data**

To view database data a database query must be made. The query will then fetch data from the database and create a new data layer in the map window. To perform a query click the "Query" button on the toolbar, which opens a query dialog box (Figure 4.2). In the query dialog box select a structure class and area and click OK. After the query is completed a new data layer is added to the layer list, and the structure data is drawn in the window.

![Query data window](image)

**Figure 4.2 Query data window**

**Viewing structure data**

To view structure attribute data zoom the map to the area where the preferred structure is located and click the structure graphic with the mouse (when the Arrow tool is active). This will open a dialog window showing the structure data (Figure 4.3). The displayed attributes depend on structure class.

To view all the attribute data of a data layer in table format, click the layer title in the layer list with the right button, and select "Show table" from the popup menu. This will open a table view of all structure attribute data (Figure 4.4). The table rows can be selected using the mouse and copied to Clipboard by pressing Ctrl-C on the keyboard.
Other functionality

"Zoom" – toolbar button has some zoom shortcuts, including, "TonleSap river", "TonleSap lake" and "Full extent".
"Areas" – toolbar button can be used to draw selection areas to map window. This includes subcatchments, provinces and mediumflood boundary
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Hydrology Component

INFLUENCE OF BUILT STRUCTURES ON TONLE SAP HYDROLOGY AND RELATED PARAMETERS

Prepared by

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Environmental Impact Assessment Center of Finland Ltd

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EXECUTIVE SUMMARY

A set of tools and analyses has been applied to assess the impacts of built structures on Tonle Sap hydrology, hydrodynamics, sediments, water quality and conditions for fish. Three scales of impacts have been studied: (i) upstream basin-wide development impacts, (ii) Tonle Sap catchment development impacts, and (iii) local scale individual structures.

Four scenarios have been studied. The (i) baseline scenario represents the current development level of the Mekong Basin. Two additional basin-wide scenarios have been studied: (ii) upstream tributaries' intensive irrigation and hydropower dam development, and (iii) mainstream dams + upstream tributaries' intensive development as in (ii). For the Tonle Sap scale (iv) the impact of catchment irrigation and hydropower dam development has been modeled.

The different tools and methodologies used in the study include:
- Hydrological, hydrodynamic, sediment and water quality field measurements
- Laboratory experiments for fishing gears
- Hydrological water balance studies
- Tonle Sap Lake, River and floodplain three-dimensional hydrodynamic, sediment and water quality model
- Stung Chinit irrigation system three-dimensional hydraulic, hydrodynamic, sediment and water quality model
- Model applications for floodplain structures including roads and irrigation reservoirs
- Water resources allocation model for irrigation and hydropower.

NATURAL VARIABILITY AND BUILT STRUCTURE IMPACTS

The human impact is relatively small compared with the high natural variability of the floods. Fish have adapted to the varying conditions and consequently, at least to a degree, are resistant to the human impacts. However, dry years can be critical because built structure impacts are most pronounced then and fish are most vulnerable to additional stress.

BASIN-WIDE DEVELOPMENT IMPACTS

The upstream development impacts can be summarized as:
- Increased dry season water levels that will probably permanently inundate and destroy the lake edge flooded forest that functions as an important habitat and buffer between the Tonle Sap Lake and its floodplain
- Decreased sediment input and consequently impacts on primary productivity
- Delay of flooding and accompanied adverse impact on larvae drift and floodplain habitat oxygen conditions
- Decreased flood season flooded area and volume resulting in less primary production and habitat for fish.

The cumulative impact of the individual impacts may result is serious consequences for Cambodia’s fisheries.

TONLE SAP CATCHMENT DEVELOPMENT IMPACTS

Implementation of the planned Tonle Sap catchment large-scale dam development plans would result in impacts similar to those in the basin-wide intensive development scenario. The impact on maximum water levels would be similar, but the floods would be delayed longer. Also, the sediment input into the lake would be diminished.

Local developments will considerably strengthen the impacts of upstream developments because both act in a similar way.
STUNG CHINIT RESERVOIR

- The conditions in the reservoir are favorable for fish – good oxygen conditions and sedimentation for primary productivity. However, the structure hinders natural fish migration.
- Positive influence on oxygen concentrations of the river, values increasing by approximately 20% downstream of the structure.
- Slight flushing effect of the reservoir during the flood season, total nutrient and suspended sediment concentrations have to some extent increased and visibility value decreased downstream of the structure.
- Drainage water from irrigation canals is slightly loading the river downstream.
- Data on the full hydrological cycle is required to see total changes in nutrient and sediment dynamics.
- Generalizations about the impacts of other reservoirs should be cautious because local hydrological, water quality, soil and land use conditions influence the impacts.

FISHING GEARS

- Slight opposing influence of bamboo fences on flow velocity can be observed when velocity is higher than 10 cm s\(^{-1}\).
- Opposing influence of nylon nets is slight and appears only when velocity is higher than 20 cm s\(^{-1}\).
- Flow velocities in the Tonle Sap Lake on the Prek Toal area were principally under 10 cm.s\(^{-1}\) in August 2006 and January 2007; consequently, the hydrological and hydrodynamic impacts are small.

PRIVATE IRRIGATION RESERVOIRS ON THE FLOODPLAIN

- The reservoirs trap only a small portion of the flood waters and have a small impact on the large-scale hydrology.
- No major changes in water quality inside and outside of the reservoir.
- Significant changes in water quality can be seen only in the values of chemical oxygen demand. Oxygen demand is increased because of trapped organic matter, sediment and the detritus of biomass production in the reservoir.

FLOODPLAIN ROADS

- In general, roads do not have a major impact on hydrology as long as enough bridges and other openings are built.
- In certain places roads may block main flood flow routes that supply fresh water, sediments and larvae/fish to the floodplain. It is important to understand the hydrodynamic behavior of the floodplain before road construction.

SUMMARY OF THE IMPACTS AND RECOMMENDATIONS

The large-scale basin and catchment irrigation and hydropower dams have the most significant impact on the Tonle Sap’s hydrological and related conditions. However, the cumulative impact of a large number of small structures can be significant and should be clarified.

If intensive basin-wide and local development is realized, the impacts could be critical for the Tonle Sap fisheries. It is recommended that precautionary principles are applied in basin and catchment development until solid knowledge is accumulated on these impacts.
I INTRODUCTION

I.1 STUDY AREA AND BACKGROUND

Importance of the Tonle Sap
1. The Tonle Sap Lake and floodplains in Cambodia contain the largest continuous areas of natural wetland habitats remaining in the Mekong system, while being the largest permanent freshwater body in Southeast Asia. Tonle Sap is a crucially important source for food and livelihoods in Cambodia. More than one million people live in the immediate surroundings of the Tonle Sap Lake and wetlands. These are the poorest people in Cambodia, and they are highly dependent on agriculture and fisheries. Tonle Sap fisheries provide 60% of the animal protein in Cambodia. The lake also operates as a natural reservoir for the Lower Mekong Basin, offering flood protection and contributing significantly to the dry season flow to the Mekong Delta.

Tonle Sap ecosystem
2. The Tonle Sap is among the most productive freshwater ecosystems in the world (e.g. Bonheur, 2001; Lamberts, 2001; van Zalinge et al., 2003). Its high productivity depends on the flood pulse from the Mekong which transfers terrestrial primary products into the aquatic phase during flooding (e.g. Lamberts, 2001). For many of the Mekong fish species, the floodplain of the lake, and particularly the riparian flooded forest and shrublands, offers good conditions for feeding, breeding and rearing their young (Poulsen et al., 2002).

Figure 1. Tonle Sap Lake and its floodplains.

3. The basic hydrological and limnological processes, such as sediment transport and dissolved oxygen levels, are now relatively well documented (e.g. Bonheur, 2001; Carbonnel and Guiscafre, 1963; Koponen et al., 2004; Kummu et al., 2005; Lamberts, 2001; Penny et al., 2005; Sarkkula et al., 2004; Sarkkula et al., 2003; Tsukawaki, 1997;
van Zalinge et al., 2003; WUP-FIN, 2003), but the status and dynamics of biological productivity within the lake are not well studied. This is a major shortcoming in the understanding of the lake’s ecological system (Kummu et al, 2006). Nonetheless, what is well identified about the Tonle Sap ecosystem is the concept of flood pulse (Lamberts, 2001). The concept was developed in Amazon Basin by Junk (1997), and should be utilized in Tonle Sap studies.

**Flood pulse**

4. On floodplains, the fluctuation of water level over time is the principal factor that causes the biota to adapt and produce characteristic community structures (Junk, 1997). Ecosystems that experience fluctuations between terrestrial and aquatic conditions are called pulsing ecosystems, and fall within the domain of the flood pulse concept. Junk’s (1997) flood pulse concept has been widely accepted as describing highly productive floodplain environments and the ecology of pulsing systems. This information can be applied in basins with similar characteristics, such as the Lower Mekong Basin that, like the Lower Amazon, experiences large water level variation and one flood pulse per year. The importance of the flood pulse concept has been recognised by many authors working on the Mekong River/Tonle Sap system (see, for example, Bonheur and Lane, 2002; Fox, 2004; Lamberts, 2001; Poulsen et al., 2002; Sverdrup-Jensen, 2002).
II METHODS, TOOLS AND STUDY LOCATIONS

II.1 FIELD STUDIES

II.1.1 Introduction

5. Hydrological field measurements support the validation of the Tonle Sap hydrodynamics and water quality model and the assessment of the influence of built structures. The field measurements were performed at the irrigation system on the Stung Chinit River, fishing lot area in Prek Toal and private irrigation reservoir on the floodplain in Stung Staung district. Measurements consisted of flow velocity and direction, discharge, water level and water quality analyses at the study sites. The period of field activities coincided with the annual hydrological cycle from August 2006 to January 2007.

II.1.2 Stung Chinit

6. The goal of field measurements at the Stung Chinit irrigation system was collecting hydrological and water quality data for model calibration, assessing how the structure is changing discharges and water quality and what kind of new habitat the reservoir and canal network is creating for the fish population. Measurements were performed every second week from August 2006 to January 2007.

Figure 2. Measurement locations in the Stung Chinit irrigation scheme.
7. Hydrological measurements consisted of discharge and water level measurements. Discharge into the reservoir upstream of the reservoir and discharge from the reservoir right after the dam and next to the national road bridge were measured by an ADCP-device (Acoustic Doppler Current Profiler) (Figure 2.). Water levels were recorded in the reservoir next to the fish pass, downstream under the national road bridge and temporarily upstream at the discharge measurement location.

![Image: Discharge measurements by ADCP in Stung Chinit River.](image)

8. Water quality measurements were carried out by water sampling in the locations where discharges were measured to find out possible changes in the river water quality caused by the structure. In addition to the river water analyses, samples were taken from the reservoir and from the irrigation canals. Water quality of the reservoir was sampled in the middle and near the outlet of the reservoir. Water quality in the irrigation canals was sampled in the secondary and tertiary drainage canals and in the secondary irrigation canal (Figure 3.). All water samples were analysed in the water quality laboratory of the Ministry of Water Resources and Meteorology in Phnom Penh. Analysed parameters were DO (dissolved oxygen), COD (chemical oxygen demand), TSS (total suspended solids), TDS (total dissolved solids), pH, conductivity, alkalinity, TOT-N (total nitrogen), NO3 (nitrate), NH4 (ammonium), TOT-P (total phosphorus) and PO4 (phosphate).

II.1.3 Prek Toal

9. Fieldwork in the Prek Toal area aimed at finding out the impacts of fishing gears on the lake’s hydrology. The major impacts of fishing gears on the flow fields of the lake are caused by thick bamboo fences which are used on fishing lot fence systems. The fences are assembled with bamboo mats attached to wooden poles placed at a distance of 50 to 70 cm from each other. The distance between the bamboo slats is 10 to 15 mm (Deap et. al. 2003). The impacts of bamboo fences on flow velocity and direction were studied by field measurements and laboratory experiments. The lake flow field without fences was studied by point measurements in the Prek Toal area in August 2006. Measurements were carried out by recording current meter (RCM9). Measurements were repeated in January 2007 when bamboo fences were installed on the lake.
Laboratory experiments were performed in the laboratory of hydraulics in the Asian Institute of Technology (AIT) in Bangkok. Bamboo fences were installed to a fixed bed flume where flow velocity and discharge were controlled by setting the power of pumps. Water level was kept at approximately the same level in each measurement in the flume by setting the level of the tail gate at the end of the flume. The experiment was carried out with seven different flow velocities from 5 cm s\(^{-1}\) to a maximum velocity of 68 cm s\(^{-1}\). Three different pieces of bamboo fence were installed on the flume one by one for measurement at each flow velocity. Water level was recorded on both sides of the fence to find out the possible trapping effect of the fence. In addition to bamboo fence measurements the experiment was carried out with a piece of nylon net (net size 5 mm), which is replacing fences on the lake. Bamboo fences last only two years on the lake while cheaper nylon net lasts three years longer. Bamboo fences have therefore replaced nylon nets at several locations.
11. In addition to the laboratory measurements, the impacts of bamboo fences were studied on the lake in the Prek Toal area. Flow velocity was measured by an Acoustic Doppler Current Profiler (ADCP, Figure 5.) on both sides of the bamboo fence of Fishing Lot No. 2 at the end of January 2007. Cross sections were measured at a distances of 2 m, 10 m, 50 m and 100 m of the fence both inside and outside of the fenced area.

II.1.4 Private irrigation reservoir in Stung Staung District

12. Development of the Tonle Sap floodplain is most dramatically shown in the building up of huge private irrigation reservoirs. Reservoir banks are simply made by heaping up soil (Figure 6) to a sufficient height to trap rising floods. The height of embankments varies normally between 1.5 and 3 meters. When the flood level decreases and the area nearby the reservoir dries, the water in the reservoir is used to irrigate surrounding rice fields. Almost 40 reservoirs can be found in the Kampong Thom area. To study the impacts of private irrigation reservoirs, one of the reservoirs in Stung Staung district was chosen (Figure 6). The field measurement results indicate reservoir impacts on the floodplain hydrology and water quality. Water quality was measured by water sampling inside and outside of the reservoir (Figure 7.) when (i) the flood level was high, (ii) the water level was decreasing and the floodplain on the north side of the reservoir was already dry and (iii) all surrounding areas were dry and rice growing was started. Water samples were analysed in the water quality laboratory of the Ministry of Water Resources and Meteorology in Phnom Penh. Analysed parameters were DO, COD, TSS, TDS, pH, conductivity, alkalinity, TOT-N, NO3, NH4, TOT-P and PO4. In addition to the water sampling, water level was measured daily inside and outside of the reservoir by the reservoir staff.
II.2 MODELS

II.2.1 Modeling requirements

13. Modeling is a powerful tool to integrate heterogeneous data, fill in spatial and temporal data gaps, study dynamic processes and illustrate natural processes. In many cases, modeling is also the only practical tool to assess impacts of planned developments in a systematic and quantitative way. In the Tonle Sap built structures case, models have been used to study the different types of structures and impacts from the basin-wide to the very local scale. A 3D hydrodynamic and water quality model has been used. Three dimensionality means that both the horizontal and vertical differences in the water properties are modeled. The Tonle Sap system and reservoirs are highly three dimensional. That is, their properties vary significantly in both horizontal and vertical directions, so the use of a 3D model is necessary. As an example conditions in the lake proper and the floodplain are totally different, floodplain flow and mixing being just a fraction of the corresponding properties in the lake proper. In the floodplain, in the vertical direction the flow, sediment and oxygen conditions are quite different on the surface and near the bottom.
II.2.2 Overview of the EIA 3D hydrodynamic model

14. The EIA 3D hydrodynamic and water quality floodplain/lake/river model utilized in the study is probably the only existing 3D flood model in the world, at least on the level of a practical tool. It has been developed based on a previous 3D lake and sea model. The EIA 3D model was developed by the Environmental Impact Assessment Center of Finland Ltd (EIA Ltd.). The development work started 1974 when EIA Ltd. was still part of the Technical Research Centre of Finland. The model has been applied under the Cambodian National Mekong Committee (CNMC) and Mekong River Commission Secretariat (MRCS) to the Tonle Sap since 2001 (WUP-FIN, 2003).

15. The EIA 3D model system is a fully three-dimensional model based on rectangular grid representation. The system accommodates meteorological, hydrological, topographic, land use and infrastructure characteristics of the area under study. The modelling platform includes data processing, model control, GIS, database control, model data products and visualization. The model is able to describe the three-dimensional characteristics of the flooding, flow, water quality, erosion and sedimentation in the lakes, reservoirs, river channels and floodplains. The EIA 3D model system structure is presented in Figure 8.

Figure 8. Schematic EIA model structure. GUI = Graphical User Interface.
II.2.3 Hydrodynamic model equations

16. Computed flows are determined by the following factors:
   1. wind force,
   2. atmospheric pressure at the surface,
   3. conservation and incompressibility of water,
   4. internal friction (viscosity),
   5. transport of velocity differences with water currents (advection),
   6. Coriolis force caused by the earth's rotation,
   7. density differences and water level gradients (hydrostatic pressure),
   8. bottom friction,

17. The motion of a fluid particle on the surface of the earth is governed by the Navier-Stokes equation of motion (the force balance equation) /1/

\[
\frac{\partial \mathbf{u}}{\partial t} = \mathbf{f} - \frac{1}{\rho_0} \frac{\partial \mathbf{p}}{\partial \mathbf{x}} + \frac{\partial}{\partial \mathbf{x}} \left( v_{\text{hor}} \frac{\partial \mathbf{u}}{\partial \mathbf{x}} \right) + \frac{\partial}{\partial \mathbf{y}} \left( v_{\text{hor}} \frac{\partial \mathbf{u}}{\partial \mathbf{y}} \right) + \frac{\partial}{\partial \mathbf{z}} \left( v_{\text{ver}} \frac{\partial \mathbf{u}}{\partial \mathbf{z}} \right) - \mathbf{u} \cdot \nabla \mathbf{u} \quad (1)
\]

\[
\frac{\partial \mathbf{v}}{\partial t} = -\mathbf{f} - \frac{1}{\rho_0} \frac{\partial \mathbf{p}}{\partial \mathbf{y}} + \frac{\partial}{\partial \mathbf{x}} \left( v_{\text{hor}} \frac{\partial \mathbf{v}}{\partial \mathbf{x}} \right) + \frac{\partial}{\partial \mathbf{y}} \left( v_{\text{hor}} \frac{\partial \mathbf{v}}{\partial \mathbf{y}} \right) + \frac{\partial}{\partial \mathbf{z}} \left( v_{\text{ver}} \frac{\partial \mathbf{v}}{\partial \mathbf{z}} \right) - \mathbf{u} \cdot \nabla \mathbf{v} \quad (2)
\]

\[
\frac{\partial \mathbf{p}}{\partial \mathbf{z}} = -g \rho
\]

\[
\nabla \cdot \mathbf{u} = 0 \quad (4)
\]

\[\mathbf{u} = \text{velocity vector, m/s}\]
\[\mathbf{u}, \mathbf{v} = \text{horizontal velocity components, m/s}\]
\[t = \text{time, s}\]
\[p = \text{pressure, Pa}\]
\[f = \text{Coriolis coefficient}\]
\[\rho_0 = \text{average density of water, kg/m}^3\]
\[\rho = \text{density of water, kg/m}^3\]
\[g = 9.81 \text{ m/s}^2\]
\[v_{\text{hor}}, v_{\text{ver}} = \text{horizontal and vertical eddy momentum viscosity, m}^2/\text{s}\]
\[\nabla = \text{gradient operator, m}^{-1}\]

The forces included are (from left to right) local acceleration, advective (or convective) accelerations, pressure gradient, gravitation, Coriolis force and molecular viscosity.

Equation (4) is the continuity equation (mass conservation equation). /3/ The vertical viscosity can either be calculated by a turbulence model such as k-\(\varepsilon\) or given. In the Tonle Sap models a constant vertical viscosity of 35 cm\(^2\)/s is used.
II.2.4 Hydrodynamic model input and output data

18. Model input data consists of:
   1. bathymetric data for the model grid, either as shorelines, point depth data and depth isolines, or as a digital elevation model,
   2. wind measurements from the modelled area for wind forcing computation, wind speed (m/s) and direction (degrees) with a 3 – 6 h or better time resolution,
   3. boundary flows (m³/s) including rivers and open boundaries (daily or more frequent values),
   4. flow and/or water level measurements for model calibration, flow is often measured in cm/s for every ten minutes, for surface height the time resolution depends on the modelled area and may vary from 10 minutes to one day,
   5. land use (vegetation types).

19. The land use types affect both the hydrodynamic and water quality parameters. In the hydrodynamic model the effect comes from three sources:
   • wind fetch
   • wind shielding
   • vegetation stress (friction).

   Average vegetation height, cover and friction are given for each land use type. These in turn determine wind and flow friction in different depth zones. Wind friction is diminished proportional to the vegetation cover above the water level. Vegetation flow friction affects flow only in the layers that are lower than the vegetation height.

20. Model outputs include:
   1. water depth (DEPS, DEPZ)
   2. water elevation (SURF)
   3. flow velocity components (U, V)
   4. flood duration (FLDU-files)
   5. flood arrival time (FLAR-files).

II.2.5 Sediment model

21. The governing equation for the ith fraction of suspended solids includes advection, dispersion, settling and erosion by re-suspension. It retains the conventional form of the general transport equation as follows:
\[
\frac{\partial c_i}{\partial t} + u \frac{\partial c_i}{\partial x} + v \frac{\partial c_i}{\partial y} + w \frac{\partial c_i}{\partial z} = D_h \frac{\partial^2 c_i}{\partial x^2} + D_h \frac{\partial^2 c_i}{\partial y^2} + D_v \frac{\partial^2 c_i}{\partial z^2} - k_{s,i} c_i + S_{c,i}.
\]

\( c_i \) concentration of a substance, units/m³
\( t \) time, s
\( u, v, w \) known water flow velocity components, m/s
\( D_h \) horizontal concentration diffusivity, m²/s
\( D_v \) vertical concentration diffusivity, m²/s
\( k_{s,i} \) settling coefficient cm/d
\( S_{b,i} \) net upward suspended sediment flux, depends on critical shear bottom stress or velocity.

A 7 cm/d settling velocity has been used for the Tonle Sap sediment model. It is based on grain size measurements and model calibration. A 12 cm/d settling velocity is used for the Stung Chinit model in order to accommodate large grain size sediments.

The model input values include initial and boundary sediment concentrations. They are obtained from measurements.

II.2.6 Oxygen model

22. Dissolved oxygen concentrations are governed by sediment oxygen demand, BOD (biochemical oxygen demand) and aeration. The equation for oxygen without transport and diffusion (these are the same as in equation 5) is:

\[
\frac{\partial c}{\partial t} = -k_1 \text{BOD} + k_2 (c_s - c)
\]

Here \( k_1 \) is the BOD rate, \( k_2 \) aeration rate and \( c_s \) oxygen saturation value. In the bottom layer the effect of the bottom sediment oxygen demand is added to the equation.

23. In addition, BOD7 (biological oxygen demand) is one of the calculation parameters. It has not been used so far because of the amount of time required for BOD load modelling. Instead bottom sediment oxygen demand (SOD) is used.

24. The aeration and bottom sediment oxygen demand values are given for each land use class. It is obvious that the vegetation cover and land use type have a strong effect on aeration and the decaying biological material on the ground. The degradable biological material in the water phase (BOD) is transported around and consumes oxygen at a rate that is not assumed to be strongly land use dependent. The values for the SOD vary between 0.05 and 1.4 mg/m²/d depending on the land use (vegetation) type. Similarly the aeration coefficient varies between 1 and 10 cm/d.
II.3 TONLE SAP 3D MODEL SET-UP

II.3.1 Model grid

25. The model covers a 261 km x 196 km = 51 000 km² area. During the highest flood about 15'000 km² of this area is flooded. The model area includes the main tributaries and the Tonle Sap River from Prek Kdam to the lake (Figure 9).

![Figure 9. The 3D model application area for Tonle Sap Lake and its floodplain.](image)

26. The basic grid size is 1 km and the number of grid cells on the horizontal plane 261 x 196 = 51 156. On the vertical plane there are 14 layers which are 1 m thick to 12 m depth. Below that grid thickness is 1.5 and 2.5 m. Near the bottom the layer thickness varies depending on the total depth. Altogether there are 716 184 3D grid points. Part of the Tonle Sap model grid is shown in Figure 10.
II.3.2 Topographic and land use data

27. The floodplain topography is based on the Certeza survey from 1964. It includes first and second order leveling around the lake, 1400 linear km of profile surveys and photogrammetry. The data has been compared to other topographic data, satellite data and recent surveys. The comparisons indicate that the Certeza data is accurate enough for modelling purposes. The data has been further checked and supplemented with MRCS/CNMC topographic survey data consisting of 22 survey lines totaling 470 km.

28. The lake proper and the Tonle Sap River topography are based on the MRCS Hydrographic Atlas survey of 1999. The data has been transformed to the same reference system as the floodplain topography (Ha Tien MSL - Mean Sea Level).
The land use data is based on the JICA Reconnaissance Survey. In the model the 59 original classes have been aggregated to 8 model classes. For instance “shrubland” and “abandoned field covered by shrub” are combined. Only the main classes are used, that is:

1. agricultural land
2. grassland
3. shrubland
4. forest
5. water
6. soil and rock.

II.3.3 Boundary conditions

30. Lake wind measurements are used. They have been conducted by the MRCSW WUP-FIN project. Phnom Penh airport winds are quite different, and have not been used.

31. Discharges are provided on the model boundaries:
   - 12 tributaries shown in Figure 9
   - Prek Kdam
32. The discharges in tributaries are based on the latest rating curves and hydrological model (MRCS/SWAT) results. The Tonle Sap River and overland flow have been correlated to the available Mekong, Tonle Sap River and Lake water levels and discharges.

33. Oxygen and sediment measurements are used for the model boundary values and for model calibration and validation. For each discharge boundary there are also oxygen and sediment boundaries. Oxygen concentrations are based on the monthly averages of the available measurements. Sediment concentrations in tributaries are based on the CNMC and MRC measurements. Sediment concentrations in Prek Kdam are based on the MRC Water Quality Monitor Network data.

II.3.4 Model calibration and validation results

34. The measured and modelled water levels are shown in Figure 12. The simulation was conducted from June 1996 to November 2004. The match is surprisingly good considering that the Prek Kdam and overland flows have been estimated based on one point water level measurements and a second order lake volume model.

![Water levels](image)

Figure 12. Measured (red dots) and WUP-FIN model calculated water levels at the Tonle Sap (Kampong Luong).

35. The total suspended sediment (TSS) results from Kampong Chhnang (KCH1) station are presented in Figure 13. For the validation, the time period between May 2001 and May 2002 was used. Because of the limited measurement data, only surface suspended sediment (SS) concentrations (0-1 m below the water surface) were used. When comparing the observed SS concentrations with the calculated ones, the correlation is good during the flood period (July-September) except the very high peak when the observed values are higher than the calculated. During the receding flood (October-January) the computed values are higher than the observed ones. This may be due to high sediment resuspension rates in the lake during low water level.
Simulated sedimentation (Figure 14) corresponds well with the natural levees that can be seen in the Tonle Sap near the lake proper edge. The simulated net sedimentation is nearly zero in the lake proper, which has been confirmed by field measurements.

Figure 14. Calculated net sedimentation between May 1. – Sept. 13, 2001.

36. According to measurements the characteristic feature of the floodplains is the large-scale anoxia. The model reproduces this phenomenon well. Figure 15a illustrates typical measured oxygen distributions in two cross-sections from the western floodplains and from the middle of the lake. The measured distribution of surface oxygen can be compared with the simulated values as shown in Figure 15b. In the floodplain the model also produces anoxia near the bottom.
Figure 15a. Two water quality measurement cross-sections and sampling sites. Floodplain water depths are shown on the left hand side (1 m intervals). Measured October 2002 oxygen cross-sections shown on the right hand side from the north and middle of the lake.

Figure 15b. Modelled time average of the surface oxygen.
II.4 STUNG CHINIT 3D RESERVOIR MODEL

37. Stung Chinit is an irrigation system that was developed by an ADB project. The model application area can be seen in Figure 2. Corresponding model implementation is presented in Figure 16. The model grid size is 50 m. The narrow channels are described with a smaller grid size.

Figure 16. Stung Chinit model implementation area showing the reservoir on the right hand side, river and the irrigation channel system. Colors signify elevations (red lower, blue higher).

38. An alternative nested model has been applied to the area (Figure 17). It consists of 1000, 50 and 25 m grids that are combined together. The 25 m grid covers the irrigation channel system. The model has not been used in the final simulations because it requires more computation time. Also, the focus has been on the impacts of the reservoir and not on the functioning of the irrigation channel system.

39. The upstream boundary discharge has been obtained from a rating curve relating measured water levels to discharge. For the downstream a flow rating curve was developed. The reservoir spillway description proved to be a difficult part of the implementation. It was found that utilization of a hydraulic weir description gave stable results. A broad crested weir formula that is solved iteratively has been applied. The sediment and oxygen upstream boundary values have been estimated from available measurements.

40. The model has been used to simulate flow, reservoir fill-up, and sediment and oxygen levels. Similar model parameter values have been used as with the Tonle Sap model.
II.5 DEFINITION OF THE MODEL SCENARIOS

41. The model scenarios represent possible future basin-wide and Tonle Sap catchment developments. Intensive scenarios have been selected in order to see more clearly the impacts on the Tonle Sap system. The scenarios assume specific increases in hydropower and irrigation structures. The actual future development depends on economic and political factors and cannot be predicted. The scenarios give an indication of the nature and order of the magnitude of possible impacts on the Tonle Sap but are not intended to predict precisely what will happen in the future.

II.5.1 Basin-wide scenarios

42. Three basin-wide scenarios have been used in the study.

   1. **Baseline**: development of the basin is on the current level.
   2. **Intensive Development**: 55 km^3 of hydropower and irrigation dams in the Chinese Mekong mainstream and in the upstream Mekong tributaries are constructed.
   3. **Mainstream Dams**: dams in the Intensive Development scenario + 85 km^3 of mainstream dams in Lao PDR, Thailand and Cambodia (High Luang Prabang, Sayabouri, Pa Mong, Upper Thakhek, Ban Koum, Stung Treng, Sambor) are constructed.

43. The Baseline scenario is obtained from measured Tonle Sap in- and outflows. The development level changes slightly between years, but in practice the development
changes have been minor compared to the total flow volumes. Because of this the development level can be assumed to stay nearly on the same level between years.

44. The Intensive Development scenario represents possible future intensive development of the Mekong water resources (Table 1 and Norplan and EcoLao, 2004). The projected storage capacity for the year 2025 is 55 km$^3$. China and Lao PDR will clearly dominate in the hydropower capacity and storage volume and will account for about 83% of the total Mekong capacity.

45. Chinese dam cascade details for 8 dams are presented in Table 2. Plans exist for a total of 14 dams. The existing Lao PDR storage capacity is dominated by the Nam Ngum 1 reservoir with an active storage capacity of 4.7 km$^3$. At the moment the total Upper Mekong Basin hydropower capacity is 2850 MW and the Lower Basin 1800 MW.

Table 1. Existing and predicted active storage volume (km$^3$) in the Mekong Basin. (Norplan and EcoLao, 2004).

<table>
<thead>
<tr>
<th>Year</th>
<th>China</th>
<th>Lao PDR</th>
<th>Thailand</th>
<th>Cambodia</th>
<th>Vietnam</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>0.62</td>
<td>5.19</td>
<td>5.53</td>
<td>N/A</td>
<td>0.89</td>
<td>12.24</td>
</tr>
<tr>
<td>2010</td>
<td>10.52</td>
<td>12.95</td>
<td>5.53</td>
<td>N/A</td>
<td>0.92</td>
<td>29.92</td>
</tr>
<tr>
<td>2025</td>
<td>23.19</td>
<td>22.61</td>
<td>5.53</td>
<td>N/A</td>
<td>3.59</td>
<td>54.92</td>
</tr>
</tbody>
</table>

Table 2. Characteristics of the Chinese Mekong dam cascade (Norplan and EcoLao, 2004).

<table>
<thead>
<tr>
<th>No.</th>
<th>Project</th>
<th>Year of commissioning</th>
<th>Installed capacity (MW)</th>
<th>Active storage (km$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Manwan</td>
<td>1993-96</td>
<td>1500</td>
<td>0.26</td>
</tr>
<tr>
<td>2</td>
<td>Dachaoshan</td>
<td>2001-2004</td>
<td>1350</td>
<td>0.37</td>
</tr>
<tr>
<td>3</td>
<td>Xiaowan</td>
<td>2010-14</td>
<td>4200</td>
<td>9.9</td>
</tr>
<tr>
<td>4</td>
<td>Gonguoqiao</td>
<td>2012</td>
<td>750</td>
<td>0.12</td>
</tr>
<tr>
<td>5</td>
<td>Jinghong</td>
<td>2013</td>
<td>1500</td>
<td>0.25</td>
</tr>
<tr>
<td>6</td>
<td>Nuozhadu</td>
<td>2014</td>
<td>5500</td>
<td>12.3</td>
</tr>
<tr>
<td>7</td>
<td>Mengsong</td>
<td>Before 2025</td>
<td>600</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Ganlanba</td>
<td>Before 2025</td>
<td>150</td>
<td>-</td>
</tr>
</tbody>
</table>

46. The Mainstream Dams (MS) scenario is based on the Indicative Basin Plan of the Mekong Committee in 1970. It is not very probable that the MS scenario will be realized because of the environmental and socioeconomic impacts and political complications. However, these plans are still discussed and have even been presented recently in the Thai media. Because of this it is relevant to study the possible impact of these dams.

II.5.2 Tonle Sap watershed scenarios

47. The net storage capacities for hydropower and irrigation development have been obtained from the Lower Mekong Water Resources Inventory (WATCO, 1984). The planned total net storage is 5.5 km$^3$ in the upper reaches of the Tonle Sap tributaries. The division of the storage between the sub-basins is presented in Table 3 and location of the storages and accompanying irrigation areas in Figure 18.
Table 3. The division of the Tonle Sap hydropower and irrigation storage between the sub-basins (source: Tonle Sap Built Structures database)

<table>
<thead>
<tr>
<th>Sub-basin</th>
<th>Net storage capacity million m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sen</td>
<td>2900</td>
</tr>
<tr>
<td>Staung</td>
<td>550</td>
</tr>
<tr>
<td>Chikreng</td>
<td>160</td>
</tr>
<tr>
<td>Mongkol Borey</td>
<td>115</td>
</tr>
<tr>
<td>Sreng</td>
<td>610</td>
</tr>
<tr>
<td>Chinit</td>
<td>390</td>
</tr>
<tr>
<td>Pursat</td>
<td>860</td>
</tr>
<tr>
<td>Total</td>
<td>5585</td>
</tr>
</tbody>
</table>

Figure 18. Tonle Sap Hydropower and Irrigation: Baseline + 5.5 km³ of net storage for hydropower and irrigation in the upper reaches of the Tonle Sap tributaries. Presented in Lower Mekong Water Resources Inventory (WATCO, 1984).

48. Although at the moment there are no major hydropower or irrigation dams in the Tonle Sap, developments are going to be realized in the near future. The China Daily reported on February 17th 2007 that Chinese companies have signed several agreements with Cambodian government officials to build a hydropower plant in Battambang province. The plant will cost USD 190 million. Its power generation capacity will be 53 MW. The plant will be quite small compared to the Chinese dams described in Table 2, but could have a significant impact locally.
III BASIN-WIDE TONLE SAP SCALE RESULTS

III.1 TONLE SAP HYDROLOGICAL CHARACTERISTICS

49. The area of the lake varies between the dry and wet season from around 2,500 km² up to about 15,000 km², while the water level of the lake increases from less than 1.4 m to 6.8-10.3 m above the mean sea level (amsl) in Ha Tien datum, depending on the year. The bottom of the lake is approximately 0.5 - 0.7 m amsl. During the wet season, the volume of the lake increases from about 1.3 km³ during the dry season up to 75 km³, depending on the flood intensity. The summary of the available data is presented in Table 4 and Figure 19. Here the year represents the flood cycle which begins in May of the year in question.

Table 4. Summary of the hydrological data in Tonle Sap Lake during the years 1997-2003.

<table>
<thead>
<tr>
<th></th>
<th>Water level [m]</th>
<th>Lake area [km²]</th>
<th>Lake volume [km³]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>max</td>
<td>min</td>
<td>max</td>
</tr>
<tr>
<td>max</td>
<td>10.36</td>
<td>1.48</td>
<td>15278</td>
</tr>
<tr>
<td>min</td>
<td>6.86</td>
<td>1.19</td>
<td>9637</td>
</tr>
<tr>
<td>average</td>
<td>9.11</td>
<td>1.34</td>
<td>13218</td>
</tr>
</tbody>
</table>

Figure 19. Annual variation of water level in the Tonle Sap Lake. Years 1997, 1998, and 2000 represent average flood, dry year, and high flood, respectively. Water levels are above the mean sea level in Ha Tien, Vietnam. Bottom of the lake lies about 0.7 m above the mean sea level.
50. The Tonle Sap Lake and its sub-catchments with the main tributaries are presented in Figure 20. Also, the locations of the Prek Kdam measurement station, where the discharge into and out of the lake to/from the Mekong is measured, and Kampong Luong, where the lake’s water level is measured, are presented.

![Figure 20. Tonle Sap Basin and its sub-catchments with the main rivers.](image)

51. The following data have been used for the water balance calculations (numbers located in Figure 21):

1. Water level of the lake at Kampong Luong ($WL_{KL}$) and water level of the Tonle Sap River at Prek Kdam ($WL_{PK}$) and Phnom Penh Port ($WL_{PP}$)
2. Inflow into and out of the lake through the Tonle Sap River at Prek Kdam - $Q_{TSR}$
3. Overland flow from the Mekong to the Tonle Sap through floodplains – $Q_{OVR}$
4. Inflow from the 12 main tributaries - $Q_{TRIB}$
5. Rainfall data around the lake from two stations - $Q_{PREC}$
6. Evaporation from two stations – $Q_{EVAP}$
52. Figure 21 illustrates the location of different components of the water balance study.

![Figure 21. Illustration of the water balance calculation elements' locations.](image)

53. Due to the flooding, the discharge can be measured only from the part upstream from the floodplain. In Table 5 the total area and observed area for each tributary is presented. The total area of the catchment, without the dry season lake area, is 83,011 km$^2$ from which 54.4% or 48,684 km$^2$ was observed by the measurements. The total area of the Tonle Sap Basin including the dry season lake, as presented in Figure 20, is 85,786 km$^2$. This is around 10.8% of the total area of Mekong Basin (Mekong River Commission, 2003).
Table 5. Total catchment and observed area. Observe that Sisophun and Mongkol Borey are separated here whereas in Figure 20 they are combined.

<table>
<thead>
<tr>
<th>Data available</th>
<th>Area km²</th>
<th>Observed area km²</th>
<th>%</th>
<th>Not observed km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinit</td>
<td>8236</td>
<td>4130</td>
<td>50.1%</td>
<td>4106</td>
</tr>
<tr>
<td>Sen</td>
<td>16359</td>
<td>14000</td>
<td>85.6%</td>
<td>2359</td>
</tr>
<tr>
<td>Staung</td>
<td>4357</td>
<td>1895</td>
<td>43.5%</td>
<td>2462</td>
</tr>
<tr>
<td>Chikreng</td>
<td>2714</td>
<td>1920</td>
<td>70.7%</td>
<td>794</td>
</tr>
<tr>
<td>Siem Reap</td>
<td>3619</td>
<td>670</td>
<td>18.5%</td>
<td>2949</td>
</tr>
<tr>
<td>Sreng</td>
<td>9986</td>
<td>8175</td>
<td>81.9%</td>
<td>1811</td>
</tr>
<tr>
<td>Sisophun</td>
<td>4310</td>
<td>4310</td>
<td>100.0%</td>
<td>0</td>
</tr>
<tr>
<td>MKBorey</td>
<td>10565</td>
<td>4170</td>
<td>39.5%</td>
<td>6395</td>
</tr>
<tr>
<td>Sangker/Battambang</td>
<td>6052</td>
<td>3230</td>
<td>53.4%</td>
<td>2822</td>
</tr>
<tr>
<td>Dauntri</td>
<td>3695</td>
<td>835</td>
<td>22.6%</td>
<td>2860</td>
</tr>
<tr>
<td>Pursat</td>
<td>5965</td>
<td>4480</td>
<td>75.1%</td>
<td>1485</td>
</tr>
<tr>
<td>Baribor</td>
<td>7153</td>
<td>869</td>
<td>12.1%</td>
<td>6284</td>
</tr>
<tr>
<td>Catchment</td>
<td>83011</td>
<td>48684</td>
<td>54.4%</td>
<td>34327</td>
</tr>
<tr>
<td>Dry season lake</td>
<td>2774</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catch.+lake</td>
<td>85785</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

54. The monsoon climate has two main seasons in Southeast Asia:
- Wet season from May to October
- Dry season from November to April.

55. Around 87% of the precipitation occurs during the 6 month rainy season as can be seen from Table 6 and Figure 22. The annual average precipitation in Siem Reap was 1494 mm during the years 1997-2004 while in Prek Kdam it was 1079 mm. The average, used in this study for rainfall, was 1287 mm (Table 6).

Table 6. Monthly average precipitation at Siem Reap (SR) and Prek Kdam stations.

<table>
<thead>
<tr>
<th></th>
<th>SR</th>
<th>Prek Kdam</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.7</td>
<td>15.8</td>
<td>8.2</td>
</tr>
<tr>
<td>Feb</td>
<td>4.6</td>
<td>1.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Mar</td>
<td>20.8</td>
<td>17.2</td>
<td>19.0</td>
</tr>
<tr>
<td>Apr</td>
<td>62.9</td>
<td>40.2</td>
<td>51.6</td>
</tr>
<tr>
<td>May</td>
<td>164.7</td>
<td>112.8</td>
<td>138.7</td>
</tr>
<tr>
<td>Jun</td>
<td>245.7</td>
<td>140.1</td>
<td>192.9</td>
</tr>
<tr>
<td>Jul</td>
<td>234.2</td>
<td>139.1</td>
<td>186.7</td>
</tr>
<tr>
<td>Aug</td>
<td>205.9</td>
<td>134.2</td>
<td>170.1</td>
</tr>
<tr>
<td>Sep</td>
<td>272.1</td>
<td>183.4</td>
<td>227.7</td>
</tr>
<tr>
<td>Oct</td>
<td>210.4</td>
<td>192.6</td>
<td>201.5</td>
</tr>
<tr>
<td>Nov</td>
<td>65.4</td>
<td>85.2</td>
<td>75.3</td>
</tr>
<tr>
<td>Dec</td>
<td>7.0</td>
<td>17.8</td>
<td>12.4</td>
</tr>
<tr>
<td>Annual prec</td>
<td>1494.4</td>
<td>1079.4</td>
<td>1286.9</td>
</tr>
</tbody>
</table>
Overland flow from the Mekong through the floodplains is an important element in the Tonle Sap hydrology (Figure 24). However, based on the modelling done by the MRCS WUP-JICA study (CTI Engineering, 2004), the overland flow was reduced significantly after the national road construction. This happened due to the damming effect of the road and other embankments on the floodplain which link the Mekong River mainstream and Tonle Sap Lake floodplains.

Basing the calculations on rating curves or monitoring the overflow continuously is almost impossible. Thus, to be able to include the overland flow in the water balance study the accurate hydrodynamic model should be applied. However, this is not available yet and the overland flow was calculated based on the difference between the calculated flow volume of the tributaries and Tonle Sap River and the measured volume.
58. The average overland flow into the lake was 4.4 km³ during 1997 – 2003, while the average overland flow from the lake was only 0.7 km³.

59. The Tonle Sap water balance is summarized in Table 7. The total inflow to the Tonle Sap varies from 44.1 km³ (1998) to 106.5 km³ (2000), the average being 79.0 km³. Of the inflow, around 87% ends up to Mekong through the Tonle Sap River, 1% through overland flow while 12% evaporates directly from the lake.

Table 7. Summary of the inflow and outflow in km³. Mekong part includes both, flow in Tonle Sap River and overland flow.

<table>
<thead>
<tr>
<th>Year</th>
<th>Tribs_in km³</th>
<th>Mekong_in km³</th>
<th>Prec_in km³</th>
<th>TOTAL_in km³</th>
<th>Evap_out km³</th>
<th>Mekong_out km³</th>
<th>Balance km³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>23.1</td>
<td>47.3</td>
<td>8.5</td>
<td>78.9</td>
<td>64.2</td>
<td>8.7</td>
<td>72.9</td>
</tr>
<tr>
<td>1998</td>
<td>12.6</td>
<td>24.8</td>
<td>6.7</td>
<td>44.1</td>
<td>36.8</td>
<td>6.7</td>
<td>43.5</td>
</tr>
<tr>
<td>1999</td>
<td>27.4</td>
<td>41.0</td>
<td>11.3</td>
<td>79.8</td>
<td>72.9</td>
<td>10.5</td>
<td>83.3</td>
</tr>
<tr>
<td>2000</td>
<td>39.7</td>
<td>51.8</td>
<td>15.0</td>
<td>106.5</td>
<td>93.3</td>
<td>11.5</td>
<td>104.8</td>
</tr>
<tr>
<td>2001</td>
<td>27.1</td>
<td>52.9</td>
<td>12.4</td>
<td>92.5</td>
<td>83.0</td>
<td>10.5</td>
<td>93.5</td>
</tr>
<tr>
<td>2002</td>
<td>21.7</td>
<td>56.8</td>
<td>11.3</td>
<td>89.8</td>
<td>84.3</td>
<td>10.0</td>
<td>94.3</td>
</tr>
<tr>
<td>2003</td>
<td>15.2</td>
<td>58.5</td>
<td>7.9</td>
<td>71.6</td>
<td>50.4</td>
<td>7.5</td>
<td>57.9</td>
</tr>
<tr>
<td>avg</td>
<td>23.8</td>
<td>44.7</td>
<td>10.4</td>
<td>79.0</td>
<td>69.3</td>
<td>9.3</td>
<td>78.6</td>
</tr>
<tr>
<td>% of total</td>
<td>29.7%</td>
<td>57.0%</td>
<td>13.3%</td>
<td>87.8%</td>
<td>12.2%</td>
<td>3.8% values</td>
<td></td>
</tr>
</tbody>
</table>

60. In Figure 24 the annual water balances have been presented. The inflows are precipitation, tributary flows and flow from the Mekong. The outflows are evaporation and flow to the Mekong.

Figure 24. Annual water balances for Tonle Sap Lake (1997-2003). Positive values are flows into the lake and negative ones out of the lake.
In Figure 25 and Table 8 the monthly average water balances have been presented. The Tonle Sap fills up in May – September and dries out in October – April.

Table 8. Summary of the inflow and outflow in km³. Mekong part includes both, flow in Tonle Sap River and overland flow.

<table>
<thead>
<tr>
<th></th>
<th>Inflow</th>
<th>Mekong</th>
<th>Precipitation</th>
<th>Outflow</th>
<th>Mekong2</th>
<th>Evaporation</th>
</tr>
</thead>
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<tr>
<td>Jan</td>
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<td>0.0</td>
<td>0.1</td>
<td>-0.9</td>
<td>-0.8</td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>-0.4</td>
<td>-0.6</td>
<td></td>
</tr>
<tr>
<td>Mar</td>
<td>0.3</td>
<td>0.0</td>
<td>0.1</td>
<td>-0.2</td>
<td>-0.5</td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>0.4</td>
<td>0.0</td>
<td>0.1</td>
<td>-1.2</td>
<td>-0.4</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>0.8</td>
<td>0.9</td>
<td>0.3</td>
<td>-0.7</td>
<td>-0.3</td>
<td></td>
</tr>
<tr>
<td>Jun</td>
<td>1.3</td>
<td>5.6</td>
<td>0.7</td>
<td>-0.2</td>
<td>-0.4</td>
<td></td>
</tr>
<tr>
<td>Jul</td>
<td>2.2</td>
<td>11.2</td>
<td>1.1</td>
<td>-0.1</td>
<td>-0.7</td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>3.6</td>
<td>15.5</td>
<td>1.5</td>
<td>-0.3</td>
<td>-0.9</td>
<td></td>
</tr>
<tr>
<td>Sep</td>
<td>4.7</td>
<td>10.2</td>
<td>2.6</td>
<td>-1.5</td>
<td>-1.1</td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>6.0</td>
<td>1.3</td>
<td>2.7</td>
<td>-17.3</td>
<td>-1.2</td>
<td></td>
</tr>
<tr>
<td>Nov</td>
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<td>0.0</td>
<td>0.8</td>
<td>-18.9</td>
<td>-1.3</td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>0.7</td>
<td>0.0</td>
<td>0.1</td>
<td>-14.7</td>
<td>-1.2</td>
<td></td>
</tr>
</tbody>
</table>

Figure 25. Monthly Tonle Sap water balances.
III.2 MEKONG SCALE BUILT STRUCTURE IMPACTS

III.2.1 Human impact compared with natural variability

62. The conditions in the Tonle Sap are very variable. The total inflow to Tonle Sap varies from 44.1 km$^3$ (1998) to 106.5 km$^3$ (2000), average being 79.0 km$^3$. The maximum lake volume varies between 30 and over 70 km$^3$ (see Figure 27). The maximum area varies between 10,000 and 15,000 km$^2$ and maximum lake height between 7 to 10 m.

![Tonle Sap lake flood volume](image)

Figure 26. Yearly variation of the Tonle Sap Lake volume

63. The magnitude of the natural variability can be compared with the human impact on the Tonle Sap flow. The change of inflow for the Intensive Development Scenarios is about 4.5 km$^3$ and for the Mainstream Dams about 11 km$^3$. These are about 10% and 25% of the dry year (1998) total inflows respectively. In a wet year (2000) the percentages fall to 4% and 10% of the total inflow.

64. The computed impact of the development scenarios is shown in Figure 27 (for a definition of the scenarios see Chapter II.5). The figure presents the current water level (solid line) compared with the Tonle Sap hydropower and irrigation dam (grey line), Basin-wide Intensive (tightly dotted line) and Mainstream Dams Development scenarios. The scenarios change the dry season water level, flood timing and maximum flood height. The changes are most pronounced in the dry year (1998), and because of this in consequent chapters the results are mostly presented from the year 1998.
Upstream developments cause changes in the Mekong water levels and consequently in the Tonle Sap River flow. The estimated flow changes in the Intensive Development scenarios are based on the basin-wide MRCS model results. The flow changes have been added to the measured in- and outflows. For the Mainstream Dam scenario it is assumed that the flow into the lake changes proportional to the mainstream flow change. The outflows are adjusted to get 20 cm and 40 cm dry season lake water level rises respectively in the Intensive and Mainstream cases. As is discussed below, the actual dry season water level rise is uncertain. Here the lower end of the water level rise is used.

III.2.2 Upstream development impacts

In general, development of upstream water resources can have a major impact on the Tonle Sap fisheries. This follows from the fact that the Tonle Sap is strongly influenced by the Mekong. Around 57% of the Tonle Sap water originates from the Mekong either through the Tonle Sap River (52%) or overland flow (5%) while tributaries share is around 30% and precipitation 13%. Not only the Mekong strongly impacts the Tonle Sap, but some of the Tonle Sap fish migrate upstream the Mekong. Obviously, Mekong conditions have a direct impact on these types of fish.

As seen in Figure 27, the impact of the upstream dams is most pronounced during dry years. This results from the fact that during dry years the storage capacity of the dams is greatest relative to the flow. The impacts are aggravated by the fact that the fisheries are most stressed during dry years and consequently more vulnerable to adverse flow changes.

Figure 27. Natural water level variation between years (solid black line) compared with the scenario water levels (gray and dotted lines).
68. Figure 28 presents the calculated water levels in 1998 for the Baseline, Intensive Development and Mainstream Dams scenarios. Increasing upstream water storage for hydropower and agriculture lowers the maximal flood height and depth and consequently the flooded area. Although a straightforward relationship between Tonle Sap fisheries productivity and inundated area has been cast into question with recent years’ catch data, it is clear that a decreasing flood means less primary production and fish habitat. The decrease of the maximum flood height for the Basin-wide Intensive Development scenario is about 0.5 m and corresponding flooded area about 10% during the dry year (1998). The loss of inundation happens in the very high areas that are flooded in any case for a short period of time. In addition, they are estimated to be nutrient poor and oxygen depleted habitats. A more serious problem is the decreased flood depth and volume over the lower reaches of the floodplain.

69. As seen from Figure 29, increasing upstream water storage delays and shortens the flooding, which impacts fish migration, habitats and fish growth. The delay and shortening depends on the floodplain elevation zone (compare Figure 29a), year (wet/ dry/ average), intensity of the upstream developments and reservoir operation. The largest impacts are encountered during the dry years when the storage capacity is relatively large compared to the natural flows.

![Water Level in 1998](image)

Figure 28. Lake water levels in the Baseline (uppermost line), Intensive Development (middle) and Mainstream Dams (lowest) scenarios.

70. The modelled impact of the Intensive Development scenario on the flood arrival time is presented in Figure 30a. The delay in inundation is typically one week compared to the current situation. In the Extreme Mainstream Dams Development scenario the delay can even be one month in a dry year. The flood duration is related to the flood arrival time. The shortening of the inundation is typically 1 – 2 weeks in the upper areas of the Tonle Sap floodplain (Figure 29b).
Because the start of the flood season happens quite regularly every year within a window of a few days, the delay in the flooding can adversely affect fish breeding. Shortening of the inundation affects the habitats on the floodplain and decreases the time fish can feed and grow on the floodplain.

Figure 29a. The impact of Intensive Development scenario on flooding. The figure shows the arrival time difference between the Baseline and Intensive Development scenarios. In other words the values show how many days the flood is delayed because of the upstream developments.

Figure 29b. Impact of Intensive Development scenario on flooding. The figure shows shortening and lengthening of the flood in days because of the upstream developments. The simulation year (1998) is a dry year. The lengthening of the inundation near the lake edge is caused by raising water levels during the dry season.
72. During the dry season upstream hydropower dams release water, keeping the Mekong and Tonle Sap River and Lake water levels higher than normal. The estimates for the water level change vary between 0.15 and 0.9 m depending on the study. The studies have been based either on use of rating curves or mathematical models. In the scenario runs it is assumed that the Intensive Development scenario will raise the dry season water levels 20 cm and the Mainstream Dams 40 cm.

73. The permanent water level change impacts the flooded forest near the Lake edge (Figure 30a). The flooded forest in a very narrow fringe on the lake edge acts as a buffer protecting the floodplain against rough conditions in the lake. It is also an important habitat for fish where it can search for shelter for breeding and feeding while benefiting from the oxygen and nutrient rich lake conditions. The dry season lake edge moves to the floodplain permanently inundating the lake edge forest (Figure 31b) and destroys the forest that requires periodical dry conditions. The increase of the dry season lake area is 300 – 900 km², or 15 – 45% of the dry season lake area.

Figure 30a. Flooded forest based on JICA (1999) land use map for the Tonle Sap Lake.
74. Although the lake productivity is not well understood, it may be assumed that the sediments may play a key role in providing nutrients to the Tonle Sap system and thus sustaining its high productivity. About 70% of the sediment influx to the Tonle Sap originates from the Mekong (Figure 31). Thus, the changes in the amount and composition of sediment caused for instance by upstream dam development or land use changes can have a major impact on the sediment inflow and Tonle Sap productivity.

75. As an example of the upstream development impact on sedimentation, the impact of the Chinese dam cascade was studied. More than 50% of Mekong downstream suspended sediment originates from China. The planned Chinese dam cascade potentially traps nearly all of this sediment resulting in reduced sediment input and Tonle Sap productivity. Figure 32 represents the corresponding reduction in sedimentation in the Tonle Sap floodplain obtained from modeling results. The most impacted areas shown in dark are also high fisheries productivity areas. The hydrological year strongly affects the sediment input and
also the impact of the dams. In the figure the average hydrological year (1997) is presented. During 1998 the impact is less pronounced because the sediment input from the Mekong is smaller.

![Annual TSS flux into and out from Tonle Sap Lake](image)

**Figure 31.** Annual TSS flux into and out from the Tonle Sap Lake (1997-2003). Results based on flow and TSS measurements.

![Dam trapping impact on sedimentation in 1998](image)

**Figure 32.** Modelled decrease of sedimentation due to the dam’s trapping of sediments. The most impacted areas shown in blue are also high fisheries productivity areas. The average hydrological year (1997) is shown. During 1998 the impact is less pronounced because smaller Mekong sediment input.
Figure 33. Modelled sedimentation per square meter in different hydrological years: light grey dry year (1998) and dark grey wet year (2000). On the left hand side western part of the Tonle Sap and right hand side eastern. Results are presented for different land use classes (agriculture, grassland, shrubland, forest and water). The area of the agricultural land is marginal.

76. The impact of the hydrological year on sedimentation is shown in Figure 35. The dry year (1998) is shown in light grey and the wet year (2000) in dark grey. The figure presents the average simulated sedimentation per unit area, and changes in inundated area should be taken into account in estimating the total sedimented material. The impact of the hydrological year can be seen especially on the western part of the lake (left box in the figure). During a high flood year the flood is able to carry significantly more sediment to the western part than during a dry year.

77. The sediment processes in the Mekong Basin are not very well known. The origin of the very fine sediments (average grain size 13 µm) that are most important for the Tonle Sap, has not been specifically studied. Also, the actual dam trapping capacity of the finer sediments has not been estimated. Because of this uncertainty the results presented above must be considered with caution.

78. Oxygen conditions are important for the fish. Fish species have developed strategies to cope with low oxygen conditions, but in general good oxygen conditions favor fish breeding and growth. The upstream developments can negatively impact oxygen conditions in critical breeding areas. The impact is caused by the flood delay especially in dry years and consequent delay of arrival of oxygen rich waters to the floodplain (Figure 36). This delay can have a negative impact on the sensitive juveniles on the floodplain. As the figure shows, the simulated oxygen values diminish by about 0.5 – 2 mg/l during August – September in the highly productive Lake Chhma area. When the oxygen values are low to start with, the reduction can be critical for the fish.
Figure 34. Modelled surface dissolved oxygen concentration difference between Baseline and Intensive Development scenario for 1998. The area is located about 5 km from the lake edge near Lake Chhma. The flat period when the time series is 0 corresponds to time when the area is dry land.

The changing flow regime changes water flow in the lake and the floodplain. This in turn impacts fish larvae and juvenile drift. The key process in the larvae drift is the entrance of the migratory fish larvae from the Mekong and drift to the breeding areas. Figure 35 shows the simulated fate of the Mekong larvae and juveniles in the Tonle Sap Lake. Practically all larvae end up on the northern and eastern shores. The intensive development scenario changes the drift more to the western basin. The change of the drift needs to quantified and its importance assessed by fisheries experts.
Figure 35. Simulated fish larvae drift from the Tonle Sap River during July – August 1997. Crosses indicate first point where larvae touches the flooded forest. Dots show drifting larvae. Observe lack of drift to the southern/western shore and concentration of the larvae on the eastern and Lake Chhma areas. Increased drift to the western basin in the intensive development scenario, which may result in decreased productivity in the Fishing Lot No 2.

80. Above the impacts of the development scenarios on specific Tonle Sap hydrological, sediment, water quality and fish larvae processes are discussed. Even taken individually, some of the impacts such as destruction of the riparian forest near the lake edge and decrease of sediment input to the lake could potentially have a significant impact on fisheries. When taken together impacts strengthen each other and even the smaller impacts may be important when taken together.

III.3 TONLE SAP SCALE IMPACTS

81. The Tonle Sap development was studied based on the Lower Mekong Water Resources Inventory, WATCO 1984 (see chapter “Tonle Sap watershed scenarios”). The inventory is based on a feasibility study for hydropower and irrigation development. At the moment the watershed water resources remain largely undeveloped. The actual implementation of the plans cannot be predicted, although some hydropower dams are under consideration.

82. For the whole Tonle Sap, the combined hydropower and irrigation storage potential represents relatively a small portion of the total inflow to the Tonle Sap. The total Tonle Sap storage capacity in the WATCO Inventory is 5.5 km$^3$ (see Table 3). This can be compared to the annual total inflow to the Tonle Sap, which varies between 44 and 107 km$^3$, the average being 79 km$^3$.

83. Figure 36 presents calculated current (solid line) and Tonle Sap Dams (grey line) scenario water levels. The levels are compared with the Intensive Development scenario (dotted line). During the rising flood the Basin-wide and Tonle Sap scenarios behave quite similarly. In the Tonle Sap scenario the flood delay starts earlier, but this depends on the actual operation of the dams. Because the Basin-wide Development and Tonle Sap Dams
scenarios are close together, the results presented in the previous chapter are mostly relevant for the Tonle Sap Dams scenario.

![Scenario water levels](image)

**Figure 36.** Impact of the potential Tonle Sap dam developments on the Lake water levels. Solid line the Base-line, dotted one Intensive Upstream Development scenario and the grey one Tonle Sap developments defined in Table 3.

84. The Tonle Sap dam storage behaves in similar way to the upstream dams reducing flood flow and increasing dry season flow. The total magnitude of the impact during the rising flood is similar compared to the Basin-wide Intensive Development scenario. Because of this, *the Tonle Sap hydropower and irrigation storage structures can significantly strengthen the upstream development impacts*. The total cumulative impact of the Tonle Sap Dams and Basin-wide Developments scenarios would be about the same as in the Mainstream Dams scenario during the rising flood.

85. The main difference between the upstream Mekong and local Tonle Sap development is that the local developments have less impact on the total inflow. Eventually stored water is released from the local storages minus the amount evaporated from the reservoirs and possible irrigation schemes.
IV LOCAL SCALE RESULTS

IV.1 INFLUENCE OF ROADS

86. Figure 37 presents a figure showing the calculated flow field during rising flood in Pursat province near the Pursat River. The left figure is without road and the right one with a 10 km road from the upper floodplain to the lake edge. The flow velocities are in general very small in the floodplain compared to the lake and flows can easily bypass the road on the lakeside. A road in this type of place does not impact the flooding, although it can block flow from one part of the floodplain to another.

87. A road placed on the upper left hand corner of the area shown in Figure 39 would block the flow from the river to the floodplain as long as there was not be a bridge. The flow can be important in bringing oxygen and nutrient rich water to the floodplain as well as spawn from upstream. The importance of taking into account the hydrodynamic conditions of the floodplain is highlighted in Figure 40 showing the fish-rich Lake Chhma area. The complex channel network should not be blocked in order not to cause degradation of conditions by decreased flow, oxygen, nutrient, and spawn inputs.

Figure 37. Impact of a road construction on floodplain flow in the Pursat province near the Pursat River. Left without a road and right with about 10 km long road. Lake flow is indicated by large arrows. Flow from the Pursat River to the floodplain indicated on the north-western corner of the figure. Observe very low floodplain flow velocities and small impact on either the floodplain or lake flow.
IV.2 INFLUENCE OF IRRIGATION SCHEMES ON HYDROLOGY, SEDIMENTS, WATER QUALITY AND FISH

IV.2.1 Field study based Stung Chinit impact assessment

88. As a representative reservoir, the Stung Chinit irrigation scheme was studied both by modelling and field sampling. The map of the area, set-up of the field study and the measurement points are presented in the chapter "Methods and Tools". The main results indicating reservoir impacts are studied below.

89. Inflow to the Stung Chinit irrigation reservoir and outflow from the reservoir were approximately the same on the measurement days (Figure 39.). Main structure impacts on the flow (inflow versus outflow) are not present. Small differences can be observed, and can be attributed to rainfall pulses, lake water level oscillations caused e.g. by wind, backwater effects and operation of the irrigation system.

90. Figure 39 illustrates the abrupt change in hydrological conditions during the flood and dry seasons. In November the flow is about a fifth of that in October. In January the flow is less than 10% of the peak flood flow. The balance between the in- and outflows did not change during the observation period.
Figure 39. Measured Stung Chinit reservoir impact on flow in September – January 2007. The blue bars show measured inflow (discharge) and red and yellow ones outflow measured in different downstream locations (compare to Figure 2).

91. The Stung Chinit irrigation system positively affects the downstream oxygen conditions. Oxygen concentration in the river increases after flowing over the spillway and through the sluice gate of the dam (Figure 42, outflow oxygen concentrations). The concentration of outflowing water is approximately 20% higher than the concentration of the river water entering the reservoir. This is because of the spillway and sluice gate aerate the through-flowing water effectively.

92. In the reservoir oxygen concentration decreases to some extent because of decay of organic material. Slow flow velocities in the reservoir and the biomass production of the reservoir increase the amount of sedimented organic matter on the bottom. Decay of this material as well as of the inundated terrestrial organic material consumes oxygen. Oxygen concentration decreases in deeper water layers if flow and waves are not able to mix stratified water layers (Figure 42, reservoir profiles). Decreased oxygen concentrations occur especially in the sheltered deep water areas where flow velocities are low, but open areas can also stratify during calm periods. Decreased oxygen concentrations on the bottom layer may have negative impact on some oxygen sensitive fish species and it also increases nutrient concentrations due to anoxic processes. Low oxygen concentrations in the reservoir occur in any case locally. The overall impact of the reservoir is to increase the oxygen concentrations of the outflowing river water. In addition, the surface oxygen concentrations remain good in the reservoir.

93. The oxygen values can be compared with different flow conditions in November and January. In January the flow is less than half of the November flow. The outflowing water is well oxygenated in the whole water column. In January the dissolved oxygen concentration is about 1 mg/l higher because the water temperature is lower and oxygen concentration higher. Surprisingly, the reservoir oxygen conditions are not appreciably affected by the through-flow and the reservoir is rather well oxygenated even near the bottom both in November and January.
94. The overall tendency of the reservoir is to slightly increase total suspended sediment concentrations (Figure 43.). Values of inflowing water vary between 15 - 37 mg l⁻¹ and values of outflowing water between 11 - 45 mg l⁻¹. Visibility, measured as Secchi depth, has a correspondingly decreasing trend in the influence area of the structure. The visibility decreases more or less steadily from upstream to downstream (Figure 44.). The increased value of total suspended sediment concentration and decreased visibility downstream of the structure can be caused by phytoplankton production in the reservoir and resuspension. Erosion of the riverbank downstream of the dam may also explain the changes in the values.

Figure 40. Oxygen profiles in the sampling locations 2.11.2006 and 28.1.2007.

Figure 41. Total suspended sediment concentration one meter under the water surface (on the left) and one meter above the bottom (on the right).

Figure 42. Secchi depths at the sampling locations (on the left) and total suspended sediment mass balance in the river (on the right).
95. A significant reservoir impact on the river nutrient dynamics cannot be observed. Total nitrogen and phosphorus concentrations of inflowing, reservoir and outflowing water vary without a very clear trend (Figure 45.). There is anyway a weak average trend in concentration and nutrient mass balance (Figure 46.) results. During the flood season nutrients are released from the reservoir, during the flood peak trapped in the reservoir, and with smaller discharges the balance is approximately stable.

Figure 43. Total nitrogen and phosphorus concentrations one meter under the water surface (on the left) and one meter above the bottom (on the right) at the sampling locations.

Figure 44. Total nitrogen (on the left) and total phosphorus (on the right) mass balance in the river.

96. Comparing suspended sediment, total nitrogen and total phosphorus concentrations at different times with radically different flows shows that they do not depend on flow in a straightforward way. However, it is important to note that the fluxes are much smaller in the dry season (November and January) than in the flood season because of the much smaller flows (Figure 44).
In general, the water quality characteristics of the river water are not significantly impacted by the reservoir. Proportions of phosphorus and nitrogen fractions stay stable or vary inconsistently in the influence area. Also, other measured parameters do not indicate any significant changes in the river water quality. Minimum, maximum and average values of other water quality parameters are listed in Table 9.

Table 9. Chemical oxygen demand, pH, alkalinity and conductivity values.

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<th>pH</th>
<th>ALK+ mgCa</th>
<th>Cond. mS m(^{-1})</th>
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The irrigation canal network maintains water balance in the rice fields and at the same time offers, together with the reservoir, a new habitat for fish. When irrigation is active the discharges of the canals are relatively high. Nutrients and total suspended sediments are released from rice fields and canals during that period. Concentrations of total nitrogen, phosphorus and suspended sediments increase in the irrigation and drainage canals compared to the values in the reservoir (Figure 45). High peaks in the nutrient concentration values indicate the impact of fertilizers. Water flowing back into the river via drainage canals has a loading effect downstream of the river. However, the loading effect of the system is small due to the small through-flow.

Connectivity of the canal network depends on the operational status of the irrigation system. When irrigation is active the canal flows are relatively high and the canals are connected with each other. When irrigation is passive the canal flows decrease and many of the canals dry up. During the measurement period irrigation was active until 20.12. At that time the secondary irrigation canal was dry and discharges of tertiary and secondary drainage canals were so small that canals were not connected. All the canals were dry by 28.1. During the passive irrigation phase the connectivity of the canals breaks reducing fish movement and the suitability of the habitat for fish.
Figure 45. Total nitrogen (above on the left), total phosphorus (above on the right) and total suspended sediment concentrations in the irrigation canals.

100. Oxygen conditions are good in the irrigation canals and chemical oxygen demand is equivalent to the values of the reservoir (Table 10). Significant changes can be seen in the drainage water pH, alkalinity and conductivity. The values are smaller compared to the values in the reservoir.

Table 10. Oxygen, chemical oxygen demand, pH, alkalinity and conductivity values in the reservoir and irrigation canals.
IV.2.2 Model based Stung Chinit impact assessment

101. The reservoir has a relatively small hydrological impact. This follows from the small volume of the reservoir compared to the through-flow. Filling up of the reservoir is presented in Figure 46. The figure shows the simulated reservoir water level starting from an empty reservoir. The reservoir fills up in less than a week even in June when flow volumes are not at their peak. When the reservoir is full it has an insignificant impact on flows. This is confirmed by field measurements presented in Figure 41.

![Filling up the reservoir](image)

Figure 46. Simulated reservoir fill-up in June 2000 shown by the water level. The simulation starts with an empty reservoir and ends up being full in less than a week.

102. Conditions in the reservoir favor fish growth. Figure 47 presents simulated reservoir oxygen conditions on the surface (line in the middle) and near the bottom (lowest line). The reservoir values are compared to a natural stream (the highest line). Even in the bottom of the reservoir oxygen remains relatively high because of the high through-flow. This finding is supported by field measurements presented in the previous chapter, which gives similar results.
The simulated reservoir impact on sediment concentration is shown in Figure 48. Based on upstream measurements, the suspended sediment concentration in a free flowing stream is around 25 mg/l. The simulated outflow concentration is slightly below 20 mg/l. In the simulation resuspension from the bottom has not been taken into account. Measurements do not show any clear trapping impact. If there is trapping the downstream productivity could be influenced slightly. On the other hand the reservoir productivity would be enhanced by the trapped sediments.

Figure 48. Simulated reservoir outflow suspended sediment concentration. The green line shows concentration in a natural river and black one in the reservoir outflow. Observe dam trapping effect of the reservoir.
104. The sediments provide a source of nutrients for productivity. Figure 49 shows the simulated sedimentation pattern in the reservoir after 1.5 months. Sedimentation varies between 50 and 100 g/m², which corresponds to about 0.05 mm sediment thickness.

![Figure 49. Simulated 1.5 month sedimentation. Sedimentation is about 50 to 100 g/m² corresponding to about 0.05 mm in sediment thickness.](image)

105. Although the reservoir favors fish growth, it has substantial impacts on fish migration and the breeding of local species. Also, the reservoir may have some negative impact on downstream productivity. Because of this, the total impact of reservoirs should be assessed by qualified fisheries experts.

106. The generalization of the results to other reservoirs should be done cautiously. The characteristics of the reservoir including storage capacity, area, water depth, through-flow, residency time, soil properties, vegetation, inflowing water quality etc. govern the impacts and are difficult to be generalized. Each planned reservoir should be studied properly.
IV.3 FLOODPLAIN IRRIGATION RESERVOIRS

107. Intensive irrigation structure development is ongoing on the Tonle Sap floodplain. Figure 50 shows the recent developments in Kampong Thom province. The total area of the structures in the figure is about 30 km².

108. The cumulative storage capacity of the floodplain irrigation structures is quite limited because the trapped water depth is only 1.5 m. Even assuming further development of 400 1 km² reservoirs would amount to only 0.6 km³ storage volume. This can be compared to the total flood volume between 40 and 107 km³. However, in the upper reaches of the floodplain the reservoirs trap a significant part of the flood.

Figure 50. Private irrigation structures in Kampong Thom province. Blue indicates irrigation dams and green the accompanying irrigated rice paddies.
109. A private irrigation structure in Stung Staung District was selected for impact study. Details of the area are presented in the “Methods and Tools” chapter. Results presented below are based on field measurements of the reservoir.

110. Water level reached maximum level on the flood plain next to the reservoir on 24.10 and started to decrease. The gates of the reservoir were closed on 6.11 when the water level was 1.7 meter high and the risk of collapse of the embankment was small. Water level outside and inside the reservoir is presented in Figure 51. The trapping effect of the reservoir is shown by the grey line representing the water level in the reservoir. Initially, the water level goes down as reservoir water evaporates and possibly seeps through the embankment and ground. The water level starts to go down significantly in the middle of December when the flood waters have receded outside the reservoir and the reservoir water starts to be used for irrigation.

Figure 51. Water level on the floodplain and in the reservoir. Figure illustrates the water trapping function of the reservoir during the receding flood

111. Oxygen concentrations inside and outside of the reservoir were good except near bottom in some locations both inside and outside of the reservoir (Figure 52). Decaying organic material consumes oxygen resources on the bottom and oxygen concentration decreases if flow and wind driven waves are not able to mix the entire water mass. The area of the reservoir on the floodplain is very open, so even a light wind can mix effectively the shallow water. The maximum reservoir water depth is only two meters and the open fetch is several kilometers.
According to the point measurements, the total impact of the structures on floodplain water quality is minor. Total suspended sediment (TSS), total nitrogen and total phosphorus concentration values vary at the same level inside and outside of the reservoir (figure 52.). Similar to the total nutrient concentrations, there is not any significant change in the nutrient fractions.

The oxygen values are higher in the reservoir in January than in October. This follows from the fact that temperatures are lower in January and consequently the oxygen saturation values higher. The total suspended sediment and total phosphorus values show a decrease in November and January. This shows the trapping effect of the floodplains in general. When comparing the November and January TSS values the reservoir does not seem to trap sediments, but the conclusion is based on only two measurements. On the other hand total phosphorus concentrations seem to diminish, which would point to net utilization of the phosphorus in the water column by vegetation. Again the conclusion is inconclusive.

Values of pH, alkalinity and conductivity of the reservoir water do not differ from the values of flood water outside of the reservoir (Table 11.). Significant change can be seen only in the values of chemical oxygen demand. Values are higher in the reservoir compared to the values outside of the reservoir. Higher values in the reservoir can be caused by organic matter that is trapped and sedimented in the reservoir. The biomass production period is also longer in the reservoir than on the floodplain, which is increasing the amount of sedimented organic matter on the bottom of the reservoir.
Table 11. Chemical oxygen demand, pH, alkalinity and conductivity values in the private irrigation reservoir (points 2, 3 and 4) and outside of the reservoir (points 1 and 5).

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<tr>
<th></th>
<th>CODM mg l⁻¹</th>
<th>pH</th>
<th>ALK+ mgCa</th>
<th>Cond. mS m⁻¹</th>
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<td>max</td>
<td>3,0</td>
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115. The floodplain irrigation structures have only a relatively limited impact on the flood and water quality. Even the cumulative impact is relatively low. However, the destruction of habitat and blocking of fish movement may be important for fisheries.
IV.4 INFLUENCE OF LARGE SCALE FISHING GEARS

116. The set-up for the field and laboratory work for finding out fishing gear impacts is presented in the “Tools and Methods” chapter.

117. During the study the flow fields of the Prek Toal area were measured at four locations in entire water profile from the bottom to the surface on 5.8.2006 and 23.8.2006. Velocities of the flow were mostly below 10 cm s⁻¹ and directions varied between 62 and 250 degrees (Table 12).

Table 12. Range of flow velocity and direction in the Tonle Sap Lake at Prek Toal area, 5.8 and 23.8.

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<tr>
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<th>cm s⁻¹</th>
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<td></td>
<td>max</td>
<td>18.5</td>
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118. Cross section measurements on the lake do not indicate significant hydrological changes caused by the bamboo fences. Measurements were carried out at the end of January 2007 when bamboo fences were installed on the lake and the depth of the lake was about three meters. The direction of the fence was 300 degrees and it was located in the north-west corner of the lake off Prek Toal (48 P 0359713, 1459834). Average flow velocities of 200 m long cross sections were low on both sides of the fence, from three to four cm s⁻¹ (Figure 53). Direction of the flow varied between 320 and 355 degrees on both sides of the fence. According to these results bamboo fence does not decrease the velocity and change the direction of the flow with such slow flow velocities. The lowest possible velocity recorded by the survey boat (>1 m s⁻¹) was considerably high compared to the flow velocities of the lake (<0.1 m s⁻¹). Therefore, accuracy of the measured data was not very high and these results should be taken with caution.
Figure 53. Average velocity and direction of the flow on both sides of the bamboo fence on the lake in Prek Toal area.

119. Laboratory experiments in the fixed bed flume show that the slight opposing influence of the bamboo fences on flow velocities can be observed when the velocity in the flume rises higher than 10 cm s\(^{-1}\) (Figure 54). Water level clearly rises upstream of the fence with higher velocities. The opposing influence of the nylon net is minor, the slight influence appearing when flow velocity is higher than 20 cm s\(^{-1}\), but even with the maximum velocity of the flume the influence is still slight.
Figure 54. Influence of fishing gears on water level (upper picture) and flow velocity in the fixed bed flume.

120. As a summary typical low floodplain flow velocity causes only small impact on water levels and flooding. The water level changes caused by the fishing gears are in general small, and the low flow velocities encountered in the floodplain cause only slight resistance to the flow. The flood will not be delayed by the gears. The water quality impacts are similarly small because water can flow relatively easily through the structures. The impact of fishing gears on hydrology and water quality is small. However, other impacts to fish such as obstruction of fish movement can be serious.
V CONCLUSIONS AND RECOMMENDATIONS

121. The report describes built structure impacts on Tonle Sap hydrology and water quality. The impacts have been studied by analysis of existing data, new field measurements and mathematical modelling. Currently the Tonle Sap fisheries productivity and its dependence on hydrology and water quality is not understood very well, and consequently quantitative fisheries impact analysis is not possible. However, the study demonstrates the relative importance of different types of structures to the fisheries and presents conclusions related to the main risks and benefits of the developments.

122. The built structures development scenarios that have been studied represent intensive Mekong tributaries, Mekong mainstream and Tonle Sap tributaries/floodplains developments. Also, small-scale Tonle Sap structure impacts including different types of irrigation reservoirs, roads and fishing gears have been studied in detail. The actual development of the Mekong region cannot be exactly predicted, and the scenarios are only indicative.

123. The Tonle Sap system’s hydrological characteristics show great natural variability. The lake area is about six times larger during the peak flood season compared to the dry season. The water depth increases about seven and volume about sixty times compared to the dry season. There is also large variability between different years. The flow volumes into the lake can be over two times higher in a wet hydrological year compared to a dry year. The maximum flooded area varies by about 50% between dry and wet years.

124. During wet years, even massive developments have relatively small impacts on the Tonle Sap compared to the natural variability. The study estimates that intensive upstream hydropower and irrigation development will decrease the Tonle Sap inflow by only 4 – 10% during wet years.

125. Upstream developments have the largest impact during dry years. Then storage volumes are relatively larger than during the wet years compared to flow volumes. The Tonle Sap inflow can decrease 10 – 25% during a dry year. A 10% inflow decrease corresponds to about a 0.5 maximal flood height decrease and a 10% decrease in the flooded area. A decrease in the area flooded means less breeding habitat for fish, and a decrease in flood height means less volume for fish food production.

126. The upstream dam developments delay flood arrival from one week to one month. The flood duration is correspondingly shortened. The delay can be critical for breeding fish which may have adapted to the quite regular onset of the flood season. It is also clear that shortened inundation shortens the time fish can feed on the floodplain.

127. The dry season impacts are aggravated by the fact that the fisheries are already stressed during dry years. Whether the additional stress caused by built structures can significantly affect the fisheries cannot be reliably assessed based on the available fisheries data. However, it is clear that realisation of all hydropower and irrigation potential in the Mekong Basin represents a serious threat to fisheries especially during dry years.

128. The water stored in the reservoirs is released during the dry season. Although water release can have a beneficial impact on river water quality and river channel fish habitats, it can also negatively impact floodplain habitats. The river water levels are increased during the dry season and consequently the Tonle Sap water level will stay higher during the dry
season. Because the floodplain vegetation has been adapted to alternation of dry and wet (terrestrial and aquatic) periods, it cannot survive permanent inundation. The flooded forest near the lake edge will be destroyed. The flooded forest is an important fish habitat and it also acts as a protective barrier against strong lake currents and waves. The estimates for the dry season water level rise vary. The estimated increase of the permanently inundated area is 300 – 900 km², or 15 – 45% of the dry season lake area.

129. The local Tonle Sap dam development has similar impacts to the upstream Mekong developments. Realisation of the full hydropower and irrigation potential in the Tonle Sap catchment would result in impacts of the same order of magnitude as intensive Mekong upstream tributaries’ development. When both local and upstream developments are realised they cause significant impacts together.

130. As described above the dam build-up decreases flows especially in the beginning of the flood season. Decreased flows cause reduced water exchange in the floodplain and can worsen the oxygen conditions. The oxygen conditions are naturally critical in the floodplain because of the large amounts of decaying organic material and because of the sheltering effect of vegetation decreasing aeration and water mixing. The young juveniles feeding in the floodplain are especially sensitive to oxygen conditions and could suffer critically from the oxygen decrease.

131. Although sediment impacts on productivity are not well understood in the Mekong region, there are indications that sediments play a central role in providing nutrients to both aquatic and flooded terrestrial ecosystems. In the worst case scenario the planned Chinese dam cascade will trap nearly all sediments originating from the upper Mekong reaches. This could cause about a 50% sediment concentration decrease in the Lower Mekong Basin. Because most of the sediment in the Tonle Sap originates from the Mekong, this would cause a correspondingly significant sediment input decrease to the Tonle Sap. The exact assessment of the dam impact would require a Mekong scale in-depth sediment study that has currently not been done. Also, the sediment relation to the fisheries productivity needs to be understood better, but potentially the sediment trapping can have serious impact on fisheries productivity.

132. Modelling results show that changing flow regimes alter larvae and juvenile drift especially from the Tonle Sap River. The significance of this drift change cannot at the moment be assessed but needs more in-depth study.

133. Compared to the large-scale upstream and Tonle Sap developments, local small-scale floodplain and near floodplain dams have a rather small impact on hydrology and water quality. The floodplain irrigation reservoirs that are increasingly being built have, even in large numbers, a small storage capacity. Also, their impact on water quality is small. The same applies to the relatively small-scale upstream irrigation schemes such as Stung Chinit. The reservoir provides good conditions for fish breeding. However, structures can significantly disturb fish habitats and block fish migration and movement. Also, the cumulative impact of a large number of small-scale structures may be significant, although it is not well understood.

134. Especially when assessing the impact of any planned reservoir, generalizations drawn from one case should be avoided. The characteristics of the reservoir including storage capacity, area, water depth, through-flow, residency time, soil properties, vegetation, inflowing water quality, etc. govern the impacts and are difficult to be generalized.
135. The floodplain roads in general do not have a significant impact on floodplain hydrology or water quality. However, if built on important flow routes they may decrease oxygen and sediment rich water flows as well as larvae and juvenile drift to important fish breeding grounds. The floodplain’s hydrological and hydrodynamic characteristics should be understood before road construction begins, and mitigation structures such as bridges should be built in appropriate places.

136. Fishing gears including bamboo fences and nylon nets have a small impact on hydrology and water quality. However, they can seriously block fish movement and have a significant impact on fisheries.

137. As discussed above, the major uncertainty in the fisheries impact analysis stems from the poor understanding of fisheries dependence on hydrological, hydrodynamic, water quality and habitat conditions. It is necessary first to understand primary productivity and its dependence on these factors. Both terrestrial and aquatic productivity are important for providing food for fisheries and the (quantitative) pathways from primary productivity to fisheries need to be clarified. When the productivity and fisheries are understood, the potential risks to them can be identified and the quantitative impacts of different development scenarios can be estimated.

138. As well as biological uncertainties, physical and chemical ones need to be decreased. The major uncertainties are related to the fate of the sediments, nutrient dynamics, Tonle Sap flow changes, and the magnitude of dry season water level changes. Existing data needs to be utilized more intensively, new field measurements conducted and modelling tools developed and further verified.

139. Especially because the fisheries are understood poorly, upstream and local developments should be planned carefully and cautiously. The operation of reservoirs should take into account downstream conditions and impacts. For instance, the reservoirs could be filled more cautiously in the beginning of the flood season to minimize impacts on early flooding.

140. Although the natural variability of the Tonle Sap system is high and the fish have adapted to it, upstream developments may change conditions in the lake especially during critical periods in a way that the fish can not cope with. The above discussion highlights dry years in this respect.

141. The impacts of the built structures have been discussed mostly individually. The cumulative impact of the individual changes is rather difficult to assess. For instance, changes in flood timing and changes in the floodplain’s early flood oxygen conditions both have negative impacts on fisheries, but together they may have an overall impact more important than the sum of individual impacts. However the cumulative impact of many small structures has not been understood very well. This applies especially to the Mekong upstream, but also locally.
VI REFERENCES


Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Fisheries Component

RELATIONSHIPS BETWEEN BIOECOLOGY AND HYDROLOGY AMONG TONLE SAP FISH SPECIES

Prepared by

Eric BARAN1, SO Nam2, LENG Sy Vann2, Robert ARTHUR1, Yumiko KURA1

1 WorldFish Center
2 Inland Fisheries Research and Development Institute

January 2007
EXECUTIVE SUMMARY

Creation of a database of all Tonle Sap fish species

- This report details how several sources of information and databases have been merged together to create a database of all Tonle Sap species and of all bioecological information documented about these species.

- The Tonle Sap species database results from the integration of four main sources of information: i) from scientific publications, summarized in FishBase; ii) from publications and fishers' knowledge as compiled in the MRC Mekong Fish Database; iii) from biological studies undertaken at IFReDI; and iv) from traditional knowledge gathered during the course of the Built Structures project.

- The information available in the Tonle Sap species database covers five fields: i) species identification (Species name in Latin, family; author; name in Khmer; name in Khmer (roman); name in English; ii) biology (max. total length; max. standard length; length at maturity; food; iii) response to hydrological changes (discharge as migration trigger; water level as migration trigger); iv) reproduction (spawning location, date of spawning; reproductive guild; fecundity; nursing location; possible breeding in reservoirs); and v) ecology (Tonle Sap distribution; field notes; migration type; feeding place; status; habitat; resilience; ecological guild.

- Two hundred and ninety-six species are recorded in the Tonle Sap. This is more than double than recorded so far in scientific publications. In terms of fish biodiversity, this makes the Tonle Sap the third richest lake in the world, after lakes Malawi and Tanganyika, and much before Lake Victoria.

- The 296 Tonle Sap species belong to 44 families, the dominant ones being Cyprinids (108 species), Silurids (20 species), Bagrids and Cobitids (17 species) and Pangasids (14 species).

- Thus the Tonle Sap sub-basin, that covers 10.7% of the Mekong Basin, comprises 32% of the Mekong fish species and 48% of the Mekong fish families. This qualifies the Tonle Sap system as an exceptional biodiversity hotspot by global standards, and calls for special attention from national and international institutions.

Response of Tonle Sap species to hydrological changes

- This analysis has been undertaken to better appraise the possible consequences of flow modifications due to built structures on the migration of species targeted by the fishery.

- Among the Tonle Sap species, three species are known to have their migration triggered by a discharge variation and twenty-three species have their migration triggered by a water level variation. In that field there is a large information gap about the other species, i.e. 91% of the Tonle Sap fish community.
• However among the species whose migration is triggered by a variation of water level, three taxa (Cyclocheilichthys spp., Paralaubuca typus and Pangasius spp.) contribute 13% to overall catches in Cambodia. This means that each year at least 38,000 and 56,000 tons of fish depend on species whose migration is triggered by hydrological cues altered by built structures. If Henicorhinchus spp. (Trey riel) is included, then the figure goes up to 38% of the catch, i.e. between 110 and 164,000 tons.

Ecological guilds

• It is usually considered that floodplain fishes belong to two ecological groups of fishes (“guilds”): either black fish, that spend the dry season in floodplain ponds, or white fish, that undertake long distance migrations at the end of the rainy season. Our results show that it is necessary to consider a third group of fish, named “grey fish”, whose behavior is neither black nor white. These grey fish spend for instance the dry season in the Tonle Sap tributaries or in the main lake.

• According to current knowledge, 8% of Tonle Sap species belong the “Grey fish” guild. Detailed analyses show that differences between guilds are mainly behavioural, and that there is no significant difference between these guilds in terms of average length of fish. There is also no significant difference between the average trophic level of guilds.

• Last, a resilience analysis focussing on the ability of species to adjust to heavy exploitation has highlighted the species whose resilience is low, and that should be subject to specific monitoring.
I INTRODUCTION

This aim of this study is to clarify the relationship between the bioecology of Tonle Sap fish species and hydrology.

Information is available from:
- scientific publications, summarized in FishBase maintained by the WorldFish Center (Froese and Pauly 2000, and www.fishbase.org).
- published and expert information, summarized in the Mekong Fish Database produced by the Mekong River Commission (MFD 2003);
- expert information available with IFReDI and its biologists;
- traditional knowledge gathered during the course of the Built Structures project.

This approach has already been used in Baran et al. (2005) and Baran (in press).

We aim to combine these different sources of information to create a repository of the best available information on Tonle Sap fish species, with a focus on black, grey and white fish species. This repository will then be analysed to provide information relevant to the BayFish model of the Tonle Sap fish resource.

II MATERIAL AND METHODS

II.1 INFORMATION EXTRACTED FROM FISHBASE

The web-based version of FishBase (www.fishbase.org) is used for up-to-date information. In 2005 a specific module has been created by the FishBase team to generate a matrix of all species of a given system, and a number of life-history parameters for these species. A fraction of the quantitative information available in this matrix is summarised in Table I.

Table I: Life history variables detailed for in the species ecology matrix

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbreviation; (unit)</th>
<th>Meaning</th>
<th>Measured or calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum length</td>
<td>Lmax; (cm)</td>
<td>Maximum length ever reported for the species in question</td>
<td>Measured</td>
</tr>
<tr>
<td>Life span</td>
<td>tmax; (year)</td>
<td>Approximate maximum age that fish of a given population would reach</td>
<td>Calculated (estimated from Linf., K and to.)</td>
</tr>
<tr>
<td>Age at first maturity</td>
<td>tm; (year)</td>
<td>Average age at which fish of a given population mature for the first time</td>
<td>Calculated (estimated from Linf., K and to.)</td>
</tr>
<tr>
<td>Length at maturity</td>
<td>Lm; (cm)</td>
<td>Average length at which fish of a given population mature for the first time</td>
<td>Calculated (estimated from Linf.)</td>
</tr>
<tr>
<td>Length for max. yield</td>
<td>Lopt; (cm)</td>
<td>Length class with the highest biomass in an unfished population</td>
<td>Calculated (estimated from Linf.)</td>
</tr>
<tr>
<td>Trophic level</td>
<td></td>
<td>Rank of a species in a food web, calculated from food items, weighted by the contribution of the various food items to the diet.</td>
<td>Calculated</td>
</tr>
</tbody>
</table>

The option used in this study is thus the “Information by ecosystem” (Tonle Sap ecosystem), with the sub-option “Species ecology matrix” (Figure 1).
II.2 INFORMATION EXTRACTED FROM THE MEKONG FISH DATABASE

This information in MFD is of different nature than that of Fish Base, as it includes much more ecological information gathered through field surveys and questionnaires on traditional ecological knowledge. This database includes in particular the knowledge gathered by Chan Sokheng *et al.* (1999), Poulsen (2000, 2003), Poulsen and Valbo-Jorgensen (2000), AMFC (2001), Valbo-Jorgensen and Poulsen (2001) Bao *et al.* (2001), Poulsen *et al.* (2002).

The species found specifically in the Tonle Sap Basin are identified in MFD in an “Occurrence” table, than can be related to the detailed “Location” table and to a “Species Data” table. The tables
of the database have been combined to summarize in one table all the information scattered in different tables. For each species of the life history matrix, information on migration was automatically extracted, in MS Access mode, from the Mekong Fish Database. For species listed in FishBase but not present in the MDF, all possible synonyms were searched from a synonyms correspondence table, and the relevant information was then extracted from the synonym species.

II.3 INFORMATION FROM IFREDI

Over the years, the Cambodian Inland Fisheries Research and Development Institute and its biologists previously involved in MRC fisheries monitoring projects have accumulated a significant body of knowledge. This knowledge is partly reflected in the MRC documents on spawning and migrations in the Mekong Basin, but is also still scattered in several local publications such as So et al. (1999, 2005), So and Haing (2006) or So (2005). The corresponding list of species is given in Annex A.

II.4 INFORMATION FROM THE BUILT STRUCTURE PROJECT

Last the Built Structures project undertook a sampling of traditional ecological knowledge around the Tonle Sap Lake. This project is based on the interviews of 24 experienced senior fishers in 6 sites round the lake. The methodology is based on the recommendations of IIRR (1996) and Cambpbell and Salagrama (1999) supplemented by Ticheler et al. (1998). Experience relative to gathering traditional knowledge of Mekong fishers was integrated thanks to Baird and Overton (2001), Baird (2003) and Dubois (2005). Questionnaires to fishers are detailed in Annex 1. The questions focussed on 30 species identified by their Khmer name, and for these species, on spawning habitat; spawning location; feeding habitat; nursing habitat and ecology type (black white or grey type).

Equivalences between Khmer fish names and Latin fish names were drawn from Baran (2003) and Baran and Chheng (2003). These two documents tackle the issue of several Latin names for one Khmer name, and provide a list of scientific species for each Khmer fish name. Last, the latest valid Latin names of fish followed the list of Baran and Garilao (2003) based on FishBase.

II.5 MERGER OF DATABASES

II.5.1 FishBase matrix

The FishBase matrix of life history parameters was used as a basis. The original variables of this matrix, including information from “Resilience” and “All Species” supplementary matrices, are as follows:

<table>
<thead>
<tr>
<th>Latin name</th>
<th>Author</th>
<th>Family</th>
<th>English name</th>
<th>Max. total length (cm)</th>
<th>Max. standard length (cm)</th>
<th>Life span (years)</th>
<th>Length at maturity (cm)</th>
<th>Length for max. yield (cm)</th>
<th>Length-weight (cm)</th>
<th>Main food</th>
<th>Trophic level</th>
<th>Status</th>
<th>Habitat</th>
<th>Resilience</th>
</tr>
</thead>
</table>

One hundred and ninety three species are listed as Tonle Sap species in FishBase. This matrix is converted into an Excel table for further analysis.
II.5.2 MRC database

The ecological information used mostly originates from the MRC Mekong Fish Database. In fact the file used was created for the analyses of migrations and migration triggers in the Mekong Basin (Baran, in press). This file combines to the FishBase life history matrix of all Mekong species all the ecological information available in MFD. This information is as follows:

Table III: Main variables extracted from the Mekong Fish Database

<table>
<thead>
<tr>
<th>Species</th>
<th>Migrating?</th>
<th>Migration info</th>
<th>Migration type</th>
<th>Spawning info</th>
<th>Breeds in reservoirs?</th>
<th>Note</th>
<th>Mekong distribution</th>
<th>Feeding info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes text</td>
<td>Longitudinal</td>
<td>text</td>
<td>Yes text</td>
<td>text</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>#N/A</td>
<td>Lateral</td>
<td>#N/A</td>
<td>No</td>
<td>#N/A</td>
<td>#N/A</td>
<td>#N/A</td>
<td></td>
</tr>
<tr>
<td>#N/A</td>
<td>Both</td>
<td>#N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the resulting table, for readability, it has been concentrated into one single column “Ecological information” compiling all the others listed above.

II.5.3 IFReDI Tonle Sap species list

The list of species met in the Tonle Sap, provided in Annex 1, mainly bears two variables: Scientific name and Khmer name. Several species were removed from this list, with the following arguments:

Table IV: Species removed from the IFReDI list

<table>
<thead>
<tr>
<th>Latin name</th>
<th>Family</th>
<th>Tonle Sap distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arius caelatus</td>
<td>Ariidae</td>
<td>Probably not (Vietnam only)</td>
</tr>
<tr>
<td>Batrachocephalus mino</td>
<td>Ariidae</td>
<td>Marine and estuarine only (tidal zone)</td>
</tr>
<tr>
<td>Butis gymnopomus</td>
<td>Eleotridae</td>
<td>No information at all in MFD, Indonesian species not in Cambodia according to FishBase</td>
</tr>
<tr>
<td>Clarias canius</td>
<td>Clariidae</td>
<td>Unknown from MFD and from FishBase</td>
</tr>
<tr>
<td>Cynoglossus puncticeps</td>
<td>Cynoglossidae</td>
<td>Common in the freshwater tidal zone of the Mekong Delta, but not yet reported from Cambodia (Ref. 12693).</td>
</tr>
<tr>
<td>Hemipimelodus bicolor</td>
<td>Ariidae</td>
<td>Only in the delta</td>
</tr>
<tr>
<td>Lobocheilos davisi</td>
<td>Cyprinidae</td>
<td>No evidence at all</td>
</tr>
<tr>
<td>Lobocheilos quadrilineatus</td>
<td>Cyprinidae</td>
<td>Unlikely (Laos only)</td>
</tr>
<tr>
<td>Mystus cavasius</td>
<td>Bagridae</td>
<td>5 occurrences only in Cambodia, none is TS related</td>
</tr>
</tbody>
</table>

This information was added to the previous compilation of matrices.

II.5.4 Built Structures questionnaires

The database integrating the information gathered through the questionnaires of the Built Structures project included questions about the following variables:

Table V: Main variables of the Built Structures – Species ecology database

<table>
<thead>
<tr>
<th>Species</th>
<th>Spawning location</th>
<th>Feeding habitat</th>
<th>Nursing habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Khmer</td>
<td>Floodplain lake / rice field</td>
<td>Floodplain</td>
<td>Floodplain</td>
</tr>
<tr>
<td></td>
<td>Major river / river</td>
<td>Never caught</td>
<td>Never caught</td>
</tr>
<tr>
<td>Stream / Inlet</td>
<td>TS permanent lake</td>
<td>Never caught</td>
<td></td>
</tr>
</tbody>
</table>

The questions asked focussed on 38 taxa selected because they are either i) dominant and important fish species for livelihoods; ii) important fish species for aquaculture development; iii) little known from an ecology viewpoint, or iv) potentially vulnerable.
The corresponding list of taxa, identified by their Khmer name, is as follows:
Ampil tum, Andat chhkae, Angkot prak, Bandol ampov, Chhlang, Chunlungh moan, Chunteas phluk, Dong khteng, Ka-ek, Kamphleav, Kanhchos bai, Kanhchras thom, Kantrorng preng, Kaock, Kasan, Kes, Khlang hay, Kromorm, Krum, Phtoung, Reus Chek,

The problem is that in this case, the specific information is recorded on the field under its Khmer name, and there are often several species corresponding to one Khmer name. So two documents were used to establish the equivalence between Khmer names and Latin names. Baran (2003) in particular, based on FishBase 2004, gives for each Latin names the number of occurrences of a given translation; this allows an assessment of the reliability of the translation. We propose below a list of equivalences between Khmer names and Latin names (Annex B).

II.5.5 Merging the databases

FishBase and the MFB have in common Latin species names; the IFReDI compilation of species includes Latin species names and Khmer fish names, and the database of ecological knowledge gathered during the Built Structures project is based on Khmer names. Ultimately these databases are merged (Figure 4).

Figure 4: View of the FishBase options for Tonle Sap specific additional information

In view of quantitative analyses, some variables initially expressed qualitatively (e.g.; migration pattern) have been coded. Codes are as follows (Table VI):
Table VI: Coding used in the Tonle Sap species database

<table>
<thead>
<tr>
<th>MIGRATION</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caught in dry season</td>
<td>1</td>
</tr>
<tr>
<td>Caught in dry then rainy season</td>
<td>2</td>
</tr>
<tr>
<td>No migration pattern</td>
<td>3</td>
</tr>
<tr>
<td>Caught in rainy season</td>
<td>4</td>
</tr>
<tr>
<td>Unknown</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MIGRATION TYPE</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal and lateral migrations</td>
<td>1</td>
</tr>
<tr>
<td>Only longitudinal migrations</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DISCHARGE VARIATION AS MIGRATION TRIGGER</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WATER LEVEL VARIATION AS MIGRATION TRIGGER</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STATUS</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>native</td>
<td>1</td>
</tr>
<tr>
<td>Introduced</td>
<td>2</td>
</tr>
<tr>
<td>Misidentification</td>
<td>3</td>
</tr>
<tr>
<td>Questionable</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RESILIENCE</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td>High</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HABITAT</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benthopelagic</td>
<td>1</td>
</tr>
<tr>
<td>Demersal</td>
<td>2</td>
</tr>
<tr>
<td>Pelagic</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RESERVOIR BREEDING</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>2</td>
</tr>
<tr>
<td>No</td>
<td>3</td>
</tr>
</tbody>
</table>

III RESULTS

III.1 CONTENTS OF THE TONLE SAP FISH SPECIES DATABASE

The information compiled in the database of Tonle Sap species can be classified as follows:

Identification
Species name in Latin, Family; Author; Name in Khmer; Name in Khmer (roman); Name in English:

Biology
Max. total length; Max. standard length; Length at maturity; Food:

Ecology vs. Hydrology
Discharge as migration trigger; Water level as migration trigger

Reproduction
Spawning location (floodplain lakes / rice fields; rivers; streams; / inlets; TS permanent lake); Date of spawning (based on % of respondents); Reproductive guild; Fecundity; Nursing location; Possible breeding in reservoirs

Ecology
Tonle Sap distribution; All MFD ecological information; Migration type; Feeding place; Status; Habitat; Resilience; Guild (black, grey or white fish)

It is the first time that all the information available about Tonle Sap species is concentrated into a single place.
III.2 PRELIMINARY ANALYSES

The table created is very rich as it covers all the species of the Tonle Sap, and all the information known about these species. It allows all kinds of quantitative analyses. We propose below some exploratory analyses about global trends revealed by this table.

III.2.1 Species and families

The results of this comprehensive review show that two hundred and ninety-six species are recorded in the Tonle Sap. These 296 species represent 2.5 times the number of species identified in 1999 by Puy Lim et al. (1999; 120 species) and twice more than twice the 149 species mentioned by Campbell et al. (2006). This is also significantly more than the 95 Tonle Sap species whose ecology has been detailed in Chan et al. (2001)

When compared to the other major lakes worldwide (figures from FishBase 2004), the Tonle Sap appears to be the third richest lake of the world in terms of fish biodiversity (Table VII and Figure 5). This exceptional feature has never been highlighted before.

Table VII: Comparison of Tonle Sap fish biodiversity with that of other lakes worldwide

<table>
<thead>
<tr>
<th>Lake</th>
<th>Number of species</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malawi</td>
<td>433</td>
<td>Southeast Africa. Over 2 million years old</td>
</tr>
<tr>
<td>Tanganyika</td>
<td>309</td>
<td>East central Africa. About 20 million years old.</td>
</tr>
<tr>
<td>Tonle Sap</td>
<td>296</td>
<td>Southeast Asia. About 6000 years old. Combination of freshwater and estuarine fish faunas</td>
</tr>
<tr>
<td>Victoria</td>
<td>222</td>
<td>East central Africa. About 4 million years old. World's second largest freshwater lake</td>
</tr>
<tr>
<td>Chilka</td>
<td>210</td>
<td>India. Largest tropical lake in Asia</td>
</tr>
<tr>
<td>Lake Chad/ Chari River</td>
<td>170</td>
<td>Central Africa</td>
</tr>
<tr>
<td>Turkana</td>
<td>60</td>
<td>East Africa</td>
</tr>
<tr>
<td>Rukwa Basin</td>
<td>54</td>
<td>East Africa</td>
</tr>
<tr>
<td>Taal</td>
<td>53</td>
<td>Philippines</td>
</tr>
<tr>
<td>Kainji</td>
<td>45</td>
<td>Northern Nigeria. It is part of the Niger river</td>
</tr>
<tr>
<td>Liambezi</td>
<td>43</td>
<td>Southwest Africa/ Namibia</td>
</tr>
<tr>
<td>Baikal</td>
<td>42</td>
<td>Siberia and north of Mongolia. Largest, deepest and oldest freshwater lake, about 25-30 million years old.</td>
</tr>
<tr>
<td>Kariba</td>
<td>41</td>
<td>Southern Africa</td>
</tr>
</tbody>
</table>

Figure 5: Place of the Tonle Sap fish biodiversity among other lakes worldwide
Forty-four fish families are present in the Tonle Sap. The family represented by most species is that of Cyprinidae (minnows or carps), with 108 species. It is followed by Siluridae (catfishes, 20 species), Bagridae (catfishes, 17 species), Cobitidae (loaches, 17 species) and Pangasidae (catfishes, 14 species).

These 5 dominant families are supplemented by 39 others including from 1 to 10 species: Akysidae, Ambassidae, Anabantidae, Anguillidae, Ariidae, Balitoridae, Belonidae, Callionymidae, Carcharhinidae, Centropomidae, Channidae, Claridae, Clupeidae, Coiidae, Cynoglossidae, Dasyatidae, Datnioididae, Eleotridae, Engraulidae, Gobiidae, Gyrinocheilidae, Hemiramphidae, Mastacembelidae, Megalopidae, Nandidae, Notopteridae, Ophichthidae, Osphronemidae, Plotosidae, Poeciliidae, Polynemidae, Schilbeidae, Sciaenidae, Sisoridae, Soleidae, Synbranchidae, Syngnathidae, Tetraodontidae, and Toxotidae (Figure 7).

Thus the Tonle Sap basin that covers, with 85,000 km$^2$, 10.7% of the Mekong Basin comprises 296 or 32% of the 924 Mekong species recorded in MFD$^1$. The families present in the Tonle Sap sub-basin represent 48% of the 91 families present in the Mekong Basin. This confirms the exceptional richness of the Tonle Sap by global standards, and its status of biodiversity hotspot that requires special attention from national and international institutions.

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1 (this is a conservative percentage since FishBase only records 768 Mekong species)
III.2.2 Response to hydrology

III.2.2.1 Number of species whose migration is triggered by hydrological changes

The analysis below aims at identifying species whose migrations are triggered by hydrological changes. The objective is to better appraise the possible consequences of flow modifications (mainly due to damming or built structures in general) on the migrations of the species that contribute to the catch of Cambodian fisheries. This issue has been identified by the Technical Advisory Board of the Mekong River Commission as being an important factor likely to play a major role in the sustainability of the Mekong fishery resources (Baran 2007).

The database records two types of response to hydrological changes: migrations triggered by a variation in discharge, and migrations triggered by a variation in water level.

A preliminary analysis shows that:

- three species are known to have their migration triggered by a discharge variation: *Hemisilurus mekongensis* (Kromorm in Khmer), *Pangasius macronema* (Pra chveat) and *Cyprinus carpio* (Karp samanh);


- there is no information about 270 species (Figure 8).

![Figure 8: Response of Tonle Sap species to hydrological changes](image)

Discharge variation is a migration trigger: 1%
Water level variation is a migration trigger: 8%
No information: 91%

As detailed by Baran (2007), some other species can be added to this list: *Pangasius bocourti* (Chhuon, 2000), *Puntopiltes falcifer* and the southern population of *Pangasius sanitwongsei* (Poulsen et al., 2004). “Trey riel” (*Henicorhynchus spp.* and *Cirrhinus spp.*) is apparently receptive to flood recession as well as to lunar stage, but this is an unclear case as: i) the taxonomy of the genus *Henicorhynchus* is confused (in particular with *Cirrhinus*); ii) the number of species in this genus is not fixed; and iii) the identification of most species of the genus is almost impossible in the field.

The main information resulting from the above analysis is that there is a huge knowledge gap and that the response of fish to hydrological changes is not documented for ninety percent of the Tonle

---

2 *Hemisilurus mekongensis* is also recorded among species whose migration is triggered by a water level variation
Sap species. Conversely, Baran (2007) highlights that 90% of Mekong fish species for which migration cues are documented respond to a variation in water level or in discharge. Data analysed basinwide show (not specifically on the Tonle Sap) show that among documented species, catfishes, with 15 species, are by far the group most sensitive to hydrological migration triggers. This group contributes to dominant species in catches.

### III.2.2.2 Biomass of species whose migration is triggered by hydrological changes

In addition to that taxonomic approach, a fishery-centered approach requires an analysis of biomasses at stake. Baran and Chheng reviewed in 2003 the dominant species in Cambodian fisheries. According to their list, three taxa listed above are among whose migration is triggered by a variation of water level. These species are *Cyclocheilichthys spp.* (Sraka kdam in Khmer), *Paralaubuca typus* (Sleuk russey), and *Pangasius spp.* (Trey pra) and they contribute significantly to Cambodian fish catches (by 8.3%, 2.8% and 1.9% respectively). This means that overall, without mentioning “Trey riel” that makes up to 25.2% of the total catch but whose sensitiveness to discharge is unclear, at least 13% of the fish catch in Cambodia, i.e. between 38,000 and 56,000 tons of fish a year, are made of species sensitive to hydrological variations likely to be altered by built structures. If “Trey riel” is added, this amount goes up to 38% of the catch, i.e. between 110,000 and 164,000 tons. Along the same lines, Baran et al. (2005) showed that in Southern Laos, 96% of the total biomass caught is made of species highly sensitive to discharge variations.

These results highlight the potential dramatic effect of built structures that would significantly alter the hydrology and flood dynamics in the lake.

### III.2.3 Ecological guilds

Floodplain fish are usually characterised as “black fish” or “grey fish” (Welcomme 1985), and this also applies to the Mekong system. Van Zalinge et al. define these ecological groups (also called “guilds”) as follows:

**Black fish** species undertake relatively short migrations between the flooded areas in the rainy season and permanent water bodies in or close to the floodplain in the dry season. They are adapted to withstand adverse environmental conditions (e.g. low dissolved oxygen) often prevailing on the floodplains. During the wet season the fish go back to the floodplains for feeding and spawning.

**White fish** species carry out considerably longer migrations. At the beginning of the dry season most species move from the floodplains via the tributaries to the Mekong main stream. Their migrations may extend to several hundred kilometres. In the main stream they use the deeper parts of the river as refuges for the rest of the dry season. At the onset of the rains spawning takes place near these areas before the adult fish move back again for feeding to the floodplains again for feeding. In Cambodia the fish larvae drift downstream with the river current to the floodplains.

In fact floodplain specialists have long acknowledged the need to detail this binary classification in order to better reflect the reality. Thus Régier et al. (1989) proposed a third group, of “grey fish”, made of species that do not clearly belong to white nor to black ecological guilds. This need is confirmed by Welcomme (2001) and So et al. (2006) describe grey fish as “species that leave flooded areas and return to rivers or other main water bodies (i.e. dry-season refuge) at the end of wet season. They perform short distance spawning migration (i.e. river/main water-floodplain) and spawn on floodplain in rainy season. They spend a part of their lives on floodplain and another part in rivers/tributaries/streams or other main water bodies. They also have a certain tolerance regarding water quality (e.g. DO = 4 - 5 mg/l?), meaning that water conditions acceptable for grey
Table VIII: Characteristics of Grey fish

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Grey fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygenation</td>
<td>Gills and adaptations to hypoxia</td>
</tr>
<tr>
<td>Tolerance to hypoxia</td>
<td>Low to medium oxygen rates</td>
</tr>
<tr>
<td>Type of muscular fibres</td>
<td>Red or white</td>
</tr>
<tr>
<td>Migrations</td>
<td>Short range longitudinal migrations, lateral migrations</td>
</tr>
<tr>
<td>Body shape</td>
<td>Body compressed laterally, spiny, usually with strong scales</td>
</tr>
<tr>
<td>Color</td>
<td>Dark, usually ornamented and colored</td>
</tr>
<tr>
<td>Reproduction guild</td>
<td>Nest builders and guarders, lay eggs on the substrate, phytophiles</td>
</tr>
<tr>
<td>Dry season habitat</td>
<td>Tributaries or edges of the main stream</td>
</tr>
<tr>
<td>Wet season habitat</td>
<td>Floodplain</td>
</tr>
</tbody>
</table>

Following these authors, during project field trips and questionnaires fishers were asked to detail the ecology of a list of fish, and these fish were ultimately classified categorized as belonging to the white, black or grey guild. These results are part of the matrix of Tonle Sap species, and a brief analysis shows that out of 296 species, 55 are classified as white fish, 18 are classified as Black fish, and 24 are characterized as Grey fish. The results of questionnaires are contradictory with the literature for 10 species, whose guild remain undetermined, together with 189 other species (Figure 9).

III.2.3.1 Ecological guilds and size of fishes

The database of Tonle Sap species allows detailing the size of fish for each ecological guild. The graph below, that combines total length and ecological guild (Figure 10) shows that there is no significant difference between guilds in terms of average length of fish. However White fishes includes species such as *Pangasionodon gigas* (Reach in Khmer), *Pangasius sanitwongsei* (Pra po pruy), *Catlocarpio siamensis* (Kolreang) or *Wallago attu* (Sanday) that can become giants reaching 366 cm.

The latter grey fish species are:
III.2.3.2 Ecological guilds and trophic level

The trophic level of a species is its position in the food chain, determined by the number of energy-transfer steps to that level, in other words by the nature of its diet: phytoplankton represents trophic level 1, zooplankton that eats phytoplankton represents trophic level 2, the trophic level of fish that eat zooplankton is 3, that of carnivores eating zooplanktivore fishes is 4, and top predators eating carnivores reach level 5. In practice, since fish diet almost always combines several sources of food from different levels, the trophic level of a given species can be a decimal (Pauly and Christensen 1999).

FishBase gives the trophic level of fishes whose diet has been studied. An analysis also integrating ecological guilds shows that there is no significant difference between the average trophic level of guilds (Figure 11), although white fish have a slightly lower trophic level corresponding probably to the greater abundance of planktivores in that dominant family.

III.2.3.3 Ecological guilds and species resilience

Resilience is the capacity of a system to tolerate impacts without irreversible change in its outputs or structure. In species or populations, this term is often understood as the capacity to withstand exploitation. FishBase calculates the resilience of each species based on several parameters including growth coefficient $K$, age at first maturity $t_m$ and maximum age $t_{max}$ (Musick 1999, Froese and Pauly 1999). When applied to the three guilds of Tonle Sap species, the analysis shows (Figure 12) that the guild with the highest proportion of resilient species is that of black fish; and that the group of white fish is the only one including species considered of “very low” resilience. The least resilient species (i.e. the most likely to be subject to drastic reduction in catches or collapsing) are *Cyclocheilichthys enoplos* (Chhkaok in Khmer), *Labeo chrysophekadion* (Ka-ek), *L. dyocheilus* (Pava mouk mouy) and *Probarbus jullieni* (Tra sork krohom). It is to be noted that Baird (2006) has already described the extinction threats that this species, classified as “endangered” on the IUCN red list, is subject to. Among black fish, it seems that *Channa micropeltes* (Chhdau) is the species least likely to resist intensive exploitation. These species should be given priority in...
biological studies so that their level of exposure is better assessed, and specific protection measures can be considered if necessary.

Figure 12: Resilience levels per ecological guild, and detail of species of low resilience

IV CONCLUSIONS

The exploitation of the database of Tonle Sap fish species has just been superficially initiated in that report. A number of additional analyses will follow; they should allow creating a typology of Tonle Sap species and general rules about the response of these various species groups to environmental modifications. Chief among them are the hydrological modifications (changes in water volume and discharge) as well as change in hydrodynamics (flood timing, flood duration, etc) both driven by built structures.

The major conclusion from the preliminary analyses of this report are that three Tonle Sap fish taxa have their migration triggered by changes in water level. This means that the development of built structures, such as dams, that would significantly modify the dynamics of water and the timing of the flood might disrupt the migrations of these taxa. This timing issue can have an impact on the total production, depending on whether migration, spawning, the hydrological regime and the time allowed for growth are matched optimally or not (notion of environmental window for recruitment, Cury and Roy 1989).

Since these three taxa alone contribute between 38,000 and 56,000 tons to fishery yield each year, the issue is significant. Beyond financial value, a comprehensive risk analysis should encompass the livelihood value of these fish, and their role in the diet and food security of rural populations.

Last, it should be noted that not only three taxa are at stake. The extent of our knowledge gap is such (the sensitiveness to hydrodynamics in unknown for 90% of Tonle Sap species) that it is likely that several other species significant to fisheries are sensitive to hydrological modifications induced by infrastructures and likely to collapse in case of excessive perturbations.

4 In Khone Falls for instance Cyclocheilichthys enoplos is caught between 1,500 and 20,000 m$^3$.s$^{-1}$, with a sharp peak around 3,000 m$^3$.s$^{-1}$, and Paralaubuca typus displays a sharp and intense peak around 2,000 m$^3$.s$^{-1}$
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ANNEX A: IFREDI LIST OF TONLE SAP FISH SPECIES

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</tr>
<tr>
<td>Khchoeung</td>
<td>Mastacembelus armatus</td>
<td>តើស្រមុំទឹក</td>
</tr>
<tr>
<td>Khchoeung</td>
<td><em>Mastacembelus favus</em></td>
<td>តើស្រមុំស្រគម</td>
</tr>
<tr>
<td>Khchoeung pkhar</td>
<td>Mastacembelus erythrotaenia</td>
<td>តើស្រមុំស្រក្តីព្យាយា</td>
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<tr>
<td>Khla</td>
<td><em>Datnioides pulcher</em></td>
<td>តើស្រមុំព្យាយា</td>
</tr>
<tr>
<td>Khla</td>
<td>Datnioides undecimradiatus</td>
<td>តើស្រមុំព្យាយា</td>
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<tr>
<td>Khlang hay</td>
<td><em>Belodonthichthys dinema</em></td>
<td>ប្រគ stdClassigator</td>
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<tr>
<td>Khman</td>
<td><em>Glossogobius aureus</em></td>
<td>ប្រគ stdClassigator</td>
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<tr>
<td>Khman</td>
<td>Hampala dispar</td>
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<tr>
<td>Khman</td>
<td>Hampala macrolepidota</td>
<td>ប្រគ stdClassigator</td>
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<tr>
<td>Khnorng veng</td>
<td>Labiobarbus lineatus</td>
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<td>Khya</td>
<td>Hemibagrus wyckioides</td>
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<td>Kranh</td>
<td>Anabas testudineus</td>
<td>ប្រគ stdClassigator</td>
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<td>Kray</td>
<td>Chitala blanci</td>
<td>ប្រគ stdClassigator</td>
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<td>Kray</td>
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<td>Kreum</td>
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<td>Osteochilus hasseltii</td>
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<td>Osteochilus lini</td>
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<td>Osteochilus waandersii</td>
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<td>Kros phnom</td>
<td><em>Poropuntius deauration</em></td>
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<td>Krum</td>
<td>Osteochilus melanopleurus</td>
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<tr>
<td>Kuch chreov</td>
<td>Puntioplites bulu</td>
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<tr>
<td>Kul chek</td>
<td>Epalzeorhynchos frenatum</td>
<td>អាស្រ័យ</td>
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<td>Kulreang</td>
<td>Catlocarpio siamensis</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Linh</td>
<td>Thynnichthys thynnoides</td>
<td>អាស្រ័យ</td>
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<tr>
<td>Lolouk sor</td>
<td>Osteochilus schlegeli</td>
<td>អាស្រ័យ</td>
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<td>Pase ee</td>
<td>Mekongina erythropsila</td>
<td>អាស្រ័យ</td>
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<tr>
<td>Pava mouk mouy</td>
<td>Labeo dyocheilus</td>
<td>អាស្រ័យ</td>
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<tr>
<td>Phkar ko</td>
<td>Cirrhinus jullieni</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Phkar ko</td>
<td>Cirrhinus molitorella</td>
<td>អាស្រ័យ</td>
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<td>Phtoung</td>
<td>Hyporhamphus limbatus</td>
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</tr>
<tr>
<td>Phtoung</td>
<td>Xenentodon cancila</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Pra chveat</td>
<td>Pangasius macronema</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Pra chveat</td>
<td>Pangasius polyuranodon</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Pra kae</td>
<td>Pangasius conchophilus</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Pra kandorl</td>
<td>Helicophagus waandersii</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Pra khchao</td>
<td>Pangasius bocourti</td>
<td>អាស្រ័យ</td>
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<tr>
<td>Pra po</td>
<td>Pangasius larnaudii</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Pra po pruy</td>
<td>Pangasius sanitwongsei</td>
<td>អាស្រ័យ</td>
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<tr>
<td>Pra thom</td>
<td>Pangasianodon hypophthalmus</td>
<td>អាស្រ័យ</td>
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<tr>
<td>Prama</td>
<td>Boesemania microlepis</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Proloung / Chroloeung</td>
<td>Leptobarbus hoevenii</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Pruol / Krolang</td>
<td>Cirrhinus microlepis</td>
<td>អាស្រ័យ</td>
</tr>
<tr>
<td>Reach</td>
<td>Pangasianodon gigas</td>
<td>ភីស្ត</td>
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<tr>
<td>Riel anhkam</td>
<td><em>Henicorhynchus cryptoptogon</em></td>
<td>ភីស្ត</td>
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<tr>
<td>Riel thmor</td>
<td>Cirrhinus cirrhosus</td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Riel top</td>
<td><em>Henicorhynchus siamensis</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Ros / Phtuk</td>
<td>Channa striata</td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sanday</td>
<td>Wallago attu</td>
<td>ភីស្ត</td>
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<tr>
<td>Slat</td>
<td>Notopterus notopterus</td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sleuk russey</td>
<td><em>Paralaubuca harmandi</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sleuk russey</td>
<td><em>Paralaubuca riveroi</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sleuk russey</td>
<td><em>Paralaubuca typus</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sraka kdam</td>
<td><em>Cyclocheilichthys apogon</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sraka kdam</td>
<td><em>Cyclocheilichthys amatus</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sraka kdam</td>
<td><em>Cyclocheilichthys lagleri</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Sraka kdam</td>
<td><em>Cyclocheilichthys repasson</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Stuok</td>
<td>Wallago leerii</td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Ta aon</td>
<td>Ompok bimaculatus</td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Ta aon</td>
<td><em>Ompok hypophthalmus</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Tanel</td>
<td><em>Hemibagrus filamentus</em></td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Tra sork krohom</td>
<td>Probarbus jullieni</td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Tra sork sor</td>
<td>Probarbus labeamajor</td>
<td>ភីស្ត</td>
</tr>
<tr>
<td>Trocheak domrei</td>
<td>Osphronemus exodon</td>
<td>ភីស្ត</td>
</tr>
</tbody>
</table>
ANNEX B: QUESTIONNAIRES ON TRADITIONAL ECOLOGICAL KNOWLEDGE

Fisheries Ecology Survey Form

COMPLETE 1 FORM FOR EACH INTERVIEW

Section A. - DETAILS OF THE INTERVIEW

<table>
<thead>
<tr>
<th>Respondents</th>
<th>Gender/Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td></td>
</tr>
<tr>
<td>Structure type</td>
<td></td>
</tr>
<tr>
<td>Village name</td>
<td></td>
</tr>
<tr>
<td>Commune</td>
<td></td>
</tr>
<tr>
<td>District</td>
<td></td>
</tr>
<tr>
<td>Province</td>
<td></td>
</tr>
<tr>
<td>Who identified them?</td>
<td></td>
</tr>
</tbody>
</table>

Section B. - MAPPING THE CURRENT SITUATION

Guidelines:

We get the respondents to draw a map of the area as it is now (use large piece of paper). Important aspects to include are:
1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Highlight which ones are new or have changed. Location name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that are in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.

Now go to section C.
Section D - LOCAL MIGRATIONS AND SPAWNING

D1. Use the local map and transparencies to show the location and timing of migrations and where the fisher perceives the source of young fish to be (e.g. local, tributary or Mekong).

<table>
<thead>
<tr>
<th>Species</th>
<th>Where the young fish come from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pra Thom</td>
<td></td>
</tr>
<tr>
<td>Prual</td>
<td></td>
</tr>
<tr>
<td>Riel</td>
<td></td>
</tr>
<tr>
<td>Chhpin</td>
<td></td>
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<tr>
<td>Ta Oan</td>
<td></td>
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<tr>
<td>Kanth Chos</td>
<td></td>
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<tr>
<td>Kanthou</td>
<td></td>
</tr>
<tr>
<td>Kray Srae</td>
<td></td>
</tr>
<tr>
<td>Proloong</td>
<td></td>
</tr>
</tbody>
</table>

D2. Have there been any changes in migrations and movements because of the built structure? If yes, which species and why do they think this has happened?

Section E. - NEW INFORMATION ON FISH ECOLOGY

H1. Ask fishers for which species they have knowledge of spawning, nursing, feeding and migrations within the basin. For those fish that they have knowledge, complete the following table.

For the ecology type (black/white/grey) you will need to identify this yourself.

<table>
<thead>
<tr>
<th>Species name</th>
<th>Type of Spawning habitat</th>
<th>Name of Spawning location</th>
<th>Type of Feeding habitat</th>
<th>Type of nursing habitat</th>
<th>Ecology type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andet Chhkae</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kanhchos Bay</td>
<td></td>
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</tr>
<tr>
<td>Kanchras Thom</td>
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<tr>
<td>Bandoul Ampov</td>
<td></td>
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<tr>
<td>Reus Chek</td>
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<td>Kasan</td>
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<tr>
<td>Phtoung</td>
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<td>Chlaing</td>
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<td>Ka Ek</td>
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<tr>
<td>Angkot Prak</td>
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<td>Dorng Khteng</td>
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<td>Chunteas Phluk</td>
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<td>Ampil Tum</td>
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<td>Stuk</td>
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<td>Kra Morm</td>
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<td>Ka Uk</td>
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<tr>
<td>Krum</td>
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<tr>
<td>Chunluanh Moan</td>
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<tr>
<td>Kantrang Preing</td>
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<tr>
<td>Kampleav</td>
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<tr>
<td>Khlaing Hay</td>
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<tr>
<td>Kes</td>
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</tbody>
</table>

Form completed by:
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Fisheries Component

BIOECOLOGY OF 296 FISH SPECIES OF THE TONLE SAP GREAT LAKE (CAMBODIA).

Prepared by

Eric BARAN¹, SO Nam², Robert ARTHUR¹, LENG Sy Vann², Yumiko KURA¹

¹ WorldFish Center
² IFReDI

December 2006
WARNING

This document is an advanced draft of a book to be published in the second half of 2007, after the completion of the Built Structures project. In this draft the full accuracy is not guaranteed by the authors yet. Subsequently this document should not be disseminated, cited as a reference nor used for fish species identification.
**Akysidae**

**Akysis filifer**

**Author:** Ng and Rainboth, 2005

**Max. total length (cm):** 7

**Max. standard length (cm):** 5

**Length at maturity (cm):** 3.8

**Tonle Sap distribution:** Ng and Rainboth, 2005.

**Status:** Native

**Habitat:** Demersal

**Resilience:** No information

---

**Ambassidae**

**Pseudambassis baculis**

**Author:**  Hamilton, 1822

**Name in English:** Himalayan glassy perchlet

**Max. total length (cm):** 7

**Max. standard length (cm):** 5

**Length at maturity (cm):** 3.8

**Tonle Sap distribution:** Kottelat, 1985

**Status:** Native

**Habitat:** Demersal

**Resilience:** High

---

**Ambassidae** (Asian glassfishes)

**Parambassis apogonoides**

**Author:** Bleeker, 1851

**Name in Khmer:** រតុកុមារស្នើ

**Name in English:** Iridescent glassy perchlet

**Max. total length (cm):** 13

**Max. standard length (cm):** 10

**Length at maturity (cm):** 7

**Food:** zoobenthos mainly animals

**Discharge as migration trigger:** no information

**Water level as migration trigger:** no information

**Spawns in streams / inlets (% respondents):** 100

**Date of spawning (% respondents):** Jul 2.4%, Aug-Sep 2.4% Jul-Aug 4.9%, Jun-Jul 58.5%, May-Jul 2.4%, May-Jun 29.3%

**Nurses in floodplain (% respondents):** 100

**Breeds in reservoirs:** No info on breeding in reservoirs

**Tonle Sap distribution:** Roberts, 1994
Parambassis ranga (Hossain, M.A.R.)

IDENTIFICATION - Family: Ambassidae (Asiatic glassfishes)
IDENTIFICATION - Species name: Parambassis ranga
IDENTIFICATION - Author: Hamilton, 1822
IDENTIFICATION - Name in English: Indian glassy fish
BIOLOGY - Max. total length (cm): 8
BIOLOGY - Length at maturity (cm): 5.8
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Migration type: No information on migration type
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High

Parambassis siamensis (Baird, I.G.)

IDENTIFICATION - Family: Ambassidae (Asiatic glassfishes)
IDENTIFICATION - Species name: Parambassis siamensis
IDENTIFICATION - Author: Fowler, 1937
BIOLOGY - Max. total length (cm): 8
BIOLOGY - Max. standard length (cm): 6
BIOLOGY - Length at maturity (cm): 4.5
BIOLOGY - Notes: A common species proliferating in impoundments (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Motomura et al. 2002
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Found in the Middle and Lower Mekong Basin (Roberts 1994); mainly in tributaries (Pantulu 1986); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Feeds on invertebrates (Rainboth 1996).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High
**Parambassis wolffii** (Rainboth W.)

**Identification**
- **Family**: Ambassidae (Asiatic glassfishes)
- **Species name**: Parambassis wolffii
- **Author**: Bleeker, 1851
- **Name in Khmer**: ប្រៀងបរុងមាស
- **Name in Khmer (roman)**: Kantrong preng
- **Name in English**: Duskyfin glassy perchlet

**Biology**
- **Max. total length (cm)**: 25
- **Max. standard length (cm)**: 20
- **Length at maturity (cm)**: 12.9
- **Food**: zoobenthos mainly animals

**Ecology vs. Hydrology**
- **Discharge as migration trigger**: no information
- **Water level as migration trigger**: no information

**Reproduction**
- **Spawns in streams / inlets (% respondents)**: 97.5
- **Spawns in TS permanent lake (% respondents)**: 2.5
- **Date of spawning (% respondents)**: Jun 2.6%, Jul-Oct 2.6%, Jun-Jul 66.7%, Mar-Apr 2.6%, May-Jul 2.6%, May-Jun 23.1%

**Ecology**
- **Tonle Sap distribution**: Thuok and Sina, 1997
- **All MFD information**: Migration: 0, Spawning: 0, Distribution: 0
- **Feeding**: Feeds on insects, crustaceans, and small fish (Rainboth 1996)
- **Status**: Native
- **Habitat**: Demersal
- **Resilience**: High
- **Grey fish guild (% respondents)**: 100

**Anabas testudineus** (Chavalit Vidthayanon)

**Identification**
- **Family**: Anabantidae (Climbing gouramies)
- **Species name**: Anabas testudineus
- **Author**: Bloch, 1792
- **Name in Khmer**: ប្រៀងបរុងមាស
- **Name in Khmer (roman)**: Kranh
- **Name in English**: Climbing perch

**Biology**
- **Max. total length (cm)**: 25
- **Length at maturity (cm)**: 15.7
- **Food**: Nekton mainly animals
- **Notes**: possesses an accessory air-breathing organ (Allen 1991), which makes it capable of breathing atmospheric air, and to survive away from water for days or weeks when it searches for a new habitat (Smith 1945, Rahman 1989); It is known to emerge from the water at night when it seeks new habitats by climbing over dry land using flared gill covers and flexing the caudal peduncle (Rainboth 1996); It remains buried under the mud during dry season (Rahman 1989), and can tolerate extremely unfavourable water conditions and is associated mainly with turbid, stagnant waters (Pethiyagoda 1991).

**Ecology vs. Hydrology**
- **Discharge as migration trigger**: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Thuok and Sina, 1997

ECOLOGY - All MFD information: Migration: A black fish species (Bardach 1959); which does not migrate longitudinally within the Mekong, but it undertakes lateral migrations from the main river, or any other permanent water body, to flooded areas during the flood season and returns to the permanent water body at the beginning of the dry season. In Laos and Thailand, it is reported to return to the main river during receding water and spend the dry season in pools associated with sub-merged woods and shrubs (Poulsen and Valbo-Jørgensen 2000). Spawning: Eggs were reported to occur from March to October with a peak from April to June. (Poulsen and Valbo-Jørgensen 2000); It spawns from March/April until July (Yen et al. 1979, Bardach 1959, Poulsen and Valbo-Jørgensen 2000) or August (Duangsawasdi et al. 1988) in for example rain fed and irrigated paddy (Poulsen and Valbo-Jørgensen 2000).

It is sexually mature when it is ten months old, weighs 12-16 gr. and has a body length of 7-8 cm (Khanh et al. 1999) or 10 cm (Duangsawasdi et al. 1988). The mature female has 780,000 ± 140,000 eggs/kg body weight with a diameter of 0.75 mm (Tuan 1999); Fish of 10-19 cm body length and about 38.0-126.2 g body weight have ca 10,200-52,000 eggs with an average number of egg of 26,000 (Duangsawasdi et al. 1988); Average egg diameter is 0.63 mm (Duangsawasdi et al. 1988); The eggs are floating and hatch in 18 hrs at a temperature of 28-30ºC; The newly hatched larvae are 1.96 mm long (Tuan 1999). Distribution: Occurs in the mainstream from Chiang Saen to the Mekong Delta (Poulsen and Valbo-Jørgensen 2000); and found in tributaries of the Lower Mekong (Pantulu 1986); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on macrophytic vegetation (Pethiyagoda 1991.), rice and grass seeds (Yen et al. 1979), shrimps (Pethiyagoda 1991, NIFI 1993), prawns (Yen et al. 1979), fish fry (Pethiyagoda 1991) fish (Rainboth 1996, Yen et al. 1979, NIFI 1993), zooplankton, aquatic insects, detritus (Krachangdara 1994), and plant roots (NIFI 1993).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High

Arius intermedius (Chavalit Vidthayanon)

IDENTIFICATION - Family: Ariidae
IDENTIFICATION - Species name: Arius intermedius
IDENTIFICATION - Author: Venciguerra, 1881
IDENTIFICATION - Remark: Formerly Hemipimelodus intermedius

ECOLOGY - Tonle Sap distribution: possible
ECOLOGY - Status: No information
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium

Arius sona (Chavalit Vidthayanon)

IDENTIFICATION - Family: Ariidae
IDENTIFICATION - Species name: Arius sona
IDENTIFICATION - Author: Hamilton, 1822
<table>
<thead>
<tr>
<th><strong>IDENTIFICATION</strong> - Name in Khmer:</th>
<th>អរុណារាយ</th>
<th>អរុណារាយ</th>
<th>អរុណារាយ</th>
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<tr>
<td><strong>IDENTIFICATION</strong> - Name in Khmer (roman):</td>
<td>Kaock</td>
<td>Kaock</td>
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<td><strong>IDENTIFICATION</strong> - Name in English:</td>
<td>Sona sea catfish</td>
<td>Sona sea catfish</td>
<td>Sona sea catfish</td>
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<tr>
<td><strong>BIOLOGY</strong> - Max. total length (cm):</td>
<td>92</td>
<td>92</td>
<td>92</td>
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<tr>
<td><strong>BIOLOGY</strong> - Length at maturity (cm):</td>
<td>49.7</td>
<td>49.7</td>
<td>49.7</td>
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<tr>
<td><strong>BIOLOGY</strong> - Food:</td>
<td>Mainly animals</td>
<td>Mainly animals</td>
<td>Mainly animals</td>
</tr>
<tr>
<td><strong>REPRODUCTION</strong> - Spawns in rivers (% respondents):</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>REPRODUCTION</strong> - Spawns in streams / inlets (% respondents):</td>
<td>92.5</td>
<td>92.5</td>
<td>92.5</td>
</tr>
<tr>
<td><strong>REPRODUCTION</strong> - Spawns in TS permanent lake (% respondents):</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>REPRODUCTION</strong> - Date of spawning (% respondents):</td>
<td>Apr-May 2.9% Feb-Mar 8.6% Jun-Jul 45.7% Mar-Apr 11.4%, May-Jul 2.9%, May-Jun 28.6%</td>
<td>Apr-May 2.9% Feb-Mar 8.6% Jun-Jul 45.7% Mar-Apr 11.4%, May-Jul 2.9%, May-Jun 28.6%</td>
<td>Apr-May 2.9% Feb-Mar 8.6% Jun-Jul 45.7% Mar-Apr 11.4%, May-Jul 2.9%, May-Jun 28.6%</td>
</tr>
<tr>
<td><strong>REPRODUCTION</strong> - Spawns in floodplain (% respondents):</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td><strong>ECOLOGY</strong> - Feeds in floodplains (% respondents):</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td><strong>ECOLOGY</strong> - Status:</td>
<td>Questionable</td>
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<tr>
<td><strong>ECOLOGY</strong> - Habitat:</td>
<td>Demersal</td>
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<tr>
<td><strong>ECOLOGY</strong> - Resilience:</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td><strong>GUILD</strong> - Grey fish guild (% respondents):</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**Arius thalassinus** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Ariidae

**IDENTIFICATION** - Species name: *Arius thalassinus*

**IDENTIFICATION** - Author: Rüppell, 1837

**IDENTIFICATION** - Remark: Formerly Netuma thalassinus

**IDENTIFICATION** - Name in Khmer (roman): Kaock

**BIOLOGY** - Max. total length (cm): 185

**BIOLOGY** - Length at maturity (cm): 92.2

**BIOLOGY** - Food: plant/zoobenthos/nekton

**REPRODUCTION** - Spawns in rivers (% respondents): 2.5

**REPRODUCTION** - Spawns in streams / inlets (% respondents): 92.5

**REPRODUCTION** - Spawns in TS permanent lake (% respondents): 5

**REPRODUCTION** - Date of spawning (% respondents): Apr-May 2.9% Feb-Mar 8.6% Jun-Jul 45.7% Mar-Apr 11.4%, May-Jul 2.9%, May-Jun 28.6%

**REPRODUCTION** - Nurses in floodplain (% respondents): 100

**ECOLOGY** - Tonle Sap distribution: MFD occurrence map

**ECOLOGY** - Feeds in floodplains (% respondents): 100

**ECOLOGY** - Status: Questionable

**ECOLOGY** - Habitat: Demersal

**ECOLOGY** - Resilience: Medium

**GUILD** - Grey fish guild (% respondents): 100

**Arius maculatus** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Ariidae (Sea catfishes)

**IDENTIFICATION** - Species name: *Arius maculatus*

**IDENTIFICATION** - Author: Thunberg, 1792

**IDENTIFICATION** - Name in Khmer: អរុណារាយ
IDENTIFICATION - Name in Khmer (roman): Kaock
IDENTIFICATION - Name in English: Spotted catfish
BIOLOGY - Max. total length (cm): 80
BIOLOGY - Length at maturity (cm): 44
BIOLOGY - Food: Nekton mainly animals
BIOLOGY - Notes: Occasionally forms schools (Jayaram 1984).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in rivers (% respondents): 2.5
REPRODUCTION - Spawns in streams / inlets (% respondents): 92.5
REPRODUCTION - Spawns in TS permanent lake (% respondents): 5
REPRODUCTION - Date of spawning (% respondents): Apr-May 2.9% Feb-Mar 8.6% Jun-Jul 45.7% Mar-Apr 11.4%, May-Jul 2.9%, May-Jun 28.6%
REPRODUCTION - Reproductive guild: Bearers: external brooders
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - Migration type: Only seems to display Longitudinal migrations.
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium
GUILD - Grey fish guild (% respondents): 100
known above the Khone Falls (Roberts 1993). Feeding: Feeds on fish (Rainboth 1996, Baird and Phylavanh 1999), crabs, shrimps, filamentous algae, and bark (Baird and Phylavanh 1999).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium
GUILD - Grey fish guild (% respondents): 100

Arius truncatus (Chavalit Vidthayanon)

IDENTIFICATION - Family: Ariidae (Sea catfishes)
IDENTIFICATION - Species name: Arius truncatus
IDENTIFICATION - Author: Valenciennes, 1840
IDENTIFICATION - Name in Khmer: តុកាង
IDENTIFICATION - Name in Khmer (roman): Kaock
BIOLOGY - Max. standard length (cm): 42
BIOLOGY - Length at maturity (cm): 24.9
BIOLOGY - Food: Mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in rivers (% respondents): 2.5
REPRODUCTION - Spawns in streams / inlets (% respondents): 92.5
REPRODUCTION - Spawns in TS permanent lake (% respondents): 5
REPRODUCTION - Date of spawning (% respondents): Apr-May 2.9% Feb-Mar 8.6% Jun-Jul 45.7% Mar-Apr 11.4%, May-Jul 2.9%, May-Jun 28.6%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurence map
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Found in the Lower Mekong, where the species can be quite abundant at times (Rainboth 1996). Feeding: Feeds on fishes and crustaceans (Rainboth 1996).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Low
GUILD - Grey fish guild (% respondents): 100

Hemipimelodus borneensis (Rainboth W.)

IDENTIFICATION - Family: Ariidae (Sea catfishes)
IDENTIFICATION - Species name: Hemipimelodus borneensis
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: តុកាង
IDENTIFICATION - Name in Khmer (roman): Kaork
BIOLOGY - Max. total length (cm): 37
BIOLOGY - Max. standard length (cm): 30
BIOLOGY - Length at maturity (cm): 18.5
BIOLOGY - Food: plants/detritus+animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: It is not believed to undertake long distance migrations (Rainboth 1996). Spawning: 0. Distribution: Ascends the Mekong as far as Khone Falls (Rainboth 1996); but has not been found above the Falls (Roberts 1993); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Diet consists of bivalve molluscs, crustaceans (Rainboth 1996, Bardach 1959), aquatic macrophytes (Rainboth 1996), and plant detritus (Rainboth 1996, Baird and Phylavanh 1999); insects (Baird and Phylavanh 1999) mainly aquatic insect larvae but also some flying insects (Bardach 1959), fish, algae (Baird and Phylavanh 1999, Bardach 1959), roots, bark, small leaves and other plant parts. (Baird and Phylavanh 1999), and to a lesser extent planktonic crustaceans. (Bardach 1959). This species seem to be carnivorous in the dry season, and an algae, plant matter and insect eater during high-water season. This may be an adaptation based on the fact that many of the small fish found in the Mekong mainstream in the dry season either migrate into streams or other small to medium sized tributaries close by during the rainy season (Baird and Phylavanh 1999).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium

**Hemipimelodus daugueti** (Chavalit Vidthayanon)

**IDENTIFICATION - Family:** Ariidae (Sea catfishes)
**IDENTIFICATION - Species name:** Hemipimelodus daugueti
**IDENTIFICATION - Author:** Chevey, 1932
**BIOLOGY - Max. total length (cm):** 26
**BIOLOGY - Length at maturity (cm):** 16.3
**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information**
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information**
**REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs**
**ECOLOGY - Tonle Sap distribution: Kottelat, 1985**
**ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Occurs in the large rivers of Cambodia (Rainboth 1996). Feeding: 0**
**ECOLOGY - Status: Native**
**ECOLOGY - Habitat: Demersal**
**ECOLOGY - Resilience: Medium**

**Bagrichthys macracanthus** (IFReDI Collection)

**IDENTIFICATION - Family:** Bagridae (Bagrid catfishes)
**IDENTIFICATION - Species name:** Bagrichthys macracanthus
**IDENTIFICATION - Author:** Bleeker, 1854
**IDENTIFICATION - Name in Khmer:** មានបៃត្តមានពណ៍
**IDENTIFICATION - Name in Khmer (roman):** Cheik tum
**IDENTIFICATION - Name in English:** Black lancer catfish
**BIOLOGY - Max. total length (cm):** 31
**BIOLOGY - Max. standard length (cm):** 25
**BIOLOGY - Length at maturity (cm):** 15.7
| **BIOLOGY** - Food: plants/detritus+animals |
| ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information |
| ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information |
| REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs |
| ECOLOGY - Tonle Sap distribution: Kottelat, 1985 |
| ECOLOGY - All MFD information: Migration: A black fish species (Bardach 1959). Spawning: Spawns in the beginning of the rainy season and utilizes the flooded riparian forests. Juveniles begin to appear in August (Rainboth 1996); However females with eggs have also been found in August (Baird and Phylavanh 1999). . Distribution: Occurs in the Mekong Basin in Laos where it has been collected from Tha Ngon (DoF 1987), Hatsalao (DoF 1987) and Ban Hat (Ferraris 2001); and just below Khone Falls (Roberts 1993); In Thailand at Ubon Ratchathani, and in Roi Et Province (ICLARM 2001); In Cambodia in the Tonle Sap River and at Stung Treng (Kottelat 1985). Feeding: It feeds on crustaceans, other small benthic animals (Taki, 1978), insects, earthworms, roots, and vegetal matter, may consume fruits and vegetation from flooded forests (Baird and Phylavanh 1999); It also scavenges (Roberts 1989). |
| ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations. |
| ECOLOGY - Status: Native |
| ECOLOGY - Habitat: Demersal |
| ECOLOGY - Resilience: High |

**Bagrichthys macropterus** (Baird, I.G.)

**IDENTIFICATION** - Family: **Bagridae** (Bagrid catfishes)
**IDENTIFICATION** - Species name: **Bagrichthys macropterus**
**IDENTIFICATION** - Author: Bleeker, 1853
**IDENTIFICATION** - Name in English: False black lancer
**BIOLOGY** - Max. total length (cm): 30
**BIOLOGY** - Length at maturity (cm): 18.5
**BIOLOGY** - Food: zoobenthos mainly animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985
**ECOLOGY** - Migration type: No information on migration type
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: High

**Bagrichthys obscurus** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: **Bagridae** (Bagrid catfishes)
**IDENTIFICATION** - Species name: **Bagrichthys obscurus**
**IDENTIFICATION** - Author: Ng, 1999
**IDENTIFICATION** - Name in Khmer: ឈីរាណង
**IDENTIFICATION** - Name in Khmer (roman): Cheik tum
**BIOLOGY** - Max. standard length (cm): 24.9
**BIOLOGY** - Length at maturity (cm): 15.7
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: MFD occurrence map
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: No information
**ECOLOGY** - Resilience: Medium

**Hemibagrus filamentus** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Bagridae (Bagrid catfishes)
**IDENTIFICATION** - Species name: **Hemibagrus filamentus**
**IDENTIFICATION** - Author: Fang and Chaux, 1949
**IDENTIFICATION** - Name in Khmer: រតិតាការតឹក
**IDENTIFICATION** - Name in Khmer (roman): Tavel
**BIOLOGY** - Max. total length (cm): 50
**BIOLOGY** - Length at maturity (cm): 29
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: Water level variation is a migration trigger
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: MFD occurrence map
**ECOLOGY** - All MFD information: Migration: Undertakes shorter local migrations within the Mekong mainstream at the onset of the flood season and, as the water level rises (Poulsen and Valbo-Jørgensen 2000, Singanouvong et al. 1996), it continues into small seasonal Mekong tributaries (Singanouvong et al. 1996, Poulsen and Valbo-Jørgensen 2000) and flooded forests (Rainboth 1996) in large numbers during the early wet season. The purpose of the migration is reproduction, and it has moderate to heavy fat deposits around the viscera during the time of migration (Singanouvong et al. 1996). The fish returns to the main river channel when water levels start to recede at the end of the flood season, and it spends the dry season here (Poulsen and Valbo-Jørgensen 2000). Spawning: Carries eggs year round, but most commonly from April to July; Spawning occurs on the floodplain (Poulsen and Valbo-Jørgensen 2000) in late May-July/August (Singanouvong et al. 1996). Distribution: Occurs throughout the Mekong mainstream, from the Mekong Delta to Chiang Saen. Many fishers report that the species is very common and occurs all year round (Poulsen and Valbo-Jørgensen 2000); is common in the Great Lake (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on fishes and crustaceans (Rainboth 1996) including crabs, shrimps (Singanouvong et al. 1996), and planktonic crustaceans; It also eats aquatic insect larvae, mud, and plant fragments (Bardach 1959).
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium
Hemibagrus nemurus (Warren, T.)

**IDENTIFICATION** - Family: **Bagridae** (Bagrid catfishes)
**IDENTIFICATION** - Species name: *Hemibagrus nemurus*
**IDENTIFICATION** - Author: Valenciennes, 1840
**IDENTIFICATION** - Name in English: Asian redtail catfish
**BIOLOGY** - Max. total length (cm): 80
**BIOLOGY** - Max. standard length (cm): 65
**BIOLOGY** - Length at maturity (cm): 36.6
**BIOLOGY** - Food: zoobenthos mainly animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Migration type: No information on migration type
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium

Hemibagrus spilopterus (Rainboth W.)

**IDENTIFICATION** - Family: **Bagridae** (Bagrid catfishes)
**IDENTIFICATION** - Species name: *Hemibagrus spilopterus*
**IDENTIFICATION** - Author: Ng and Rainboth, 1999
**IDENTIFICATION** - Name in Khmer: ឈឺសិបុរា
**IDENTIFICATION** - Name in Khmer (roman): Chhlang
**BIOLOGY** - Max. standard length (cm): 30.9
**BIOLOGY** - Length at maturity (cm): 19
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Spawns in streams / inlets (% respondents): 100
**REPRODUCTION** - Date of spawning (% respondents): Jun 7.7%, Jun-Jul 59%, May-Jul 2.6%, May-Jun 30.8%
**REPRODUCTION** - Nurses in floodplain (% respondents): 100
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: MFD occurrence map
**ECOLOGY** - All MFD information: Migration: A black fish species (Bardach 1959), which moves into flooded forests to spawn and the young are usually first seen in August. In the Tonle Sap, maximum numbers are found as it returns to rivers in November and December (Rainboth 1996). Spawning: Spawns in March, April, September and October, and maybe all the year in Cambodia (Bardach 1959). Distribution: Found basin wide in tributaries (Pantulu 1986); and mainstream of the Lower Mekong Basin from upland areas down to the estuary (Rainboth 1996); also recorded from the Xe Bangfai Basin (Kottelat 1998). Feeding: Its diet includes terrestrial insects, aquatic insect larvae, shrimps (Rainboth 1996), and other crustaceans, as well as fishes (Rainboth 1996, Bardach 1959); but it also eats mud (Bardach 1959).
**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.
**ECOLOGY** - Feeds in floodplains (% respondents): 100
**ECOLOGY** - Status: No information
**ECOLOGY** - Habitat: Demersal
**ECOLOGY - Resilience: Medium**

**GUILD - Grey fish guild (% respondents): 100**

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**Hemibagrus wyckioides** (Baird, I.G.)

IDENTIFICATION - Family: **Bagridae** (Bagrid catfishes)
IDENTIFICATION - Species name: **Hemibagrus wyckioides**
IDENTIFICATION - Author: Bleeker, 1858
IDENTIFICATION - Name in Khmer: ខ្មែរ (Khmao)
IDENTIFICATION - Name in Khmer (roman): Chhlang khmao

**BIOLOGY - Max. total length (cm): 87**
**BIOLOGY - Max. standard length (cm): 71**
**BIOLOGY - Length at maturity (cm): 39.6**
**BIOLOGY - Food: zoobenthos mainly animals**

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information**
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information**

**REPRODUCTION - Spawns in streams / inlets (% respondents): 100**
**REPRODUCTION - Date of spawning (% respondents): Jun 7.7%, Jun-Jul 59%, May-Jul 2.6%, May-Jun 30.8%**
**REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs**

**ECOLOGY - Tonle Sap distribution:** Lim et al. 1999
**ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.**

**ECOLOGY - Feeds in floodplains (% respondents): 100**
**ECOLOGY - Status: Native**
**ECOLOGY - Habitat: Demersal**
**ECOLOGY - Resilience: Medium**

**GUILD - Grey fish guild (% respondents): 100**

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**Hemibagrus wyckioides** (Warren, T.)

IDENTIFICATION - Family: **Bagridae** (Bagrid catfishes)
IDENTIFICATION - Species name: **Hemibagrus wyckioides**
IDENTIFICATION - Author: Fang and Chaux, 1949
IDENTIFICATION - Name in Khmer: ខ្មែរ (Khmao)
IDENTIFICATION - Name in Khmer (roman): Khya

**BIOLOGY - Max. total length (cm): 130**
**BIOLOGY - Length at maturity (cm): 67.5**
**BIOLOGY - Food: zoobenthos mainly animals**

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information**
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information**
**Mystus albolineatus** (Baird, I.G.)

IDENTIFICATION - Family: **Bagridae** (Bagrid catfishes)
IDENTIFICATION - Species name: **Mystus albolineatus**
IDENTIFICATION - Author: Roberts, 1994
IDENTIFICATION - Name in Khmer: រឿង្គងអាប្ស
IDENTIFICATION - Name in Khmer (roman): Kanhchos bai

**BIOLOGY** - Max. total length (cm): 43
**BIOLOGY** - Max. standard length (cm): 35
**BIOLOGY** - Length at maturity (cm): 21.2
**BIOLOGY** - Food: zooplankton mainly animals

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information

**REPRODUCTION** - Date of spawning (% respondents): May 2.6% Jul 2.6%, Jul-Aug 7.7%, Jun-Jul 56.4% May-Jun 28.2%, May-Sep 2.6%
**REPRODUCTION** - Nurses in floodplain (% respondents): 100
**REPRODUCTION** - Spawns in streams / inlets (% respondents): 100
**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999
**ECOLOGY** - All MFD information: Migration: 0. Spawning: Spawns just prior to, or at the onset of the rainy season and its young are first seen in July and August (Rainboth 1996). Distribution: 0. Feeding: Feeds on insect larvae, including chironomids, as well as zooplankton and fishes (Rainboth 1996).

**ECOLOGY** - Feeds in floodplains (% respondents): 100
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: Medium
**GUILD** - Grey fish guild (% respondents): 100

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**Mystus bocourti** (Baird, I.G.)

IDENTIFICATION - Family: **Bagridae** (Bagrid catfishes)
IDENTIFICATION - Species name: **Mystus bocourti**
Mystus micracanthus (FAO)

**IDENTIFICATION - Family:** Bagridae (Bagrid catfishes)

**IDENTIFICATION - Species name:** Mystus micracanthus

**IDENTIFICATION - Author:** Bleeker, 1846

**IDENTIFICATION - Name in English:** Twospot catfish

**BIOLOGY - Max. total length (cm):** 15

**BIOLOGY - Length at maturity (cm):** 10

**BIOLOGY - Food:** Mainly animals

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information

**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** MFD occurrence map

**ECOLOGY - All MFD information:** Migration: A black fish species (Bardach 1959). Spawning: 0. Distribution: Common in the Tonle Sap near the Great Lake (Rainboth 1996); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Feeds on crustaceans and benthic invertebrates (Rainboth 1996)

**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.

**ECOLOGY - Status:** Native

**ECOLOGY - Habitat:** Demersal

**ECOLOGY - Resilience:** High

Mystus multiradiatus (Rainboth W.)

**IDENTIFICATION - Family:** Bagridae (Bagrid catfishes)

**IDENTIFICATION - Species name:** Mystus multiradiatus

**IDENTIFICATION - Author:** Roberts, 1992

**IDENTIFICATION - Name in Khmer:** រឿងដឹក

**IDENTIFICATION - Name in Khmer (roman):** Kanhchos chnot
Mystus mysticetus (Rainboth W.)

**IDENTIFICATION** - Family: Bagridae (Bagrid catfishes)
**IDENTIFICATION** - Species name: Mystus mysticetus
**IDENTIFICATION** - Author: Roberts, 1992
**IDENTIFICATION** - Name in Khmer: រឺុតេស៊ីកតារ
**IDENTIFICATION** - Name in Khmer (roman): Kanhchos chnot

**Biology** - Max. total length (cm): 16
**Biology** - Max. standard length (cm): 13
**Biology** - Length at maturity (cm): 8.8
**Biology** - Food: zooplankton mainly animals
**Biology** - Notes: Often found in mixed schools with M. multiradiatus, which congregate around tree limbs and other solid objects, browsing the hard surfaces (Rainboth 1996).

**Ecology vs. Hydrology** - Discharge as migration trigger: no information
**Ecology vs. Hydrology** - Water level as migration trigger: no information

**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs
**Ecology** - Tonle Sap distribution: Lim et al. 1999

**Ecology** - All MFD information: Migration: Moves into flooded forests during the rainy season and returns to rivers in November and December (Rainboth 1996). Spawning: Eggs are spherical, yellow in colour, demersal and attach to the substrate (Pongsirijun et al. 2002). Distribution: Recorded from Mun River (Pongsirijun et al. 2002), and Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on insect larvae, worms, freshwater prawns, small fishes (Pongsirijun et al. 2002), zooplankton, aquatic insects, crustaceans, and rotifers (Rainboth 1996).

**Ecology** - Status: Native
**Ecology** - Habitat: Demersal
**Ecology** - Resilience: High
IDENTIFICATION - Family: **Bagridae** (Bagrid catfishes)
IDENTIFICATION - Species name: **Mystus wolffii**
IDENTIFICATION - Author: Bleeker, 1851

IDENTIFICATION - Name in Khmer: [ឈឺកាយ]
IDENTIFICATION - Name in Khmer (roman): Kanhchos

**BIOLOGY** - Max. total length (cm): 20
**BIOLOGY** - Length at maturity (cm): 12.9
**BIOLOGY** - Food: zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999; Kottelat, 1985

**ECOLOGY** - All MFD information: Migration: It may utilize the seasonally inundated areas as seen in other species of Mystus (Rainboth 1996). Spawning: 0. Distribution: It is found in fresh water well upstream in the Tonle Sap (Rainboth 1996). Feeding: Diet consists primarily on insects and crustaceans (Rainboth 1996).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: High

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**Pseudomystus siamensis** (Baird, I.G.)

IDENTIFICATION - Family: **Bagridae** (Bagrid catfishes)
IDENTIFICATION - Species name: **Pseudomystus siamensis**
IDENTIFICATION - Author: Regan, 1913
IDENTIFICATION - Remark: Formerly Leiocassis siamensis
IDENTIFICATION - Name in English: Asian bumblebee catfish

**BIOLOGY** - Max. total length (cm): 20
**BIOLOGY** - Length at maturity (cm): 12.9
**BIOLOGY** - Food: zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: -

**ECOLOGY** - All MFD information: Migration: A black fish species (Bardach 1959). Spawning: Adult females has well-developed ova in February, and spawning takes place at the beginning of the rainy season, with the young appearing in fishing nets during August (Rainboth 1996); However the presence of eggs in specimens in July and August indicates that the spawning season is much more protracted; Sexually mature at 13 cm and 20 g (Baird and Phylavanh 1999). Distribution: Found basin wide in tributaries of the Lower Mekong (Pantulu 1986); Recorded from the Nam Theun and Xe Bangfai Basins (Kottelat 1998); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on insects (Baird and Phylavanh 1999, Bardach 1959), aquatic insect larvae (Rainboth 1996, Bardach 1959), including odonatans (Rainboth 1996); fish and large crustaceans (Bardach 1959), earthworms, snails, roots, fruits, and detritus (Baird and Phylavanh 1999).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: High

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**Nemacheilus pallidus** (Baird, I.G.)
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<td>Nemacheilus pallidus</td>
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<td></td>
<td>Native</td>
<td>Benthopelagic</td>
<td>Medium</td>
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<td>Schistura pellegrini</td>
<td>Rendahl, 1944</td>
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<td>Rainboth, 1996</td>
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<td>Native</td>
<td>Benthopelagic</td>
<td>High</td>
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<tr>
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<td>Balitoridae</td>
<td>Tuberoschistura cambodgiensis</td>
<td>Kottelat, 1990</td>
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<td>3.1</td>
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<td>no information</td>
<td>no information</td>
<td>No info on breeding in reservoirs</td>
<td>CNMC 1998, Scott and Crossman 1973</td>
<td></td>
<td>Native</td>
<td>Benthopelagic</td>
<td>Low</td>
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</table>
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High

Xenentodon cancila (Chavalit Vidhayanan)

IDENTIFICATION - Family: Belonidae (Needlefishes)
IDENTIFICATION - Species name: *Xenentodon cancila*
IDENTIFICATION - Author: Hamilton, 1822
IDENTIFICATION - Name in Khmer: ឱញ្ញរ័ត
IDENTIFICATION - Name in Khmer (roman): Phtoung
IDENTIFICATION - Name in English: Freshwater garfish
BIOLOGY - Max. total length (cm): 40
BIOLOGY - Length at maturity (cm): 23.8
BIOLOGY - Food: Nekton mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in streams / inlets (% respondents): 100
REPRODUCTION - Date of spawning (% respondents): Jul-Aug 5.3%, July-Sep 2.6%, Jun-Jul 63.2%, May-Jun 28.9%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Motomura et al. 2002; Lim et al. 1999
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: High
GUILD - Grey fish guild (% respondents): 100

Xenentodon cancilooides (FAO)

IDENTIFICATION - Family: Belonidae (Needlefishes)
IDENTIFICATION - Species name: *Xenentodon cancilooides*
IDENTIFICATION - Author: Bleeker, 1853
BIOLOGY - Max. total length (cm): 37
BIOLOGY - Max. standard length (cm): 30
BIOLOGY - Length at maturity (cm): 18.5
BIOLOGY - Food: Nekton mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Mekong Basin in Laos, Thailand, Cambodia and Viet Nam (Kottelat 2001). Feeding: 0
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: High
**Tonlesapia tsukawakii**

**Identification** - Family: Callionymidae

**Identification** - Species name: *Tonlesapia tsukawakii*

**Identification** - Author: Motomura and Mukai, 2006

**Biology** - Max. total length (cm): 5

**Biology** - Max. standard length (cm): 3.4

**Biology** - Length at maturity (cm): 2.6

**Ecology** - Status: Native

**Ecology** - Habitat: Benthopelagic

**Ecology** - Resilience: No information

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**Rhizoprionodon acutus** (Randall, J.E.)

**Identification** - Family: Carcharhinidae (Requiem sharks)

**Identification** - Species name: *Rhizoprionodon acutus*

**Identification** - Author: Rüppell, 1837

**Identification** - Name in English: Milk shark

**Biology** - Max. total length (cm): 175

**Biology** - Length at maturity (cm): 87.8

**Biology** - Food: Nekton mainly animals

**Ecology vs. Hydrology** - Discharge as migration trigger: no information

**Ecology vs. Hydrology** - Water level as migration trigger: no information

**Reproduction** - Reproductive guild: Bearers: Internal live bearers

**Reproduction** - Fecundity: 3

**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs


**Ecology** - All MFD information: Migration: 0. Spawning: 0. Distribution: Recorded several times from Cambodia as far upstream as the Great Lake (Rainboth 1996). Feeding: Both juveniles and adults feed on fish (Cortés 1999, Salini et al. 1992, Rainboth 1996, Salini et al.1994, Compagno 1984); mainly small pelagic and benthic bony fishes; It also takes cephalopods and other invertebrates (Compagno 1984) including crustaceans (Rainboth 1996).

**Ecology** - Status: Native

**Ecology** - Habitat: Benthopelagic

**Ecology** - Resilience: Very low

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**Lates calcarifer** (Jean-Francois Hellas / Fishing Adventures Thailand)

**Identification** - Family: Centropomidae (Snooks)

**Identification** - Species name: *Lates calcarifer*

**Identification** - Author: Bloch, 1790

**Identification** - Name in English: Barramundi

**Biology** - Max. total length (cm): 200

**Biology** - Length at maturity (cm): 72

**Biology** - Food: Nekton mainly animals

**Ecology vs. Hydrology** - Discharge as migration trigger: no information

**Ecology vs. Hydrology** - Water level as migration trigger: no information

**Reproduction** - Reproductive guild: Nonguarders: Open water/substratum egg scatterers

**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs

**Ecology** - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); A diadromous fish, inhabiting rivers before returning to the estuaries to spawn (Kailola et al. 1993); Frequent estuaries for feeding during the dry season and returns to marine environments for spawning during the rainy season (Rainboth 1996); The post larvae (and possibly larvae) move from spawning areas to brackish water seasonal habitat (Russell and Garrett 1985). Spawning: 0. Distribution: Occurs in the Mekong Delta and tidal reaches (Rainboth 1996). Feeding: Feeds on fishes (Salini et al. Scott and Crossman 1973, Rainboth 1996, Hora and Pillay 1962) and crustaceans (Rainboth 1996, Hora and Pillay 1962). ECOLOGY - Migration type: Only seems to display Longitudinal migrations. ECOLOGY - Status: Native ECOLOGY - Habitat: Demersal ECOLOGY - Resilience: Low

Channa gachua (Chavalit Vidthayanon)

IDENTIFICATION - Family: Channidae (Snakeheads)
IDENTIFICATION - Species name: Channa gachua
IDENTIFICATION - Author: Hamilton, 1822
IDENTIFICATION - Name in Khmer: រតីស៊ុង
IDENTIFICATION - Name in Khmer (roman): Kasan
BIOLOGY - Max. standard length (cm): 20
BIOLOGY - Length at maturity (cm): 11.1
BIOLOGY - Food: Mainly animals (troph. 2.8 and up)
BIOLOGY - Notes: Can tolerate very stagnant, poorly oxygenated and turbid water, and even very foul water (Rahman 1989); and temperatures up to 36.5º C (Talwar and Jhingran 1992).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in rivers (% respondents): 100
REPRODUCTION - Date of spawning (% respondents): May 23.1%, Jun 30.8%, Jul 15.4% Jun-Jul 7.7% May-Jun 23.1%
REPRODUCTION - Fecundity: 910
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: No information
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium
GUILD - Black fish guild (% respondents): 2.5
GUILD - White fish guild (% respondents): 97.5

Channa lucius (Chavalit Vidthayanon)

IDENTIFICATION - Family: Channidae (Snakeheads)
IDENTIFICATION - Species name: Channa lucius
IDENTIFICATION - Author: Cuvier, 1831
**Identification** - Name in Khmer: រតុកេប៉ារ
Identification - Name in Khmer (roman): Kanhchoun chey

**Biology** - Max. total length (cm): 49
**Biology** - Max. standard length (cm): 40
**Biology** - Length at maturity (cm): 23.8
**Biology** - Food: Nektom mainly animals

**Ecology vs. Hydrology** - Discharge as migration trigger: no information
**Ecology vs. Hydrology** - Water level as migration trigger: no information

**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs

**Ecology** - Tonle Sap distribution: Kottelat, 1985; Lim et al. 1999
**Ecology** - All MFD information: Migration: A black fish species (Bardach 1959). Spawning: Spawns during April-May and November. Fish of 14 - 30 cm body length and 134-268 g have about 1,650-21,300 eggs. The average number of egg is about 7,900. The average egg diameter is 1.29 mm (Duangsawasdi et al. 1988).
**Ecology** - Status: Native
**Ecology** - Habitat: Benthopelagic

**Ecology** - Resilience: Medium

**Channa micropeltes** (Rainboth W.)

**Identification** - Family: Channidae (Snakeheads)
**Identification** - Species name: *Channa micropeltes*
**Identification** - Author: Cuvier, 1831

**Identification** - Name in Khmer: រតុកេប៉ារ
**Identification** - Name in Khmer (roman): Chhdau
**Identification** - Name in English: Giant snakehead

**Biology** - Max. total length (cm): 159
**Biology** - Max. standard length (cm): 130
**Biology** - Length at maturity (cm): 67.5
**Biology** - Food: Nektom mainly animals

**Ecology vs. Hydrology** - Discharge as migration trigger: no information
**Ecology vs. Hydrology** - Water level as migration trigger: no information

**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs

**Ecology** - All MFD information: Migration: A black fish species (Bardach 1959); This species enters seasonally inundated areas during the rainy season (Baird and Phylavanh 1999). Spawning: Spawn in April (Duangsawasdi and Krachangdara 1994). Guards its nest and eggs vigorously and will even attack humans (Smith 1945).
**Ecology** - Migration type: Displays longitudinal as well as lateral migrations.
**Ecology** - Status: Native
**Ecology** - Habitat: Benthopelagic

**Ecology** - Resilience: Low
**Channa striata** (Rainboth W.)

**IDENTIFICATION - Family:** Channidae (Snakeheads)
**IDENTIFICATION - Species name:** Channa striata
**IDENTIFICATION - Author:** Bloch, 1793
**IDENTIFICATION - Name in Khmer:** ឈឺជឺ
**IDENTIFICATION - Name in Khmer (roman):** Ros / Phtuk
**IDENTIFICATION - Name in English:** Snakehead murrel

**BIOLOGY - Max. total length (cm):** 122
**BIOLOGY - Max. standard length (cm):** 100
**BIOLOGY - Length at maturity (cm):** 53.5
**BIOLOGY - Food:** Nekton mainly animals

**BIOLOGY - Notes:** Survives dry season by burrowing in bottom mud of lakes, canals and swamps as long as skin and breathing apparatus remain moist (Davidson 1975), and subsisting on stored fat, during this time its flesh is heavily infested by a larval trematode Isoparorchis hypsilobargi, other parasites infecting this fish include Pallisentis ophicephali in the intestine and Neocamallanus ophicephali in the pyloric caeca. (Rahman 1989). Several countries report adverse ecological impact after introduction (Talwar and Jhingran 1992);

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Reproductive guild:** Guarders: Clutch tenders

**REPRODUCTION - Fecundity:** 7733
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Thuok, N and L. Sina, 1997

**ECOLOGY - All MFD information:** Migration: A black fish species (Bardach 1959); The species does not undertake longitudinal migrations within the Mekong, but it makes lateral migrations from the main river, or any other permanent water body, to flooded areas (Poulsen and Valbo-Jørgensen 2000) including flooded forest (Roberts 1993) during the flood season and returns to the permanent water body at the beginning of the dry season (Poulsen and Valbo-Jørgensen 2000). Spawning: Carries eggs, and (Poulsen and Valbo-Jørgensen 2000), except maybe for the very driest period in April/May (Bardach 1959), probably also spawns, year round with a peak from March to June (Poulsen and Valbo-Jørgensen 2000); It spawns in flooded areas such as swamps and rice fields, but also in slow flowing parts rivers; The parent fish makes up the spawning ground and guards the young for about a month (Poulsen and Valbo-Jørgensen 2000). . Distribution: Occurs from Chiang Saen to the Mekong Delta (Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on fish (Rahman 1989, Baird and Phylavanh 1999, Bardach 1959, Rainboth 1996, NIFI 1993), smaller herbivorous fishes (Roberts 1993), crustaceans (Allen 1991, Bardach 1959, Rainboth 1996), including shrimps (NIFI 1993), snakes, tadpoles (Rahman 1989), frogs, insects, earthworms (Rahman 1989, Baird and Phylavanh 1999) detritus (Baird and Phylavanh 1999); and occasionally on plant fragments (Bardach 1959); Juveniles feed on fish (Yap 1988).

**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** Medium
**Clarias batrachus** (CAFS)

**IDENTIFICATION** - Family: **Clariidae** (Airbreathing catfishes)
**IDENTIFICATION** - Species name: **Clarias batrachus**
**IDENTIFICATION** - Author: Linnaeus, 1758
**IDENTIFICATION** - Name in Khmer: ប្រព័ន្ធមោស្រូស
**IDENTIFICATION** - Name in Khmer (roman): Andaeng reung
**IDENTIFICATION** - Name in English: Walking catfish

**BIOLOGY** - Max. total length (cm): 47
**BIOLOGY** - Length at maturity (cm): 30.7
**BIOLOGY** - Food: zoobenthos mainly animals
**BIOLOGY** - Notes: Can walk and leave the water to migrate to other water bodies using its auxiliary breathing organs (Ukkatawewat 9999, Talwar and Jhingran 1992, Smith 1945); It moves on land by wriggling from side to side on its erect pectoral fins (Rainboth 1996, Smith 1945); Several countries report adverse ecological impact after introduction (Kottelat 1998).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Reproductive guild: Guarders: Nesters
**REPRODUCTION** - Fecundity: 2005

**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999

**ECOLOGY** - All MFD information: Migration: It mainly undertakes lateral migrations from the main river, or any other permanent water body, to flooded areas during the flood season and returns to permanent water bodies at the beginning of the dry season (Poulsen and Valbo-Jørgensen 2000). Spawning: It becomes adult at 20 cm length (Bardach 1959); Mainly carries eggs from March to July; Reported to spawn in paddy fields in April to May (Poulsen and Valbo-Jørgensen 2000); and in June and October below Quatre Bras (Bardach 1959). Distribution: Found basin wide in tributaries of the Lower Mekong (Pantulu 1986); and from Chiang Saen in the north to the Mekong Delta in the south in the mainstream (Poulsen and Valbo-Jørgensen 2000); Recorded from the Xe Bangfai and Nam Theun Basins (Kottelat 1998); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on fishes (Rainboth 1996, Ukkatawewat 9999, Bardach 1959), molluscs (Rainboth 1996), zoobenthos, insects (Yap 1988), insect larvae, earthworms, shells, shrimps, aquatic plants and debris (Ukkatawewat 9999), earthworms, and insects (Baird and Phylavan 1999), and fleshy fruits (Baird et al. 2001); Consumes mud, plant fragments, planktonic crustaceans, aquatic insect larvae, fish and large crustaceans, seeds, flying insects, and molluscs and snails, in that order (Bardach 1959).

**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: High

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**Clarias macrocephalus** (Rainboth W.)
**Clarias macrocephalus**

Family: Clariidae (Airbreathing catfishes)
Species name: *Clarias macrocephalus*
Author: Günther, 1864

Identification - Name in Khmer: រត្តុះធាបៃត្តារ
Identification - Name in Khmer (roman): Andaeng toun
Identification - Name in English: Broadhead catfish

**Biology**
- Max. total length (cm): 120
- Length at maturity (cm): 62.9
- Food: Nektom mainly animals

Notes: Can like the walking catfish (*C. batrachus*) move out of the water using its extended fins (Frimodt 1995), It is nearly as common as the walking catfish (Rainboth 1996).

**Ecology vs. Hydrology**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**Reproduction**
- Breeds in reservoirs: No info on breeding in reservoirs

**Ecology**
- Tonle Sap distribution: Motomura et al. 2002; Lim et al., 1999
- Migration: 0. Spawning: Spawns in small streams (Frimodt 1995). 
- Migration type: Displays longitudinal as well as lateral migrations.
- Status: Native
- Habitat: Benthopelagic
- Resilience: High

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**Clarias meladerma** (Chavalit Vidthayanon)

Family: Clariidae (Airbreathing catfishes)
Species name: *Clarias meladerma*
Author: Beeker, 1846

Identification - Name in Khmer: រត្តុះធាបៃត្តារ
Identification - Name in Khmer (roman): Andaeng toun
Identification - Name in English: Blackskin catfish

**Biology**
- Max. total length (cm): 34
- Length at maturity (cm): 20.7

**Ecology vs. Hydrology**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**Reproduction**
- Breeds in reservoirs: No info on breeding in reservoirs

**Ecology**
- Tonle Sap distribution: possible; found in the delta and in Cambodia
- Migration: 0. Spawning: 0 . Distribution: Collected in the Mekong Delta of Viet Nam, but doubtful to occur in Thailand (Smith 1945). Feeding: Carnivorous (Rainboth 1996); Feeds on small animals (Krachangdara 1994).
- Status: Native
- Habitat: Demersal
- Resilience: Medium

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**Clarias nieuhofii** (IFReDI collection)
<table>
<thead>
<tr>
<th>Family</th>
<th>Species name</th>
<th>Author</th>
<th>Name in Khmer</th>
<th>Name in Khmer (roman)</th>
<th>Max. total length (cm)</th>
<th>Length at maturity (cm)</th>
<th>Food</th>
<th>Status</th>
<th>Habitat</th>
<th>Resilience</th>
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</thead>
<tbody>
<tr>
<td>Clariidae (Airbreathing catfishes)</td>
<td>Clarias nieuhofii</td>
<td>Valenciennes, 1840</td>
<td>ឆ្ងារ៉ាឌ្ឍុបុរម្មុល</td>
<td>Andaeng ngang</td>
<td>50</td>
<td>29</td>
<td>zooplankton mainly animals</td>
<td>Native</td>
<td>Demersal</td>
<td>Medium</td>
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<tr>
<td>Clupeidae</td>
<td>Tenualosa toli</td>
<td>Valenciennes, 1847</td>
<td>តូលិ ជើងធ្មារ</td>
<td>Toli shad</td>
<td>60</td>
<td>38.5</td>
<td>zooplankton plants/detritus+animals</td>
<td>Native</td>
<td>pelagic</td>
<td>Medium</td>
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<tr>
<td>Clupeidae (Herrings, shads, sardines, menhadens)</td>
<td>Clupeichthys aesarnensis</td>
<td>Wongratana, 1983</td>
<td>ប៉ានុលអេក្រងទឹកឈី</td>
<td>Bandol ampov</td>
<td>9</td>
<td>7</td>
<td>zooplankton mainly animals</td>
<td>Native</td>
<td>Demersal</td>
<td>Medium</td>
</tr>
</tbody>
</table>

**Tenualosa toli** (Randall J.E.)

**Clupeichthys aesarnensis** (Rainboth W.)
stage of lunar cycle (Warren 2000); Which may explain why Rainboth (1996) states that it is nocturnally active (Rainboth 1996), while Sirimongkontavon (1994) found that it is a daytime feeder that can feed at all depths (Sirimongkontavon 1994).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Spawns in floodplain lakes / rice field (% respondents): 95**
**REPRODUCTION - Spawns in streams / inlets (% respondents): 5**
**REPRODUCTION - Date of spawning (% respondents): Jun-Jul 70%, May-Jul 2.5%, May-Jun 27.5%**

**REPRODUCTION - Nurses in floodplain (% respondents): 100**
**REPRODUCTION - Breeds in reservoirs: Can breed in reservoirs**

**ECOLOGY - Tonle Sap distribution:** Lim et al. 1999
**ECOLOGY - All MFD information:** Migration: Appears to undertake nocturnal vertical migrations during certain periods of the lunar cycle (Warren 2000). Spawning: Spawning in reservoirs may occur weekly and consistently all year round. (Sirimongkontavon 1994, Sriputinipon et al. 1986.); with peaks in April to June, and September to November (Phuriphong and Ukkatawewat 1992); or throughout the rainy season from May to October (Chukajon et al. 1977) possibly affected by the stage of the lunar cycle (Warren 2000).

It spawns pelagically probably in upper water column close to the water surface (Warren et al. Scott and Crossman 1973) although earlier reported to spawn at stumps, plant roots and grasses (Soemarwotto and Costa-Pierce 1988); The eggs of the Thai river sprat are of the floating or pelagic type (Sriputinipon et al. 1986.) with a diameter of 0.27-0.4 mm. Ovaries start to develop when the fish reach a size of 13 mm and 0.025 g (Sirimongkontavon 1994); At a length of 20.3 – 46.0 mm (0.175–1.34 g), the fish carry 72-2,245 eggs with an average fecundity of 442 and 871 eggs per female in March and November, respectively (Sirimongkontavon 1994). Distribution: Occurs in the Xe Bangfai Basins (Kottelat 1998), and in many impoundments including Ubolratana, Sirindhorn and Nam Ngum reservoirs (Leelapatra et al. 2000). Feeding: Feeds on a variety of zooplankton (Sirimongkontavon 1994), especially crustaceans (Sirimongkontavon 1994, Warren 2000, Phuriphong and Ukkatawewat 1992, Rainboth 1996), which are smaller than 500 µm; Miscellaneous phytoplankton (Costa-Pierce 1988, Phuriphong and Ukkatawewat 1992); Insects (Sirimongkontavon 1994), aquatic insect larvae (Sriputinipon et al. 1986.); Larger individuals may become cannibalistic (Phuriphong and Ukkatawewat 1992) and feed on fry of its own species (Sirimongkontavon 1994), however there exists some controversy over whether this species actually feeds on pelagic eggs of other fish species (Warren 2000).

**ECOLOGY - Feeds in floodplains (% respondents): 100**
**ECOLOGY - Status: Native**
**ECOLOGY - Habitat: pelagic**
**ECOLOGY - Resilience: High**

**GUILD - Black fish guild (% respondents): 97.5**
**GUILD - Grey fish guild (% respondents): 2.5**

*Clupeichthys goniognathus* (Chavalit Vidthayanon)

**IDENTIFICATION - Family:** Clupeidae (Herrings, shads, sardines, menhadens)
**IDENTIFICATION - Species name:** *Clupeichthys goniognathus*
**IDENTIFICATION - Author:** Bleeker, 1855

**IDENTIFICATION - Name in Khmer:** ផ្កាញឈឺម្រាប់ផ្លូវ
**IDENTIFICATION - Name in Khmer (roman):** Bandol ampov
**IDENTIFICATION - Name in English:** Sumatran river sprat

**BIOLOGY - Max. total length (cm): 11**
**BIOLOGY - Max. standard length (cm): 9**
**BIOLOGY - Length at maturity (cm): 6.4**
**BIOLOGY - Food:** zooplankton mainly animals

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information
REPRODUCTION - Spawns in floodplain lakes / rice field (% respondents): 95
REPRODUCTION - Spawns in streams / inlets (% respondents): 5
REPRODUCTION - Date of spawning (% respondents): Jun-Jul 70%, May-Jul 2.5%, May-Jun 27.5%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985; Lim et al. 1999
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: High
GUILD - Black fish guild (% respondents): 97.5
GUILD - Grey fish guild (% respondents): 2.5

*Clupeoides borneensis* (Rainboth W.)

IDENTIFICATION - Family: *Clupeidae* (Herrings, shads, sardines, menhadens)
IDENTIFICATION - Species name: *Clupeoides borneensis*
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: ប្រមែន្រប់ៗឈើ
IDENTIFICATION - Name in Khmer (roman): Bandol ampov
IDENTIFICATION - Name in English: Borneo river sprat
BIOLOGY - Max. total length (cm): 10
BIOLOGY - Max. standard length (cm): 8
BIOLOGY - Length at maturity (cm): 5.8
BIOLOGY - Food: zooplankton mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in floodplain lakes / rice field (% respondents): 95
REPRODUCTION - Spawns in streams / inlets (% respondents): 5
REPRODUCTION - Date of spawning (% respondents): Jun-Jul 70%, May-Jul 2.5%, May-Jun 27.5%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which does not move very far (Blache and Goossens 1954), but it may move short distances away from the main river channels during high water periods (Rainboth 1996). Spawning: 0 . Distribution: In the Mekong Basin, it commonly occurs upstream at least as far as the Great Lake (Rainboth 1996); Recorded from the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds primarily on planktonic crustaceans (Rainboth 1996).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: High
GUILD - Black fish guild (% respondents): 97.5
GUILD - Grey fish guild (% respondents): 2.5
**Corica laciniata** (Rainboth W.)

**IDENTIFICATION** - Family: **Clupeidae** (Herrings, shads, sardines, menhadens)
**IDENTIFICATION** - Species name: **Corica laciniata**
**IDENTIFICATION** - Author: Fowler, 1935

**IDENTIFICATION** - Name in Khmer: រតុណ្តូចយុត្តិ

**IDENTIFICATION** - Name in Khmer (roman): Bandol ampov
**IDENTIFICATION** - Name in English: Bangkok river sprat

**BIOLOGY** - Max. standard length (cm): 7
**BIOLOGY** - Length at maturity (cm): 5.1
**BIOLOGY** - Notes: It is a schooling species (188), which can form huge populations in standing water bodies (Warren 2000).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Spawns in floodplain lakes / rice field (% respondents): 95
**REPRODUCTION** - Date of spawning (% respondents): Jun-Jul 70%, May-Jul 25%, May-Jun 27.5%
**REPRODUCTION** - Nurses in floodplain (% respondents): 100
**ECOLOGY** - Tonle Sap distribution: possible (Larvae/juveniles recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002).)
**ECOLOGY** - All MFD information: Migration: Migrates vertically in the water column (Warren 2000). Spawning: It probably spawns at regular intervals throughout the year in the upper water column close to water surface; The eggs are small and planktonic (Warren 2000). Distribution: Larvae/juveniles recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: planktivorous (Warren 2000).
**ECOLOGY** - Feeds in floodplains (% respondents): 100
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: pelagic
**ECOLOGY** - Resilience: High
**GUILD** - Black fish guild (% respondents): 97.5
**GUILD** - Grey fish guild (% respondents): 2.5

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**Tenualosa thibaudeaui** (Roberts, T.R.)

**IDENTIFICATION** - Family: **Clupeidae** (Herrings, shads, sardines, menhadens)
**IDENTIFICATION** - Species name: **Tenualosa thibaudeaui**
**IDENTIFICATION** - Author: Durand, 1940

**IDENTIFICATION** - Name in Khmer: ត្រុក្រឹម

**IDENTIFICATION** - Name in Khmer (roman): Kbork
**IDENTIFICATION** - Name in English: Laotian shad

**BIOLOGY** - Max. total length (cm): 37
**BIOLOGY** - Max. standard length (cm): 30
**BIOLOGY** - Length at maturity (cm): 18.5
**BIOLOGY** - Food: plants mainly plants/detritus
**BIOLOGY** - Notes: A short-lived species (Warren 2000), which numbers are declining drastically (Rainboth 1996, Roberts 1993), the reason for this is unknown, although it may be due to multiple factors including dam construction and over-fishing (Rainboth 1996); including certain traps used at Khone Falls (Roberts 1993).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: Above the Khone Falls it migrates upstream from March to June (Poulsen and Valbo-Jørgensen 2000); below the Khone Falls the fish is migrating downstream from the Falls from April to July (Poulsen and Valbo-Jørgensen 2000, Rainboth 1996) or July-August (Baird et al. 1999); It may follow the turbid floodwaters all the way to the Tonle Sap, perhaps moving into the Great Lake as it fills with water from the Mekong. As water levels in the Great Lake fall, it migrates back down the Tonle Sap to the Mekong, where it begins the movement upstream toward Khone Falls (Rainboth 1996) which continues from October or November through February (Chantepha 1972, Poulsen and Valbo-Jørgensen 2000); with a peak during November-December (Poulsen and Valbo-Jørgensen 2000) or January-February (Baird et al. 1999); No large migrations have been reported for this species for the past 15 years. The migrations that do still exist pass upstream to Thailand and the Lao PDR from Cambodia around the time of the lunar dependent Chinese New Year (Roberts 1993).
The main factors triggering the migrations were reported to be a combination of the first rain, increased water levels and increased turbidity. The fish does not seem to migrate in the Mekong Delta where it appears to be present year round; it is reported to undertake local migrations into, and out of, small streams and flooded areas too during rising and receding water levels, respectively (Poulsen and Valbo-Jørgensen 2000). Spawning: Developed eggs occur in March-June (Poulsen and Valbo-Jørgensen 2000); The fish may spawn during December-January in the Cambodian Great Lake (Janesirisak and Rungtongbaisuree 1996); and in the Middle Mekong along the Thai-Lao border, young of the year of 40 to 50 mm total length were first encountered in the middle of April (Rainboth et al. 1975); but the abundance of juveniles increases during the onset of the rising water levels when the suspended solids increase (Rainboth 1996); It spawns pelagic in open water; the eggs are buoyant, small, and planktonic (Warren 2000). Distribution: Found basin wide in the mainstream (Pantulu 1986) and large rivers (Rainboth 1996) of the Mekong Basin; Recorded from Luang Prabang (Rainboth 1996, Kottelat 1998), Nong Khai (Roberts 1993, Kottelat 1998), Vientiane, Pakse, Hatsalao, Tha Ngon and Tha Bo, also Cambodia (Kottelat 1998) where it is known from the Bassac (Rainboth 1996), it has been collected often in the delta (Roberts 1993), however it is apparently confined to fresh water (Rainboth 1996). It is also known from the Lower Xe Bangfai in Laos (Kottelat 1998) and the Chi (Leelapatra 1977) and Mun Rivers (Kottelat 1998, Janesirisak and Rungtongbaisuree 1996), its presence has been reported from Nam Song and small juveniles have been collected in Songkhram River (Valbo-Jørgensen 2001). Feeding: Specializing in microscopic food such as phytoplankton or bacteria found on particulate matter (Rainboth 1996, Warren 2000).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: Medium

**Syncrossus beauforti** (Rainboth W.)

**IDENTIFICATION** - Family: Cobitidae
**IDENTIFICATION** - Species name: *Botia beauforti*
**IDENTIFICATION** - Author: Smith, 1931
**IDENTIFICATION** - Remark: Recently renamed as Syncrossus beauforti
**IDENTIFICATION** - Name in Khmer: चमेलीडौ फौड़ि
**IDENTIFICATION** - Name in Khmer (roman): Kanhchrouk
**IDENTIFICATION** - Name in English: Chameleon loach
**BIOLOGY** - Max. total length (cm): 31
**BIOLOGY** - Max. standard length (cm): 25
**BIOLOGY** - Length at maturity (cm): 15.7
**BIOLOGY** - Food: Mainly animals
**Acantopsis dialuzona** (Sheremetyev, I.)

**Ecology** - Tonle Sap distribution: Kottelat, 1985  
**Ecology** - Status: Native  
**Ecology** - Habitat: Demersal  
**Ecology** - Resilience: Medium

**Identification** - Family: **Cobitidae** (Loaches)  
**Identification** - Species name: **Acantopsis dialuzona**  
**Identification** - Author: Van Hasselt, 1823  
**Biology** - Max. total length (cm): 31  
**Biology** - Max. standard length (cm): 25  
**Biology** - Length at maturity (cm): 15.7  
**Biology** - Food: Mainly animals  
**Ecology vs. Hydrology** - Discharge as migration trigger: no information  
**Ecology vs. Hydrology** - Water level as migration trigger: no information  
**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs  
**Ecology** - Tonle Sap distribution: Kottelat, 1985  
**Ecology** - Migration type: No information on migration type  
**Ecology** - Status: Native  
**Ecology** - Habitat: Demersal  
**Ecology** - Resilience: Medium

**Syncrossus helodes** (Rainboth W.)

**Identification** - Family: **Cobitidae** (Loaches)  
**Identification** - Species name: **Botia helodes**  
**Identification** - Author: Sauvage, 1876  
**Identification** - Remark: Recently renamed as **Syncrossus helodes**  
**Identification** - Name in Khmer: តុងកុង កូវូ  កូវូ ចិត (Kanhchrouk chnot)  
**Identification** - Name in English: Tiger botia  
**Biology** - Max. total length (cm): 37  
**Biology** - Max. standard length (cm): 30  
**Biology** - Length at maturity (cm): 18.5  
**Biology** - Food: Zoobenthos mainly animals  
**Biology** - Notes: A nocturnal or crepuscular fish (Rainboth 1996), which hides itself in mud, rocks, and logs (1038297).  
**Ecology vs. Hydrology** - Discharge as migration trigger: no information  
**Ecology vs. Hydrology** - Water level as migration trigger: no information  
**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs  
**Ecology** - Tonle Sap distribution: Kottelat, 1985; Lim et al. 1999  
**Ecology** - All MFD information: Migration: A white fish species (Bardach 1959), which moves into flooded areas during the rainy season and returns to rivers during November and December (Rainboth 1996). Spawning: 0 . Distribution: Found in small upland streams with fast currents, as
well as at bottom depths in the Great Lake (Rainboth 1996); Reported from the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on molluscs, worms (Rainboth 1996), benthic insect larvae (Rainboth 1996, Bardach 1959) and planktonic crustaceans (Bardach 1959).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium

Yasuhikotakia lecontei (Rainboth W.)

IDENTIFICATION - Family: Cobitidae (Loaches)
IDENTIFICATION - Species name: Botia lecontei
IDENTIFICATION - Author: Fowler, 1937
IDENTIFICATION - Remark: Recently renamed as Yasuhikotakia lecontei
IDENTIFICATION - Name in Khmer: ំចិត្តព្យាយាមព្យាយាម
IDENTIFICATION - Name in Khmer (roman): Kanhchrouk leung
IDENTIFICATION - Name in English: Silver loach
BIOLOGY - Max. total length (cm): 19
BIOLOGY - Max. standard length (cm): 15
BIOLOGY - Length at maturity (cm): 10
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: Like other members of the genus, this species takes shelter during the day in crevices and under rocks, tree limbs, or other objects (Rainboth 1996, 1038297), and comes out to forage during dusk and night (Rainboth 1996).

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: The young of the year return to the river from the floodplain in November and December (Rainboth 1996). Spawning: 0. Distribution: Mekong Basin in Laos and Thailand (Kottelat 2001); Recorded from the Xe Bangfai Basin (Kottelat 1998). Feeding: Feeds on molluscs and other benthic invertebrates (Rainboth 1996).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium

Yasuhikotakia modesta (Plistil, J.)

IDENTIFICATION - Family: Cobitidae (Loaches)
IDENTIFICATION - Species name: Botia modesta
IDENTIFICATION - Author: Bleeker, 1865
IDENTIFICATION - Remark: Recently renamed as Yasuhikotakia modesta
IDENTIFICATION - Name in Khmer: ំចិត្តព្យាយាមស្វាប់ភ្លើង
IDENTIFICATION - Name in Khmer (roman): Kanhchrouk krohorm
IDENTIFICATION - Name in English: Redtail botia
BIOLOGY - Max. total length (cm): 31
BIOLOGY - Max. standard length (cm): 25
BIOLOGY - Length at maturity (cm): 15.7
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: It is always living in a group with the leader in front of the group (Khamtorn 1999); Takes cover in holes under rocks or in crevices under tree limbs or other objects during the day (Rainboth 1996) and comes out to forage at night (Rainboth 1996, Mills and Vever 1989, Khamtorn 1999).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which is known to participate in large migrations during January in upland areas of the Mekong (Rainboth 1996); There is an upstream migration from around the saline intrusion zone in the Delta to just below the Khone Falls from November to March. From May to July, the species migrates the opposite way apparently to flooded areas in Southern Cambodia and the Mekong Delta. Above the Khone Falls, it migrates upstream during February to May (Poulsen and Valbo-Jørgensen 2000). It moves into small streams (Poulsen and Valbo-Jørgensen 2000) and inundated areas during high water periods and returns to rivers as water levels decline (Rainboth 1996). Spawning: Eggs are reported to occur from February to July throughout the distribution range. There is a strong peak around May-June, indicating that spawning takes place during this period (Poulsen and Valbo-Jørgensen 2000); In the Songkram River, the species spawns at the onset of the floods, and is believed to spawn on, or near floodplain areas (Vidthayanon 2001); Spawning period is from March to July, the eggs are grey-green and are semibouyant, spawning takes place in flooded areas with water plants or algae; after hatching, larvae live and forage near the hatching area but will move to small canals and then to large rivers (Khamtorn 1999); A brood fish of about 130 g and 19.5 cm in length spawn 60,000-80,000 eggs (Prugsachok et al. 1989). Distribution: Found in flowing waters of all sizes in most rivers of the Mekong Basin (Rainboth 1996); Larvae/juveniles recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002); Reported from the Xe Bangfai Basin (Kottelat 1989), Feeding: primarily a mollusc eater (Rainboth 1996, Mills and Vever 1989), but also feeds on benthic insect larvae (Rainboth 1996, Mills and Vever 1989, Bardach 1959, Khamtorn 1999, Prugsachok et al. 1989), worms (Rainboth 1996, Mills and Vever 1989, Prugsachok et al. 1989); crustaceans (Bardach 1959, Mills and Vever 1989), zooplankton (Khamtorn 1999), and scavenges (Khamtorn 1999, Prugsachok et al. 1989).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium

Botia morleti (Rainboth W.)

IDENTIFICATION - Family: Cobitidae (Loaches)
IDENTIFICATION - Species name: Botia morleti
IDENTIFICATION - Author: Tirant, 1885
IDENTIFICATION - Name in Khmer: ˚ reproduce˚
IDENTIFICATION - Name in Khmer (roman): Kanhchrouk
BIOLOGY - Length at maturity (cm): 7
BIOLOGY - Food: Mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Likely (present in Laos and in the delta)
ECOLOGY - All MFD information: Migration: probably moves into temporarily flooded areas during high water levels. Young of the year return to rivers in November and December (Rainboth 1996).
**Datnioides polota** (JJPhoto)

**IDENTIFICATION - Family:** Coiidae  
**IDENTIFICATION - Species name:** Datnioides polota  
**IDENTIFICATION - Author:** Hamilton, 1822  
**IDENTIFICATION - Remark:** Formerly Datnioides quadrifasciatus  
**IDENTIFICATION - Name in English:** Four-barred tigerfish  
**BIOLOGY - Max. standard length (cm):** 30  
**BIOLOGY - Length at maturity (cm):** 18.5  
**BIOLOGY - Food:** Mainly animals  
**ECOLOGY - Tonle Sap distribution:** possible (upper distribution range = Phnom Penh)  
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Benthopelagic  
**ECOLOGY - Resilience:** No information

**Cynoglossus cynoglossus** (FAO)

**IDENTIFICATION - Family:** Cynoglossidae  
**IDENTIFICATION - Species name:** Cynoglossus cynoglossus  
**IDENTIFICATION - Author:** Hamilton, 1822  
**IDENTIFICATION - Name in English:** Bengal tongue sole  
**BIOLOGY - Max. total length (cm):** 20  
**BIOLOGY - Length at maturity (cm):** 12.9  
**BIOLOGY - Food:** Zoobenthos mainly animals  
**ECOLOGY - Tonle Sap distribution:** Lim et al. 1999  
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Demersal  
**ECOLOGY - Resilience:** Medium

**Cynoglossus feldmanni** (Chavalit Vidthayanon)

**IDENTIFICATION - Family:** Cynoglossidae (Tonguefishes)  
**IDENTIFICATION - Species name:** Cynoglossus feldmanni  
**IDENTIFICATION - Author:** Bleeker, 1853  
**IDENTIFICATION - Name in Khmer:** ពុជប្រមាណរង្គរឃ្មី
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<th>FAMILY</th>
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<td>Ng and Kottelat, 2004</td>
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</table>

### Biology
- **Max. total length (cm):** 31
- **Max. standard length (cm):** 25
- **Length at maturity (cm):** 15.7
- **Food:** zoobenthos mainly animals

### Ecology vs. Hydrology
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

### Reproduction
- Date of spawning (% respondents): May 14.3%, Jun 57.1%, Jun-Jul 28.6%
- Breeds in reservoirs: No info on breeding in reservoirs

### Ecosystem
- **Tonle Sap distribution:** Kottelat, 1985

### Status
- Native

### Habitat
- Demersal

### Resilience
- Medium

### Guild
- White fish guild (% respondents): 100

### Migration Type
- Only seems to display Longitudinal migrations.

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Cynoglossus microlepis (Chavalit Vidthayanon)
**Cirrhinus caudimaculatus** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Cyprinidae  
**IDENTIFICATION** - Species name: *Cirrhinus caudimaculatus*  
**IDENTIFICATION** - Author: Fowler, 1934  
**IDENTIFICATION** - Remark: Formerly Henicorhynchus caudimaculatus  
**IDENTIFICATION** - Name in Khmer (roman): Riel thmor  
**BIOLOGY** - Max. total length (cm): 13  
**BIOLOGY** - Length at maturity (cm): 8.8  
**BIOLOGY** - Food: plants, plants/detritus + animals  
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information  
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information  
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs  
**ECOLOGY** - Tonle Sap distribution: Most likely to occur in Cambodian rivers that flow into the western end of the Great Lake (Rainboth, 1996)  
**ECOLOGY** - All MFD information: Migration: Migrations up small rivers and streams and out onto floodplains are well-known in Thailand. Returns to permanent waters from October with migration peaking in November and December (Rainboth 1996). Spawning: 0. Distribution: Most likely to occur in Cambodian rivers that flow into the western end of the Great Lake (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Its diet consisting of phytoplankton, periphyton, bottom algae, detritus, and some zooplankton (Rainboth 1996).  
**ECOLOGY** - Status: Native  
**ECOLOGY** - Habitat: Benthopelagic  
**ECOLOGY** - Resilience: High

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**Hypophthalmichthys molitrix** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Cyprinidae  
**IDENTIFICATION** - Species name: *Hypophthalmichthys molitrix*  
**IDENTIFICATION** - Author: Valenciennes, 1944  
**IDENTIFICATION** - Name in Khmer: ឈូធាមួលួរ  
**IDENTIFICATION** - Name in Khmer (roman): Karb sor  
**IDENTIFICATION** - Name in English: Silver carp  
**BIOLOGY** - Max. total length (cm): 10.5  
**BIOLOGY** - Length at maturity (cm): 61.9  
**BIOLOGY** - Food: plants, mainly plants/detritus  
**ECOLOGY** - Tonle Sap distribution: MFD occurrence map  
**ECOLOGY** - Status: No information  
**ECOLOGY** - Habitat: Benthopelagic  
**ECOLOGY** - Resilience: Medium
**Poropuntius malcolmi** (Warren, T.)

**IDENTIFICATION** - Family: **Cyprinidae**  
**IDENTIFICATION** - Species name: **Poropuntius malcolmi**  
**IDENTIFICATION** - Author: Smith, 1945  
**IDENTIFICATION** - Remark: Formerly Hypsibarbus malcolmi  
**IDENTIFICATION** - Name in English: Goldfin tinfoil barb  
**BIOLOGY** - Max. standard length (cm): 50  
**BIOLOGY** - Length at maturity (cm): 29  
**BIOLOGY** - Food: Mainly animals  
**ECOLOGY** - Tonle Sap distribution: MFD occurrence map  
**ECOLOGY** - Status: No information  
**ECOLOGY** - Habitat: Benthopelagic  
**ECOLOGY** - Resilience: Low

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**Albulichthys albuloides** (Rainboth W.)

**IDENTIFICATION** - Family: **Cyprinidae** (Minnows or carps)  
**IDENTIFICATION** - Species name: **Albulichthys albuloides**  
**IDENTIFICATION** - Author: Bleeker, 1855  
**IDENTIFICATION** - Name in Khmer: ឈឺេីក្ីសុីយ  
**IDENTIFICATION** - Name in Khmer (roman): Chkaok tytuy  
**BIOLOGY** - Max. standard length (cm): 30  
**BIOLOGY** - Length at maturity (cm): 18.5  
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information  
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information  
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs  
**ECOLOGY - Tonle Sap distribution: MFD occurrence map  
**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959). Spawning: Spawns from April to July in Cambodia (Bardach 1959). Distribution: Adults are common in the Great Lake and are seen sporadically downstream. Juveniles may be found as far downstream as the upper tidal zone of the Mekong Delta in Viet Nam (Rainboth 1996). Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Omnivorous, with a preference for vegetal matter (Rainboth 1996, Lim et al. 1999).  
**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.  
**ECOLOGY** - Status: Native  
**ECOLOGY** - Habitat: Benthopelagic  
**ECOLOGY** - Resilience: Low

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**Amblyrhynchichthys truncatus** (Warren, T.)
| IDENTIFICATION - Family: **Cyprinidae** (Minnows or carps) |
| IDENTIFICATION - Species name: **Amblyrhynchichthys truncatus** |
| IDENTIFICATION - Author: Bleeker, 1851 |
| IDENTIFICATION - Name in Khmer: កម្រួតសវោត្តិ | IDENTIFICATION - Name in Khmer (roman): Kambot chramos |
| IOLOGY - Max. total length (cm): 49 |
| BIOLOGY - Max. standard length (cm): 40 |
| BIOLOGY - Length at maturity (cm): 23.8 |
| BIOLOGY - Food: plants/plants/detritus+animals |
| BIOLOGY - Notes: It is a a benthepacitic riverine species, but is also found in standing water bodies. It is medium to long-lived (Warren 2000). |
| ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information |
| ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information |
| REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs |
| ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which moves into inundated forests during the flood season and returns to the rivers in October and November as floodwaters recede (Rainboth 1996) in November-December (Baird et al. 1999). It migrates up from Cambodia to Laos in January and February, and it returns to Cambodia in June-July (Baird et al. 1999). Spawning: pelagic spawner, producing buoyant or semi-buoyant eggs; Spawns in floodplains and mainstreams of large rivers during the wet-season (Warren 2000) in July (Baird et al. 1999). Distribution: Mainstream and tributaries in Lao PDR, Tonle Sap in Cambodia (Baird et al. 1999). Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Feeds on algae (Lieng et al. 1995, Baird et al. 1999); detritus (Baird and Phylavanh 1999), periphyton, phytoplankton, benthic algae, small zooplankton (Rainboth 1996, 10616, Warren 2000) and small insects (Baird et al. 1999). |
| ECOLOGY - Migration type: Only seems to display Longitudinal migrations. |
| ECOLOGY - Status: Native |
| ECOLOGY - Habitat: Benthopelagic |
| ECOLOGY - Resilience: Low |

**Balantiocheilos melanopterus** (Chavalit Vidthayanon)

| IDENTIFICATION - Family: **Cyprinidae** (Minnows or carps) |
| IDENTIFICATION - Species name: **Balantiocheilos melanopterus** |
| IDENTIFICATION - Author: Bleeker, 1851 |
| IDENTIFICATION - Name in Khmer: កោត្តស្រុង | IDENTIFICATION - Name in Khmer (roman): Keat srang |
| IDENTIFICATION - Name in English: Tricolor sharkminnow |
| BIOLOGY - Max. total length (cm): 43 |
| BIOLOGY - Max. standard length (cm): 35 |
| BIOLOGY - Length at maturity (cm): 21.2 |
| BIOLOGY - Food: plants/detritus+animals |
| BIOLOGY - Notes: Generally intolerant of habitat alterations, it has completely disappeared in Thailand and should receive special listing by the IUCN (Rainboth 1996). |
| ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information |
| ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information |
| REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs |
| ECOLOGY - Tonle Sap distribution: Heemstra, and Smith, 1986 |
| ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which moves into flooded forests during high water levels and returns to the rivers in December (Rainboth 1996). Spawning: The fish reaches adult size at 35 cm (Bardach 1959). Distribution: It occurred regularly in rivers downstream from the Great Lake in the 1950s, but the species has become rare in recent years, perhaps due to human activities. It now occurs in a few rivers flowing through relatively...

ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

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**Barbichthys nitidus** (Baird, I.G.)

<table>
<thead>
<tr>
<th>IDENTIFICATION - Family:</th>
<th>Cyprinidae (Minnows or carps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDENTIFICATION - Species name:</td>
<td><em>Barbichthys nitidus</em></td>
</tr>
<tr>
<td>IDENTIFICATION - Author:</td>
<td>Sauvage, 1878</td>
</tr>
<tr>
<td>BIOLOGY - Max. total length (cm):</td>
<td>31</td>
</tr>
<tr>
<td>BIOLOGY - Max. standard length (cm):</td>
<td>25</td>
</tr>
<tr>
<td>BIOLOGY - Length at maturity (cm):</td>
<td>15.7</td>
</tr>
<tr>
<td>BIOLOGY - Food:</td>
<td>Mainly plants/detritus</td>
</tr>
<tr>
<td>BIOLOGY - Notes:</td>
<td>Not known to persist in impoundments (Rainboth 1996).</td>
</tr>
<tr>
<td>ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:</td>
<td>no information</td>
</tr>
<tr>
<td>ECOLOGY vs. HYDROLOGY - Water level as migration trigger:</td>
<td>no information</td>
</tr>
<tr>
<td>REPRODUCTION - Breeds in reservoirs:</td>
<td>No info on breeding in reservoirs</td>
</tr>
<tr>
<td>ECOLOGY - Tonle Sap distribution:</td>
<td>Rainboth, 1996</td>
</tr>
<tr>
<td>ECOLOGY - All MFD information:</td>
<td>Migration: A white fish species (Bardach 1959); Migrates up small streams, and canals to ponds, swamps and floodplains in the rain season to spawn (Baird et al. 1999). Spawning: 0 . Distribution: Found in large and medium-sized rivers (Rainboth 1996, Baird et al. 1999) in Laos, Thailand, Cambodia and Viet Nam (Kottelat 2001). In Tonle Sap it is seen from October through December as flood waters recede, but fishermen now report it as rare (Rainboth 1996); Juveniles found in the Songkhram river (Termvichakorn 2001). Feeding: Feeds on algae and phytoplankton (Rainboth 1996).</td>
</tr>
<tr>
<td>ECOLOGY - Status:</td>
<td>Native</td>
</tr>
<tr>
<td>ECOLOGY - Habitat:</td>
<td>Benthopelagic</td>
</tr>
<tr>
<td>ECOLOGY - Resilience:</td>
<td>Medium</td>
</tr>
</tbody>
</table>

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**Barbonymus altus** (Warren, T.)

<table>
<thead>
<tr>
<th>IDENTIFICATION - Family:</th>
<th>Cyprinidae (Minnows or carps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDENTIFICATION - Species name:</td>
<td><em>Barbonymus altus</em></td>
</tr>
<tr>
<td>IDENTIFICATION - Author:</td>
<td>Günther, 1868</td>
</tr>
<tr>
<td>IDENTIFICATION - Name in Khmer:</td>
<td>កំ្តេ្ខុករ្ខ្ម</td>
</tr>
<tr>
<td>IDENTIFICATION - Name in English:</td>
<td>Red tailed tinfoil</td>
</tr>
<tr>
<td>BIOLOGY - Max. total length (cm):</td>
<td>25</td>
</tr>
<tr>
<td>BIOLOGY - Max. standard length (cm):</td>
<td>20</td>
</tr>
<tr>
<td>BIOLOGY - Length at maturity (cm):</td>
<td>12.9</td>
</tr>
<tr>
<td>BIOLOGY - Food:</td>
<td>plants mainly plants/detritus</td>
</tr>
<tr>
<td>BIOLOGY - Notes:</td>
<td>It is semi-pelagic and appears to thrive in standing waters, but it has a requirement to return to flowing water to spawn. It is medium to long-lived (Warren 2000).</td>
</tr>
</tbody>
</table>
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); Undertakes annual upstream and downstream non-reproductive and reproductive migrations (Roberts 1993, Warren 2000); Migrates up from Cambodia to Southern Lao PDR in January-February, and migrate back to Cambodia in May-June (Baird et al. 1999); Colonises inundated forest from where the adults migrate back to the river in October. Young of the year follow in the next few months as water levels recede (Rainboth 1996). Spawning: Bardach (1959) mentioned that it becomes adult at 25 cm (Bardach 1959), however, recent research has shown that it matures already at a length of 13 cm (Duangsawasdi et al. 1989, Duangsawasdi et al. 1989, Leelapatra et al. 2000); Fish of body length of 19-21 cm may carry 24,673 eggs (Duangsawasdi et al. 1989, Duangsawasdi et al. 1989). It spawns in July-August (Baird et al. 1999); However the species appears to have a protracted spawning season (Warren 2000) with a peak in the late rainy season in September (Duangsawasdi et al. 1989); It spawns pelagically in floodplains and flooded forest (Warren 2000), or among flooded vegetation (Baird et al. 1999); and has buoyant or semi-buoyant eggs, with an initial diameter of 0.74 mm (Duangsawasdi et al. 1989), which hatch 12 hours after fertilization at 28°C (Vongsongsang 1999). Although the species appears to thrive in standing waters, it has a requirement to return to flowing water to spawn (Warren 2000). . Distribution: Found basin wide in the mainstream of the Lower Mekong (Pantulu 1986, Kottelat 2001); also reported from the Xe Bangfai basin (Kottelat 1998); Larvae/juveniles have been recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on a wide variety of animal and plant matter (Rainboth 1996), gastropod snails, earthworms, shrimp, and fine green algae (Baird and Phylavanh 1999), filamentous algae (Warren 2000), detritus (Vongsongsang 1999, Warren 2000), and terrestrial fruits and plants falling in the water (Baird et al. 1999).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

Barbonymus gonionotus (Warren, T.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Barbonymus gonionotus
IDENTIFICATION - Author: Bleeker, 1850
IDENTIFICATION - Name in Khmer: ឈ្មោះព្រះពួក
IDENTIFICATION - Name in Khmer (roman): Chpin prak
IDENTIFICATION - Name in English: Java barb
BIOLOGY - Max. total length (cm): 40.5
BIOLOGY - Length at maturity (cm): 24.1
BIOLOGY - Food: plants plants/detritus+animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A migratory species (Bardach 1959, Welcomme 1988); However it is not considered to be a long-distance migratory species. Most fishers report that it is a local migrant migrating from the Mekong up into small streams and canals and onto flooded areas during the rainy season, and back again when the water recedes (Poulsen and Valbo-Jørgensen 2000); during the rainy season it migrates upstream Sekong, Sesan and Srepok (Baird et al. 1999). Spawning: It is an opportunistic spawner, in which developed eggs were
It spawns in the rainy season between May and June (Janesirisak 1971), May to July (Sangkagul and Srisuwantrat 1973) or July to August (Baird et al. 1999) depending on environmental factors such as rainfall and water current spawning season (Janesirisak 1971). It appears that spawning is highly synchronised with the occurrence of rainfall (Sukumasavin and Leelapatra 1994). The species normally reach maturity after one year (Anon 1997), but it can reach this stage only eight (Paohorm 1969) or ten (Khanh et al. 1999.) months old with a body length of 8-8.5 cm, and a weight of 9-20 g (Paohorm 1969, Khanh et al. 1999.). The eggs are semi-buoyant (Leelapatra et al. 2000, Khanh et al. 1999.), with an initial size of 0.5-0.8 mm. The maximum size after water absorption is 2.5-3.5 mm (Leelapatra et al. 2000, Khanh et al. 1999.); Hatching occurs 12 hr after fertilization at 25ºC (Leelapatra et al. 2000, Khanh et al. 1999.); Total length of the larva at hatching time is 2-3 mm (Leelapatra et al. 2000, Khanh et al. 1999.). Distribution: Occurs throughout the whole freshwater stretch on the Mekong, from the delta around the saline intrusion zone to at least Chiang Khong and Bokeo, in Thailand and Lao PDR respectively (Poulsen and Valbo-Jørgensen 2000); it is also found basin wide in tributaries (Pantulu et al. 1996); for example recorded from the Xe Bangfai basin (Kottelat 1998); Larvae/juveniles have been sampled from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Omnivorous (Rainboth 1996): Feeds on plant matter and invertebrates (Mohsin and Ambak 1983); plants, insects and detritus (Yap 1988); Larvae to 3 inches fingerlings are plankton feeders, and 3 inches to adults are herbivorous (Leelapatra et al. 2000); Fish smaller than 10 cm feed on detritus, aquatic plants and algae; Fish bigger than 10 cm feed more on plants, organic matter and algae (Anon 1997). ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations. ECOLOGY - Status: Native ECOLOGY - Habitat: Benthopelagic ECOLOGY - Resilience: Medium

Barbonyx musk fish (Barbonyx schwanenfeldii) (Baird, I.G.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Barbonyx schwanenfeldii
IDENTIFICATION - Author: Bleeker, 1853
IDENTIFICATION - Name in Khmer: ឈុតូលពណ៌សុី
IDENTIFICATION - Name in Khmer (roman): Kaheu leung
IDENTIFICATION - Name in English: Tinfoil barb
BIOLOGY - Max. total length (cm): 43
BIOLOGY - Max. standard length (cm): 35
BIOLOGY - Length at maturity (cm): 21.2
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: A temperature range of 20.4-33.7C has been recorded for this species (6129).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, M., 1985
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: High
**Barilius pulchellus** *(CAFS)*

**IDENTIFICATION**
- **Family:** *Cyprinidae* (Minnows or carps)
- **Species name:** *Barilius pulchellus*
- **Author:** Smith, 1931

**BIOLOGY**
- **Max. total length (cm):** 14
- **Max. standard length (cm):** 11
- **Length at maturity (cm):** 7.6
- **Food:** zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**REPRODUCTION**
- Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY**
- Tonle Sap distribution: Lim et al. 1999

**ECOLOGY**
- Status: Native
- Habitat: Benthopelagic
- Resilience: High

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**Catlocarpio siamensis** *(IGFA)*

**IDENTIFICATION**
- **Family:** *Cyprinidae* (Minnows or carps)
- **Species name:** *Catlocarpio siamensis*
- **Author:** Boulenger, 1898
- **Name in Khmer:** រត្តូក្រឡាចេះ(Kulreang)
- **Name in English:** Giant barb

**BIOLOGY**
- **Max. total length (cm):** 300
- **Length at maturity (cm):** 141.4
- **Food:** plants mainly plants/detritus

**ECOLOGY vs. HYDROLOGY**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**REPRODUCTION**
- Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY**
- Tonle Sap distribution: Hill, and Hill, 1994; Roberts and Warren, 1994
- All MFD information: Migration: A white fish species (Bardach 1959); Juveniles enter inundated areas during the rainy season (Baird and Phylavanh 1999). Spawning: Eggs are seen from January to August, but most fishers report eggs from May to July (Poulsen and Valbo-Jergensen 2000); It spawns in the rainy season between June to July (Baird et al. 1999) or July to August (Leelapatra et al. 2000) in swamps which receives water from the river (Smith 1945); and two to four centimetres long juveniles appears from July to November (Poulsen and Valbo-Jergensen 2000). The giant barb reaches maturity at an age of 7 years, and a body weight of 9 kg (Sukumasavin 1996.); A 60 kg female sheds about 400,000 (Tangtrongpios et al. 1986) semi-buoyant eggs, that are dark brown in colour and has an initial size of 1 mm expanding to 3 mm

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after water absorption (Leelapatra et al. 2000); Hatching occurs 20-22 hr after fertilization at 28-29°C; Larva length at hatching is about 6 mm (Unakornsawat and Aupakaratna 1996). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986); Known from large rivers and seasonally in canals and floodplains. It is now almost never seen in the Great Lake, and has become quite rare throughout Cambodia (Rainboth 1996); It has been recorded from Se Kong, Xe Lamphao, Xe Khampor and Xe Pian (Baird et al. 1999). The species seem to be encountered regularly at several localities from Nong Khai and further north up to Chiang Saen, both on the Thai and the Lao side of the river. It is also recorded at stations in Nakhon Phanom and Ubon Ratchathani. It is more common in Cambodia and Viet Nam, where it is encountered all the year at many stations (Poulson and Valbo-Jørgensen 2000). Feeding: Diet consists mainly of algae (Rainboth 1996, Leelapatra et al. 2000, Baird et al. 1999), phytoplankton (Rainboth 1996, Leelapatra et al. 2000), and during the high water season fruits of terrestrial plants (Rainboth 1996, Leelapatra et al. 2000, Baird and Phylavanh 1999, Baird et al. 1999) and vegetation (Baird and Phylavanh 1999, Baird et al. 1999); It is also known to eat fish (Baird and Phylavanh 1999). ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

*Cirrhinus jullieni* (Baird, I.G.)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: *Cirrhinus jullieni*
**IDENTIFICATION** - Author: Sauvage, 1878
**IDENTIFICATION** - Name in Khmer: ខ្លៀកក្រូ
**IDENTIFICATION** - Name in Khmer (roman): Phkar ko
**BIOLOGY** - Max. total length (cm): 25
**BIOLOGY** - Max. standard length (cm): 20
**BIOLOGY** - Length at maturity (cm): 12.9
**BIOLOGY** - Food: Mainly plants/detritus
**BIOLOGY** - Notes: This is a diurnal species (NIFI 1993).
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: Can breed in reservoirs
**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985
**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959); Migrates up the Mekong River from Cambodia to southern Lao PDR in January-February (Baird et al. 1999). Spawning: The spawning season is between April and June (Duangsawasdi et al. 1989.) or April and September (Watanadirokul K et al. 1987) depending on environmental factors such as rainfall and water current (Watanadirokul K et al. 1987); Bardach (1959) suggested that it spawns in lakes (Bardach 1959), It has been found however that fishes in some reservoirs migrate upstream the inflowing rivers for spawning (Leelapatra et al. 2000). Length at maturity is 9-13 cm. (Duangsawasdi et al. 1989., 1036798, Duangsawasdi et al. 1989.); Fish with body length of 12-21 cm are found to have 23,550-117,000 eggs (Watanadirokul K et al. 1987, Duangsawasdi et al. 1989.); The eggs are semi-buoyant, and hatching occurs 13 hr after fertilization at 27°C; The total length of the larvae at hatching is about 2 mm (Leelapatra et al. 2000). Distribution: Found basin wide in the mainstream of the Lower Mekong (Pantulu 1986); Found only downstream Khone Falls (Kottelat 2001). Feeding: Feeds on algae, detritus, occasional benthic invertebrates (Rainboth 1996, Leelapatra et al. 2000, Baird et al. 1999); phytoplankton and plant litter (NIFI 1993).
**ECOLOGY** - Migration type: Only seems to display Longitudinal migrations.
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium
IDENTIFICATION - Family: *Cyprinidae* (Minnows or carps)
IDENTIFICATION - Species name: *Cirrhinus microlepis*
IDENTIFICATION - Author: Sauvage, 1878
IDENTIFICATION - Name in Khmer: រុីឲ្យឺប៊ឺកកញ្ញ expulsion
IDENTIFICATION - Name in Khmer (roman): Prul / Krolang
IDENTIFICATION - Name in English: Small scale mud carp

**BIOLOGY**
- Max. total length (cm): 80
- Max. standard length (cm): 65
- Length at maturity (cm): 36.6
- Food: plants mainly plants/detritus
- Notes: It is a long-lived, benthopelagic, riverine species (Warren 2000), which is not known to persist in impoundments (Rainboth 1996); It is a fast swimmer, and a nervous and lively fish, which will jump many feet into the air in order to clear obstacles. The fish schools appear in certain definite periods and are captured in large amounts in only a few locations; There are reports that this fish shows four year cycles of abundance (Bardach 1959).

**ECOLOGY vs. HYDROLOGY**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information
- Breeds in reservoirs: No info on breeding in reservoirs
- Tonle Sap distribution: Hill, and Hill, 1994; Rainboth, 1996
- All MFD information: Migration: A white fish species (Bardach 1959); Above the Khone Falls it migrates downstream in June (Singanouvong et al. 1996, Bouakhamvongsa et al. 1994) or July and August (Warren 2000) to spawn at a site 48-52 km south of Pakse (Bouakhamvongsa et al. 1994, Warren 2000) possibly from as far upstream as Khammuan (Bouakhamvongsa et al. 1994); After spawning, adults and juveniles move downstream and out onto floodplains where they stay during the flood season, when the water begins to recede at the end of the flood season, the fishes move back into rivers (Poulson and Valbo-Jørgensen 2000); In Cambodia the fish moves into the Tonle Sap when the water level increases in order to feed in the rich feeding grounds of the inundated forests (Bardach 1959), at the descent of the waters they leave the Great Lake (Rainboth 1996, Bardach 1959) and the Tonle Sap regions in waves and migrate up the Mekong, like in the case with all Cambodian migrating fishes this coincides with the waxing moon, that is, it occurs between the fifth and the fifteenth day of the Vietnamese calendar (Bardach 1959); During late December or early January large individuals (2-3 kg), and some smaller individuals begin arriving in the Mekong mainstream of southern Lao PDR on their upstream dry-season migration. They appear to congregate over shallow, rocky ground where they graze on areas of filamentous algae developing on rock surfaces. Towards the middle of the dry-season, and particularly around the time of the new moon phase of the first and second lunar cycles after the winter solstice, large numbers of small individuals begin appearing in fish landings. The exact purpose of this upstream, dry-season movement is unknown but likely involves dispersal and feeding (Warren et al. Scott and Crossman 1973). Spawning: It spawns in the Mekong mainstream (Warren 2000, Poulson and Valbo-Jørgensen 2000, Bardach 1959); for example in the rapids between Sambor to Khone Falls (Bardach 1959), and at Phatomphone, 48 km south of Pakse, where they are caught in considerable numbers in full spawning condition (Warren 2000). It spawns during the wet-season (Warren 2000), in May-June (Baird et al. 1999); June to August (Kantejit 1979, Poulson and Valbo-Jørgensen 2000); or June to July (Bardach 1959); It is a pelagic spawner and the eggs are buoyant or semi-buoyant (Warren 2000, Pinyoying 1970) and drift downstream and out onto flooded areas (Poulson and Valbo-Jørgensen 2000). It is sexually mature when 17 cm long (Smith 1945); Females of 47-65 cm total length and weighing 1.8-2.9 kg may bear 131,290-271,040 eggs (Pinyoying 1970, Kantejit 1979); The diameter of the egg is about 2 mm (Kantejit 1979). Distribution: Found basin wide in the mainstream of the Lower Mekong (Pantulu 1986); from the Delta to Chiang Saen (Poulson and Valbo-Jørgensen 2000); also reported from the Xe Bangfai (Kottelat 1998), Mun (Leelapatra et al. 2000), Se Kong, Xe Pian, Xe Kamanh, and Xe Sou (Baird et al. 1999); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). There seem to be at least two
populations: One population from Loei to Chiang Saen and another from Boulikhamxay in the North to the Mekong Delta (Poulsen and Valbo-Jørgensen 2000). Feeding: Feeds on phytoplankton (Rainboth 1996, Pothipituk 1970), plant fragments (Bardach 1959, Warren 2000, Baird et al. 1999) and detritus (Warren 2000); It grazes on filamentous algae (Warren 2000, Bardach 1959, Baird and Phylavanh 1999, Singanouvong et al. 1996) especially during the clear water dry season (Singanouvong et al. 1996); With the flood it moves into the flooded forest where it feeds on leaves (Rainboth 1996, Baird and Phylavanh 1999, Baird et al. 1999) wood and lichens (Baird et al. 1999); Although it is mainly a herbivorous fish (Smith 1945), it also feeds on zooplankton (Pothipituk 1970) and insects (Rainboth 1996, Warren 2000, Baird et al. 1999).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

**Cirrhinus molitorella** (IFReDI collection)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: *Cirrhinus molitorella*
IDENTIFICATION - Author: Valenciennes, 1844
IDENTIFICATION - Remark: Formerly *Cirrhinus prosemion*
IDENTIFICATION - Name in Khmer: រត្សូបាស
IDENTIFICATION - Name in Khmer (roman): Phkar ko
IDENTIFICATION - Name in English: Mud carp
BIOLOGY - Max. total length (cm): 55
BIOLOGY - Length at maturity (cm): 31.6
BIOLOGY - Food: plants mainly plants/detritus
BIOLOGY - Notes: It is a riverine benthopelagic species (Warren 2000), which is not known to persist in impoundments (Rainboth 1996). It is medium to long-lived (Warren 2000).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: Can breed in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: Wild stocks are strongly migratory, while the cultivated stocks probably have lost the migratory behaviour (Roberts 1997); Engages in upstream dry-season migrations in the Mekong mainstream of southern Lao PDR (Baird et al. 1999) in January-February (Baird et al. 1999) and either enters tributaries, or remains in the Mekong mainstream for spawning during the wet-season months (Warren 2000), also known to migrate into floodplains (Baird et al. 1999). Spawning: It spawns in floodplains and mainstreams of large rivers during wet-season (Warren 2000, Baird et al. 1999); It is a pelagic spawner, which produces buoyant or semi-buoyant eggs (Warren 2000). Distribution: Occurs in Middle and Upper Mekong (Rainboth 1996); has also been reported from the Nam Theun, Xe Bangfai (Kottelat 1998), Nam Sekong and tributaries, Xe Kamanh, Xe Pian and Xe Sou (Baird et al. 1999). Feeding: Feeds on algae (Singanouvong et al. 1996, Baird and Phylavanh 1999, Warren 2000) including filamentous algae, periphyton and also other plant material and detritus (Warren 2000); Juveniles feed on aquatic and terrestrial plants (Dudgeon 1983); Lim et al. (1999) however postulated that it is omnivorous (Lim et al. 1999).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low
Cosmochilus harmandi (Warren, T.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Cosmochilus harmandi
IDENTIFICATION - Author: Sauvage, 1878
IDENTIFICATION - Name in Khmer: ក្រុមហ៊ុនដូរ
IDENTIFICATION - Name in Khmer (roman): Chhkok Kda / Kampoul Bai
BIOLOGY - Max. total length (cm): 100
BIOLOGY - Length at maturity (cm): 53.5
BIOLOGY - Food: plants mainly plants/detritus
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in rivers (% respondents): 97.5
REPRODUCTION - Spawns in streams / inlets (% respondents): 2.5
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Hill and Hill, 1994
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); Found in the clear waters of the main channels during the dry season and moves to floodplains and riparian forests during the rainy season. Returns to the Tonle Sap fairly early, usually during October (Rainboth 1996); Migrates upstream for spawning in June-July (Baird et al. 1999). Spawning: A female of 5.2 kg was found to be full of eggs in August (Baird and Phylavanh 1999). Distribution: Found basin wide in the Mekong mainstream (Pantulu 1986, Kottelat 2001); The species is relatively common in the upland river habitat of the Middle Mekong until water levels begin to rise (Rainboth 1996). Feeding: Feeds on plant matter (Lim et al. 1999), algae (Baird and Phylavanh 1999, Baird et al. 1999), eggs, detritus, earthworms, roots, bark (Baird and Phylavanh 1999), small gastropod snails (Baird and Phylavanh 1999, Baird et al. 1999) and zooplankton (Baird et al. 1999).
ECOLOGY - Migration type: Only seems to display Longitudinal migrations.
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low
GUILD - White fish guild (% respondents): 100

Crossocheilus reticulatus (Bui, H.M.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Crossocheilus reticulatus
IDENTIFICATION - Author: Fowler, 1934
IDENTIFICATION - Name in Khmer: ក្រុមហ៊ុនដូរ
IDENTIFICATION - Name in Khmer (roman): Changva chunchuk
BIOLOGY - Max. total length (cm): 21
BIOLOGY - Max. standard length (cm): 17
BIOLOGY - Length at maturity (cm): 11.2
BIOLOGY - Food: plants/detritus+animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: Migrates in schools from Cambodia to southern Laos in December to January. The fish species migrates into tributaries (Baird et al. 1999) and floodplains during high water (Rainboth 1996, Baird et al. 1999) in June-July and migrate back to the mainstream at the end of the flood season (Baird et al. 1999). Spawning: Spawns in floodplains in June to July (Baird et al. 1999). Distribution: Mekong Basin in Laos, Yunnan, Thailand, Cambodia and Viet Nam (Kottelat 2001); Recorded from the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on algae, periphyton, phytoplankton, and some zooplankton (Rainboth 1996).

ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

**Cyclocheilichthys apogon** (Rainboth W.)

**IDENTIFICATION - Family:** Cyprinidae (Minnows or carps)
**IDENTIFICATION - Species name:** Cyclocheilichthys apogon
**IDENTIFICATION - Author:** Valenciennes, 1842
**IDENTIFICATION - Name in Khmer:** Sraka kdam
**IDENTIFICATION - Name in English:** Beardless barb

**BIOLOGY - Max. total length (cm):** 25
**BIOLOGY - Length at maturity (cm):** 17.7
**BIOLOGY - Food:** zoobenthos plants/detritus+animals

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Breeds in reservoirs:** Can breed in reservoirs
**ECOLOGY - Tonle Sap distribution:** Rainboth, 1996

ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which moves into flooded forests and also non-forested floodplains (Rainboth 1996); Migrates upstream to spawn in August-September (Baird et al. 1999). Spawning: It is known to breed late in the high-water season from September to October as water levels peak and begin to decline (Rainboth 1996, Bardach 1959); However in reservoirs, spawning may occur all year round with peaks during December to January and July to August (Sukomon 1970); In reservoirs it may spawn at the inflow of rivers (Dumrongtripob et al. 1997). Females reach maturity at 10.3 cm while males are mature at 9.7 cm; The average fecundity in 150 mm fish is 3,943 eggs. The smallest fry is 17 mm total length and 0.33 g. (Sukomon 1970); Fish of 10.4-17.7 cm long have about 1,157–11,328 eggs of 0.8-1.1 mm diameter (Krachangdara 1994). Distribution: A common species in the Mekong (Rainboth 1996); and found basin wide in tributaries of the Lower Basin (Pantulu 1986). Feeding: Feeds on planktonic crustaceans (Bardach 1959, Leelapatra et al. 2000, Rainboth 1996), mainly Cladocera and a few Copepoda; It also feeds on diatoms, green algae, blue green algae and detritus (Sukomon 1970); Both juveniles and adults feed on zoobenthos, and insects (Yap 1988).

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** Medium
**Cyclocheilichthys armatus** (Warren, T.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Cyclocheilichthys armatus*
**IDENTIFICATION** - Author: Valenciennes, 1842
**IDENTIFICATION** - Name in Khmer: ក្រុមក្រុង
**IDENTIFICATION** - Name in Khmer (roman): Sraka kdam
**BIOLOGY** - Max. total length (cm): 29
**BIOLOGY** - Max. standard length (cm): 23
**BIOLOGY** - Length at maturity (cm): 14.6
**BIOLOGY** - Food: zooplankton mainly animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959), which lives in rivers during the dry season and migrates to floodplains to spawn in the rainy season (Rainboth 1996). Spawning: Reproduction takes place relatively late in the high-water season during September and October (Bardach 1959, Rainboth 1996, Baird et al. 1999). Distribution: A common species in the Mekong (Rainboth 1996) which is found basin wide in the mainstream (Pantulu 1986); and also recorded in the Xe Bangfai Basin (Kottelat 1998). Feeding: Diet consists of zooplankton, small crustaceans, chironomids, and other insect larvae (Rainboth 1996).
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium

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**Cyclocheilichthys enoplus** (Baird,L.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Cyclocheilichthys enoplus*
**IDENTIFICATION** - Author: Bleeker, 1850
**IDENTIFICATION** - Name in Khmer: ក្រុងរូប
**IDENTIFICATION** - Name in Khmer (roman): Chhkaok
**BIOLOGY** - Max. total length (cm): 91
**BIOLOGY** - Max. standard length (cm): 74
**BIOLOGY** - Length at maturity (cm): 41.1
**BIOLOGY** - Food: zooplankton mainly animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: Water level variation is a migration trigger
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959); which migrates upstream as a response to the first rainfall at the end of the dry season as well as rising water levels and higher turbidity (Poulsen and Valbo-Jørgensen 2000), it returns to the rivers from October to December (Blache and Goossens 1954). Spawning: It probably spawns in the early
flood season (Poulsen and Valbo-Jørgensen 2000, Rainboth 1996) July-August (Suntornratana 2001); Females reach sexual maturity at a length of 10.3 cm, while males reach this stage at 9.7 cm, the average fecundity in 150 mm fish is 3,943 eggs (Sukomon 1970); It is a total spawner (Suntornratana 2001), which spawns on floodplains, inundated riparian forests (Rainboth 1996) or in the main river channel (Poulsen and Valbo-Jørgensen 2000), eggs and larvae are pelagic (Suntornratana 2001), and drift from the spawning ground onto flooded areas or stagnant, shallow segments of the mainstream (Poulsen and Valbo-Jørgensen 2000). Distribution: Common in the Mekong (Rainboth 1996) which is found basin wide in the mainstream (Pantulu 1986); from Bokeo in the north to the Mekong Delta in the south (Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles have been recorded from the drift in the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on snails, fine algae, earthworms, detritus (Baird and Phylavanh 1999), roots (Baird and Phylavanh 1999, Ukkatawewat 1999), insect larvae, crustaceans, and fish (Rainboth 1996), bivalves, and green algae (Ukkatawewat 1999); Young feed on zooplankton (Rainboth 1996, Ukkatawewat 1999).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Very low

Cyclocheilichthys furcatus (Warren, T.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Cyclocheilichthys furcatus
IDENTIFICATION - Author: Sontirat, 1989
IDENTIFICATION - Name in Khmer: ឈុតព្រែកកែក
IDENTIFICATION - Name in Khmer (roman): Chhkaok phleung
BIOLOGY - Max. total length (cm): 74
BIOLOGY - Max. standard length (cm): 60
BIOLOGY - Length at maturity (cm): 34.1
BIOLOGY - Food: Mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: This fish migrates up the mainstream from Cambodia to Lao in two periods first time in January-February and second time in May-July (Baird et al. 1999). Probably migrates into flooded riparian forests and smaller streams during the rainy season (Rainboth 1996). Spawning: This fish species spawning between on July-August (Baird et al. 1999). Distribution: Known from the Middle Mekong along the Thai-Lao border to the Tonle Sap (Rainboth 1996); Recorded from the confluence between the Mun and the Mekong Rivers and from the Mekong at Ban Tha Kai 21 kilometres downstream from Mukdaharn. Feeding: Feeds on juvenile insects, shrimps, crabs and fish (Baird et al. 1999).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Cyclocheilichthys heteronema (Chavalit Vidthayanon)
IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Cyclocheilichthys heteronema
IDENTIFICATION - Author: Bleeker, 1853
IDENTIFICATION - Name in Khmer: រតកក្រូភ្លឺប្រៃ
IDENTIFICATION - Name in Khmer (roman): Chhkaok pukmotbai
BIOLOGY - Max. total length (cm): 15
BIOLOGY - Max. standard length (cm): 12
BIOLOGY - Length at maturity (cm): 8.2
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Rainboth, 1996
ECOLOGY - All MFD information: Migration: Typically found in the Mekong mainstream during the dry season and moves into flooded forests during high water periods (Rainboth 1996). Spawning: Fish of approx. 12.2 cm long have eggs of 0.5-0.7 mm diameter (Krachangdara 1994). Distribution: An uncommon fish in the Mekong. Occurs just upstream from Khone Falls at the mouth of the Mun River. Also recorded from the Great Lake (Rainboth 1996). Feeding: Herbivorous (Krachangdara 1994).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: High

Cyclocheilichthys lagleri (Rainboth W.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Cyclocheilichthys lagleri
IDENTIFICATION - Author: Sontirat, 1989
IDENTIFICATION - Name in Khmer: រតកក្រូភ្លឺជាតិ
IDENTIFICATION - Name in Khmer (roman): Sraka kdam
BIOLOGY - Max. total length (cm): 19
BIOLOGY - Max. standard length (cm): 15
BIOLOGY - Length at maturity (cm): 10
BIOLOGY - Food: zoobenthos mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: A longitudinal migrant (Baird et al. 1999). Spawning: It presumably forms schools and reproduces during the rainy season as do other members of the genus (Sontirat 1985). Distribution: The species has a restricted range; it has been found in Kompong Chhnang, and Chao Doc (Sontirat 1985).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium
**Cyclocheilichthys repasson** (Martin-Smith, K.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: *Cyclocheilichthys repasson*
IDENTIFICATION - Author: Bleeker, 1853
IDENTIFICATION - Name in Khmer: តិចេញទៅសិង្គាល
IDENTIFICATION - Name in Khmer (roman): Sraka kdam

BIOLOGY - Max. total length (cm): 35
BIOLOGY - Max. standard length (cm): 28
BIOLOGY - Length at maturity (cm): 17.4
BIOLOGY - Food: Mainly animals
BIOLOGY - Notes: Known to proliferate in Mekong impoundments (Rainboth 1996).

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information

REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs

ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: Migrates upstream during the wet season (Singanouvong et al. 1996) and out into the flooded forest during the high-water season (Rainboth 1996); The migrations are both for reproduction and dispersal and feeding purposes (Singanouvong et al. 1996); The precise timing of its movements is not known (Rainboth 1996). Spawning: Spawns in the rainy season (Baird et al. 1995). Distribution: Found basin wide in tributaries of the Mekong (Pantulu 1986); it has been recorded from the Xe Bangfai and Nam Theun Basins (Kottelat 1998); Larvae/juveniles have been collected from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Diet consists primarily of insects with some aquatic macrophytes (Rainboth 1996).

ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

**Cyprinus carpio carpio** (Rainboth, W.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: *Cyprinus carpio carpio*
IDENTIFICATION - Author: Linnaeus, 1758
IDENTIFICATION - Name in Khmer: កូវ៉ែងសមាត
IDENTIFICATION - Name in Khmer (roman): Karp samanh
IDENTIFICATION - Name in English: Common carp

BIOLOGY - Max. total length (cm): 147
BIOLOGY - Max. standard length (cm): 120
BIOLOGY - Length at maturity (cm): 15
BIOLOGY - Food: zoobenthos plants/detritus+animals
BIOLOGY - Notes: Occur at a temperature range of 14-35º C (Locicero 1992); In cool waters, these fish are extremely tolerant of turbidity and stream contamination (Rainboth 1996). Feeds mainly by grubbing in sediments (Scott and Crossman 1973); whereby it often uproots aquatic plants and stir up mud (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: Discharge variation is a migration trigger
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Reproductive guild: Nonguarders: Open water/substratum egg scatterers
REPRODUCTION - Fecundity: 281936
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: Migrates upstream at the Khone Falls in May-July. As flow volumes increase rapidly in June, migratory activity intensifies and become more regular. The purpose of this migration is mainly for dispersal and feeding. Local fishers claim that the small individuals that move upstream at this time do so to feed on eggs released by native spawners (Singanouvong et al. 1996). Spawning: It spawns in spring and summer (Skelton 1993); January to June in shallow water with fairly dense of aquatic plants (Sihapitukgiat et al. 1992); June-August (Singanouvong et al. 1996); It seems to be capable of reproducing in cooler waters within the Mekong basin (Rainboth 1996); A 47 cm female about 300,000 (Hart 1973); sticky eggs, which are shed in shallow vegetation (Skelton 1993). Distribution: Recorded from Chi, Mun and Mekong Rivers (Sihapitukgiat et al. 1992); Larvae/juveniles recorded from the drift in the Bassac River in An Giang (Nguyen et al. 2002). Feeding: Consumes a wide variety of plant and animal matter (Rainboth 1996), aquatic (Bisht and Das 1981, Scott and Crossman 1973, Maitland and Campbell 1992, Singanouvong et al. 1996, Sihapitukgiat et al. 1992) and terrestrial plants (Bisht and Das 1981), bark (Baird and Phylavanh 1999), weed and tree seeds, wild rice (Scott and Crossman 1973), detritus (Maitland and Campbell 1992, Singanouvong et al. 1996, Baird and Phylavanh 1999, Jørgensen 1979), zoobenthos (Maitland and Campbell 1992, Specziar et al. 1997), benthic crustaceans (Maitland and Campbell 1992), benthic algae/weeds (Maitland and Campbell 1992), molluscs (Singanouvong et al. 1996, Specziar et al. 1997, Scott and Crossman 1973) including bivalves (Specziar et al. 1997), fish (Singanouvong et al. 1996), aquatic insects, crustaceans, annelids (Scott and Crossman 1973), and algae (Scott and Crossman 1973, Sihapitukgiat et al. 1992), zooplankton, and aquatic snails (Sihapitukgiat et al. 1992).
ECOLOGY - Migration type: Only seems to display Longitudinal migrations.
ECOLOGY - Feeds in floodplains (% respondents):
ECOLOGY - Status: Introduced
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Discherodontus Schroederi (Chavalit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Discherodontus Schroederi
IDENTIFICATION - Author: Smith, 1945
IDENTIFICATION - Name in Khmer: ឈុងារឈុងតិក
IDENTIFICATION - Name in Khmer (roman): Kantuy krohorm
BIOLOGY - Max. total length (cm): 4
BIOLOGY - Length at maturity (cm): 3.1
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: 0. Feeding: 0
ECOLOGY - Status: No information
ECOLOGY - Habitat: No information
**Epalzeorhynchos frenatum** (Chavalit Vidthayanon)

**IDENTIFICATION**
- **Family:** Cyprinidae (Minnows or carps)
- **Species name:** *Epalzeorhynchos frenatum*
- **Author:** Fowler, 1934
- **Name in Khmer:** ទូក់ទុក
- **Name in English:** Rainbow sharkminnow

**BIOLOGY**
- **Max. total length (cm):** 15
- **Max. standard length (cm):** 9.3
- **Length at maturity (cm):** 6.5
- **Food:** plants/detritus+animals

**ECOLOGY**
- **Migration:** The species migrates up from Cambodia to southern Lao in January-February (Baird et al. 1999); and moves into seasonally flooded habitats and returns to the rivers as floodwaters recede (Rainboth 1996, Baird et al. 1999). Spawning: Spawns in floodplains (Baird et al. 1999). Distribution: Mekong Basin in Laos and Thailand (Kottelat 2001); Recorded from the Xe Bangfai Basin (Kottelat 1998). Feeding: Feeds on algae, periphyton, phytoplankton, and some zooplankton (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY**
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**REPRODUCTION**
- **Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** High

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**Epalzeorhynchos munense** (Rainboth W.)

**IDENTIFICATION**
- **Family:** Cyprinidae (Minnows or carps)
- **Species name:** *Epalzeorhynchos munense*
- **Author:** Smith, 1934

**BIOLOGY**
- **Max. total length (cm):** 12
- **Max. standard length (cm):** 9.3
- **Length at maturity (cm):** 6.5
- **Food:** plants/detritus+animals

**ECOLOGY**
- **Migration:** During the flood season, it moves into inundated forests and returns to the river as water levels recede (Rainboth 1996). Spawning: 0.
- **Distribution:** Known from the Mekong and Xe Bangfai Basins (Kottelat 1998); Larvae/juveniles have been recorded from the drift in the Bassac River in An Giang (Nguyen et al. 2002). Feeding: Diet consists of phytoplankton and zooplankton (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY**
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**REPRODUCTION**
- **Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** High
Esomus longimanus (Chavalit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Esomus longimanus
IDENTIFICATION - Author: Lunel, 1881
IDENTIFICATION - Name in Khmer: រត្សឈ្មតុតិត
IDENTIFICATION - Name in Khmer (roman): Changva phleang
IDENTIFICATION - Name in English: Mekong flying barb
BIOLOGY - Max. standard length (cm): 8
BIOLOGY - Length at maturity (cm): 5.8
BIOLOGY - Food: zooplankton mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Found in the Mekong from the Khorat Plateau in Thailand to the Great Lake (Rainboth 1996); and also recorded from the Xe Bangfai Basin (Kottelat 1989). Feeding: Diet consists of zooplankton, occasionally insects (Rainboth 1996), and algae (Bardach 1959).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: High

Hampala dispar (Freyhof, J.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Hampala dispar
IDENTIFICATION - Author: Smith, 1934
IDENTIFICATION - Name in Khmer: រត្សឈ្មតុតិត
IDENTIFICATION - Name in Khmer (roman): Khman
BIOLOGY - Max. total length (cm): 43
BIOLOGY - Max. standard length (cm): 35
BIOLOGY - Length at maturity (cm): 21.2
BIOLOGY - Food: zoobenthos mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: 0. Spawning: Breeds in the beginning of the rainy season (Rainboth 1996) in April May (Baird et al. 1999) and the young are found in seasonally flooded habitats in June (Rainboth 1996). Distribution: Mekong Basin in Laos, Yunnan, Thailand, Cambodia and Viet Nam (Kottelat 2001); Found basin wide in tributaries of the Lower Mekong (Pantulu 1986); Reported from the Xe Bangfai Basin (Kottelat 1998), and the Nam Se (Baird et al. 1999). Feeding: Feeds on some fishes, but mostly prawns, crabs, and shrimps, along with some insect larvae (Rainboth 1996, Baird et al. 1999).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium

_Hampala macrolepidota_ (Freyhof, J.)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: _Hampala macrolepidota_
**IDENTIFICATION** - Author: Valenciennes, 1842

**IDENTIFICATION** - Name in Khmer: ខ្មែរ
da Khaman
**IDENTIFICATION** - Name in English: Hampala barb

**BIOLOGY** - Max. total length (cm): 86
**BIOLOGY** - Max. standard length (cm): 70
**BIOLOGY** - Length at maturity (cm): 28
**BIOLOGY** - Food: nekton mainly animals
**BIOLOGY** - Notes: Diurnally active (Pupipat et al. 1987).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Fecundity: 21033
**REPRODUCTION** - Breeds in reservoirs: Can breed in reservoirs
**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985; Lim et al. 1999

**ECOLOGY** - All MFD information:
**Migration:** A white fish species (Bardach 1959); May enter flooded streams and forested habitat in the high-water season (Baird and Phylavanh 1999).
**Spawning:** Migrates into streams during the rainy season to spawn (Baird et al. 1999); Breeds throughout the rainy season (Rainboth 1996); In reservoirs spawn during January and June (Pupipat et al. 1987); In June-July and September-October south of Quatre Bras (Bardach 1959); Fish measuring 25.9-35.2 cm have about 13,325-33,052 eggs (Krachangdara 1994); 30-40 cm fish have 58,573-131,060 eggs the average number is approximately 68,902 (Duangsawasdi et al. 1992); Egg diameter is 0.91 mm (Duangsawasdi et al. 1992), 1 mm (Pupipat et al. 1987), or 1.0-1.1 mm (Krachangdara 1994). The smallest fish that was found to be spawning is 24.5 cm in length with about 210 g weight (Pupipat et al. 1987).
**Distribution:** Mekong Basin in Laos, Yunnan, Thailand, Cambodia and Viet Nam (Kottelat 2001); Found basin wide in tributaries of the Lower Mekong (Pantulu 1986); Not as common as H. dispar in the Middle Mekong, but more common in the Lower Mekong (Rainboth 1996); Abundant in the Mekong and in the Nam Ngum Reservoir (Kottelat et al. 1993); Recorded from the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002).

**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium
Henicorhynchus cryptopogon (Warren, T.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Henicorhynchus cryptopogon
IDENTIFICATION - Author: Fowler, 1935
IDENTIFICATION - Name in Khmer: រំឈូងស្វែង
IDENTIFICATION - Name in Khmer (roman): Riel anhkam
BIOLOGY - Max. total length (cm): 15
BIOLOGY - Length at maturity (cm): 10
BIOLOGY - Food: plants mainly plants/detritus
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tone Sap distribution: Lim et al. 1999
ECOLOGY - Migration type: No information on migration type
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: High

Henicorhynchus siamensis (Warren, T.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Henicorhynchus siamensis
IDENTIFICATION - Author: Sauvage, 1881
IDENTIFICATION - Name in Khmer: រំឈូងសមុទ្រ
IDENTIFICATION - Name in Khmer (roman): Riel top
IDENTIFICATION - Name in English: Siamese mud carp
BIOLOGY - Max. total length (cm): 25
BIOLOGY - Max. standard length (cm): 20
BIOLOGY - Length at maturity (cm): 12.9
BIOLOGY - Food: plants mainly plants/detritus
BIOLOGY - Notes: Not known to prosper in impoundments (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tone Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: From Xayaboury to Chiang Khong, the fish migrates upstream from March to July, first the juveniles, later followed by the adults. At Khone Falls medium sized fish migrate downstream, while large individuals migrate upstream during the wet season. These migrations are for reproductive purposes, and during the migration the fish feeds very little relying on fat deposits around the viscera (Singanouvong et al. 1996). From the Khone Falls the fish migrate downstream from May to July, towards the large floodplains located north and south of Phnom Penh and all the way to the Mekong Delta. Here, the fish migrate out of the Mekong into canals and flooded areas during August-September (Poulsen and Valbo-Jørgensen 2000). When the water recedes it enters the Tonle Sap from the flooded areas along the river and the Great Lake (Lieng et al. 1995, Poulsen and Valbo-Jørgensen 2000, Rainboth 1996), when in the Tonle Sap, they migrate down to the Mekong (Lieng et al. 1995) and from October to February.

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continue their journey upstream the Mekong, at least until they reach the Khone Falls (Lieng et al. 1995, Poulsen and Valbo-Jørgensen 2000). Spawning: Mature eggs are reported from April to July with a strong peak during May-June (Poulsen and Valbo-Jørgensen 2000, Singanouvong et al. 1996); Spawns in the rainy season (Baird et al. 1999). Distribution: Occurs from the Mekong Delta all the way along the Mekong mainstream to Chiang Khong (Poulsen and Valbo-Jørgensen 2000); also recorded from the Xe Bangfai Basin (Roberts 1997). Feeding: Feeds on algae, periphyton and phytoplankton (Rainboth 1996); Filamentous chlorophytes (Singanouvong et al. 1996).

**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.
**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** Medium

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**Hypsibarbus lagleri** (Baird, I.G.)

**IDENTIFICATION - Family:** Cyprinidae (Minnows or carps)
**IDENTIFICATION - Species name:** Hypsibarbus lagleri
**IDENTIFICATION - Author:** Rainboth, 1996
**IDENTIFICATION - Name in Khmer:** ក្រមសួង
**IDENTIFICATION - Name in Khmer (roman):** Chhpin
**BIOLOGY - Max. total length (cm):** 49
**BIOLOGY - Max. standard length (cm):** 40
**BIOLOGY - Length at maturity (cm):** 23.8
**BIOLOGY - Food:** plants/detritus+animals
**BIOLOGY - Notes:** Not known to persist in impoundments (Rainboth 1996).
**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** Rainboth, 1996
**ECOLOGY - All MFD information:** Migration: Occurs in large rivers in the dry season and moves to medium-sized rivers in the wet season. May migrate into flooded forest immediately adjacent to rivers, but does not occur over fine-grained sediments, preferring rocks instead (Rainboth 1996). The species migrates up from Cambodia to southern Lao PDR in January-February, and migrates back to Cambodia in June-July; It sometimes enters the tributaries Sekong, Sesan, and Srepok (Baird et al. 1999). Spawning: 0 . Distribution: Occurs in large and medium sized rivers in the Middle Mekong Basin (Rainboth 1996, Kottelat 2001). It is not found in the Tonle Sap or the Great Lake (Rainboth 1996). Feeding: Feeds on green leaves and bark (Baird and Phylavanh 1999, Baird et al. 1999); This species probably consumes considerable amounts of plant matter from seasonally inundated forests during the rainy season (Baird and Phylavanh 1999); Also consumes zooplankton, worms, and algae (Rainboth 1996, Baird et al. 1999).
**ECOLOGY - Migration type:** Only seems to display Longitudinal migrations.
**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** Low

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**Hypsibarbus pierrei** (Baird, I.G.)

**IDENTIFICATION - Family:** Cyprinidae (Minnows or carps)
**IDENTIFICATION - Species name:** Hypsibarbus pierrei
**IDENTIFICATION** - Author: Sauvage, 1880

**IDENTIFICATION** - Name in Khmer: រត្សប <in>

**IDENTIFICATION** - Name in Khmer (roman): Chhpin

**BIOLOGY** - Max. total length (cm): 37
**BIOLOGY** - Max. standard length (cm): 30
**BIOLOGY** - Length at maturity (cm): 18.5

**BIOLOGY** - Notes: It is not likely to persist in impoundments (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985

**ECOLOGY** - All MFD information: Migration: This fish species migrate up the Mekong River in southern Lao PDR in March-April (Baird et al. 1999). Spawning: 0 . Distribution: Mekong Basin in Laos, Cambodia and Viet Nam (Kottelat 2001); Possibly occurs in the Middle Mekong of Cambodia or rivers coming from the Viet Nam highlands, but not yet recorded from there (Rainboth 1996). Feeding: Feeds on snails, leaves, bark and seeds; Snails are believed to be its main source of food during the low-water season (Baird and Phylavanh 1999).

**ECOLOGY** - Status: Native

**ECOLOGY** - Habitat: Benthopelagic

**ECOLOGY** - Resilience: Medium

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**Hypsibarbus wetmorei** (Jean-Francois Helias / Fishing Adventures Thailand)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: Hypsibarbus wetmorei
**IDENTIFICATION** - Author: Smith, 1931

**IDENTIFICATION** - Name in Khmer: រត្សប <rhorm>

**IDENTIFICATION** - Name in Khmer (roman): Chhpin krohorm

**BIOLOGY** - Max. total length (cm): 25
**BIOLOGY** - Length at maturity (cm): 15.7

**BIOLOGY** - Notes: Does not tolerate impoundments (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: MFD occurrence map

**ECOLOGY** - All MFD information: Migration: According to Rainboth not known to migrate, but may move upstream during periods of high water levels (Rainboth 1996); However Baird et al states that it migrates up from Cambodia to southern Lao PDR in May - June (Baird et al. 1999). Spawning: A 42 cm female weighing 1,300 g examined in February was full of eggs (Baird and Phylavanh 1999). Feeding: Feeds on filamentous algae, leaves, bark, and roots (Baird and Phylavanh 1999), grasses, (Baird and Phylavanh 1999, Baird et al. 1999), fruits, flowers of trees, fish, shrimps, snails, small molluscs, and worms (Baird et al. 1999); This species certainly relies heavily on forest leaves for food in the rainy season, and is probably mainly an algae feeder in the dry season (Baird and Phylavanh 1999).

**ECOLOGY** - Status: No information

**ECOLOGY** - Habitat: Benthopelagic

**ECOLOGY** - Resilience: Medium
**Labeo chrysophekadion** (Baird, I.G.)

**IDENTIFICATION - Family:** Cyprinidae (Minnows or carps)
**IDENTIFICATION - Species name:** Labeo chrysophekadion
**IDENTIFICATION - Author:** Bleeker, 1850

**IDENTIFICATION - Name in Khmer:** រតីកេញ
**IDENTIFICATION - Name in Khmer (roman):** Ka-ek
**IDENTIFICATION - Name in English:** Black sharkminnow

**BIOLOGY - Max. total length (cm):** 90
**BIOLOGY - Length at maturity (cm):** 48.8
**BIOLOGY - Food:** plants mainly plants/detritus

**BIOLOGY - Notes:** A long-lived, riverine, benthopelagic species, which is also found in standing water bodies (Warren 2000). It has an inferior mouth (Boonmon and Kantejit 1977), which it uses to suck food from the bottom (Boonmon and Kantejit 1977, Leelapatra et al. 2000).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information

**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** Water level variation is a migration trigger

**REPRODUCTION - Spawns in rivers (% respondents):** 97.5
**REPRODUCTION - Spawns in streams / inlets (% respondents):** 2.5
**REPRODUCTION - Date of spawning (% respondents):** Apr 5.6%, May 27.8%, Jun 5.6%, Jul 11.1% Apr-May 11.1% Feb-Mar 5.6% Jun-Jul 5.6% Mar-Apr 11.1% May-Jun 16.7%

**REPRODUCTION - Nurses in floodplain (% respondents):** 100
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Thuok, N and L. Sina, 1997

**ECOLOGY - All MFD information:** Migration: Fishers in Lao PDR and Thailand agree that it migrates upstream from March to August, when the water colour changes from clear to reddish-brown (when the rainy season starts) or when the water starts rising (Poulsen and Valbo-Jørgensen 2000). They continue into tributaries, small streams and canals (Poulsen and Valbo-Jørgensen 2000) and seasonally flooded areas (Rainboth 1996), where it probably spawns (Poulsen and Valbo-Jørgensen 2000). The fry immediately move into inundated grasses along the bank and continue to follow the leading edge of the advancing water as floodwaters spread over the land.

They return to rivers, including the Tonle Sap, from October to December. By this time the young of the year have attained a length of about 10 cm (Rainboth 1996). Spawning: Reported to carry eggs from February to October, however, there are significantly more reports on eggs from April to July (Poulsen and Valbo-Jørgensen 2000); Spawning begins after the first thunderstorms of the coming rainy season (Rainboth 1996) and peaks in June-July in the Mekong River (Bardach 1959, Baird et al. 1999), where 2-4 cm juveniles are reported year round (Poulsen and Valbo-Jørgensen 2000); Spawning takes place later in reservoirs July – October (Chabjinda et al. 1992, Boonmon and Kantejit 1977, Kamonrat et al. 1972, Watanadirokul et al. 1983); It is reported to spawn in swamps (Smith 1945), flooded areas (Poulsen and Valbo-Jørgensen 2000, Baird et al. 1999), or just upstream from shallow sandbars that line long river bends (Rainboth 1996).

It can reproduce when two years old (Kotaban and Benjakarn 1988, Chabjinda et al. 1992); at a length of around 40 cm (Kamonrat et al. 1972); or 62 cm and 3 kg and (Chabjinda et al. 1992); Fecundity estimates are highly variable from 10,000-300,000 (Boonmon and Kantejit 1977) up to 1,090,000 in a 49 cm female (Kamonrat et al. 1972); The eggs are semi-buoyant (Leelapatra et al. 2000, Watanadirokul et al. 1983, Tienciaroen and Oonsrisong 1990) and will hatch in 14-16 hrs at 28°C (Leelapatra et al. 2000, Watanadirokul et al. 1983); The newly hatched larvae are 6 – 7 mm long (Watanadirokul et al. 1983). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986); Recorded from the Xe Bangfai (Kottelat 1998), Mun (Duationswasdi and Chukajorn 1991, Duationswasdi and Duangswasdi 1992, Tantong and Siriran 1968, Boonmon and Kantejit 1977), Chi (Duationswasdi and Duangswasdi 1992, Leelapatra 1977) and Pong Rivers.
(Duangsawasdi and Duangsawasdi 1992); in Sirindhorn (Dumrongtripob and Janesirisak 1996) and Ubolratana Reservoirs (Veravute and Jaiyen 1970); and in Sapang (Dumrongtripob et al. 1998) and Kwan Phayao Swamps (Jaiyen et al. 1997); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002); There seem to be multiple populations along the Mekong River (Poulsen and Valbo-Jørgensen 2000). Feeding: Feeds mainly on algae (Watanadirokul et al. 1983, Rainboth 1996, Warren 2000, Baird and Phylavanh 1999, Baird et al. 1999) including green algae, diatoms (Veravute and Jaiyen 1970, Pothipituk 1970, Boonmon and Kantejit 1977), blue-green algae and desmids (Veravute and Jaiyen 1970), periphyton and phytoplankton (Rainboth 1996); and also plant roots (Pothipituk 1970) and other plant material (Warren 2000, Bardach 1959, Baird et al. 1999), detritus (Warren 2000, Veravute and Jaiyen 1970, Rainboth 1996, Baird et al. 1999) and mud (Bardach 1959); and some protozoan and crustaceans (Veravute and Jaiyen 1970).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Very low
GUILD - Grey fish guild (% respondents): 2.5
GUILD - White fish guild (% respondents): 97.5

*Labeo dyocheilus* (Jean-Francois Helias / Fishing Adventures Thailand)

IDENTIFICATION - Family: *Cyprinidae* (Minnows or carps)
IDENTIFICATION - Species name: *Labeo dyocheilus*
IDENTIFICATION - Author: McClelland, 1839
IDENTIFICATION - Name in Khmer (roman): Pava mouk mouy
BIOLOGY - Max. total length (cm): 90
BIOLOGY - Length at maturity (cm): 48.8
BIOLOGY - Notes: Long-lived, benthopelagic, riverine species (Warren 2000), which is known to proliferate in impoundments (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); In the rainy season it moves into the floodplain (Baird et al. 1999), where it enters flooded forests, preferring areas with at least some current (Rainboth 1996). The species migrates up from Cambodia to southern Lao PDR in January-February; Small individuals migrate upstream in May-July (Baird et al. 1999). Spawning: The fish species spawning on August-September (Baird et al. 1999); It spawns pelagically in the mainstream in the wet season the eggs are buoyant or semi-buoyant (Warren 2000). Distribution: Found basin wide in the mainstream (Pantulu 1986); and large rivers in the Lower Mekong Basin, including the upper edge of the freshwater tidal zone, and also known from the Tonle Sap (Rainboth 1996, Warren 2000), Sekong Basin, Xe Pian, Xe Kamanh, and Xe Sou (Baird et al. 1999); According to Warren (2000) absent from lower section of the Cambodian Mekong (Warren 2000); However larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on algae (Singanouvong et al. 1996, Baird et al. 1999); fine and filamentous algae (Baird and Phylavanh 1999, Warren 2000), bottom algae, phytoplankton, periphyton (Rainboth 1996), and detritus (Rainboth 1996, Warren 2000, Baird et al. 1999).
ECOLOGY - Migration type: Only seems to display longitudinal migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Very low
**Labeo erythropterus** (Warren, T.)

**IDENTIFICATION**  - **Family:** *Cyprinidae* (Minnows or carps)
**IDENTIFICATION**  - **Species name:** *Labeo erythropterus*
**IDENTIFICATION**  - **Author:** Valenciennes, 1842
**BIOLOGY**  - **Max. total length (cm):** 86
**BIOLOGY**  - **Max. standard length (cm):** 70
**BIOLOGY**  - **Length at maturity (cm):** 39.1
**BIOLOGY**  - **Food:** Mainly plants/detritus
**ECOLOGY vs. HYDROLOGY**  - **Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY**  - **Water level as migration trigger:** no information
**REPRODUCTION**  - **Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY**  - **Tonle Sap distribution:** Rainboth, 1996
**ECOLOGY**  - **Migration type:** No information on migration type
**ECOLOGY**  - **Status:** Native
**ECOLOGY**  - **Habitat:** Benthopelagic
**ECOLOGY**  - **Resilience:** Very low

**Labiobarbus leptochela** (Warren, T.)

**IDENTIFICATION**  - **Family:** *Cyprinidae* (Minnows or carps)
**IDENTIFICATION**  - **Species name:** *Labiobarbus leptochela*
**IDENTIFICATION**  - **Author:** Valenciennes, 1842
**IDENTIFICATION**  - **Remark:** Formerly recorded as *Labiobarbus kuhli*
**IDENTIFICATION**  - **Name in Khmer:** ជំនួយព្រែក
**IDENTIFICATION**  - **Name in Khmer (roman):** Khnorng veng
**BIOLOGY**  - **Max. total length (cm):** 37
**BIOLOGY**  - **Max. standard length (cm):** 30
**BIOLOGY**  - **Length at maturity (cm):** 18.5
**BIOLOGY**  - **Food:** plants mainly plants/detritus
**ECOLOGY vs. HYDROLOGY**  - **Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY**  - **Water level as migration trigger:** no information
**REPRODUCTION**  - **Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY**  - **Tonle Sap distribution:** Kottelat, 1985; Lim et al. 1999
**ECOLOGY**  - **Migration type:** No information on migration type
**ECOLOGY**  - **Status:** Native
**ECOLOGY**  - **Habitat:** Benthopelagic
**ECOLOGY**  - **Resilience:** Medium
**Labiobarbus lineatus** (CAFS)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Labiobarbus lineatus*
**IDENTIFICATION** - Author: Sauvage, 1878

**IDENTIFICATION** - Name in Khmer: ក្រុងវែង
**IDENTIFICATION** - Name in Khmer (roman): Khnorng veng

**BIOLOGY** - Max. total length (cm): 27
**BIOLOGY** - Length at maturity (cm): 0.9

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Ng and Rainboth, 2005

**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959). The species migrates from Cambodia to Lao PDR in January-February, in June -July it moves into the floodplains for spawning. After spawning, the fish migrates down the Mekong River again (Baird et al. 1999). Spawning: It spawns in June, August and possibly September (Bardach 1959); Spawns in floodplains in June-July (Baird et al. 1999). Distribution: Found basin wide in tributaries of the Mekong (Pantulu 1986); Reported from the Cambodian Mekong, but its populations may be localized (Rainboth 1996); Also reported from the Xe Bangfai Basin (Kottelat 1998). Feeding: Feeds on aquatic animals, small water plant and algae (Baird et al. 1999).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium

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**Labiobarbus siamensis** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Labiobarbus siamensis*
**IDENTIFICATION** - Author: Sauvage, 1881

**IDENTIFICATION** - Name in Khmer: ក្រុងបូក
**IDENTIFICATION** - Name in Khmer (roman): Arch kok

**BIOLOGY** - Max. total length (cm): 22
**BIOLOGY** - Length at maturity (cm): 14.1
**BIOLOGY** - Food: plants/detritus+animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs


**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959); The species migrates from Cambodia to Lao PDR in January-February, in June -July it moves into the floodplains for spawning. After spawning, the fish migrates down the Mekong River again (Baird et al. 1999). Spawning: It becomes adult at 20.0 cm (Bardach 1959); Spawns in floodplains in June-July (Baird et al. 1999). Distribution: In Laos, Thailand and Cambodia (Kottelat 2001). Feeding: Feeds on aquatic animals, small water plant and algae (Baird et al. 1999).
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Benthopelagic  
**ECOLOGY - Resilience:** Medium

**Leptobarbus hoevenii** (Chavalit Vidthayanon)

**IDENTIFICATION - Family:** Cyprinidae **(Minnows or carps)**  
**IDENTIFICATION - Species name:** Leptobarbus hoevenii  
**IDENTIFICATION - Author:** Bleeker, 1851  
**IDENTIFICATION - Name in Khmer:**  
**IDENTIFICATION - Name in Khmer (roman):** Proloung / Chroloeung  
**IDENTIFICATION - Name in English:** Mad barb

**BIOLOGY - Max. total length (cm):** 122  
**BIOLOGY - Max. standard length (cm):** 100  
**BIOLOGY - Length at maturity (cm):** 53.5  
**BIOLOGY - Food:** plants mainly animals  
**BIOLOGY - Notes:** It is a long-lived species, which is either bottom dwelling or semi-pelagic (Warren 2000); Swims in shoals (Roberts 1989). Reported to become intoxicated and behave in a peculiar manner when feeding on toxic fruits and seeds (Roberts 1989, Leelapatra et al. 2000).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information  
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** MFD occurrence map  
**ECOLOGY - All MFD information:** Migration: Non-migratory (Blache and Goossens 1954, Roberts 1993); but participates in local trophic migrations to and from inundated forests (Rainboth 1996, Warren 2000); Other authors state that it is migratory (Schouten et al. 2000) and that it migrates upstream during January and February and downstream in May-June (Baird et al. 1999).

**Spawning:** It is a pelagic spawner (Warren 2000), which spawns in floodplains during the wet-season (Warren 2000) from May to September (Watanadirokul and Kongship 1987, Meanakarn 1985), mainly June-July (Baird et al. 1999); The eggs semi-buoyant, the fertilized eggs hatch within 15-18 hours at 26-29°C. (Meanakarn 1985), and the newly hatched larvae are about 5 mm long (Konggratanakosol and Chesoh 1995). Fishes with body weight 0.5-0.6 kg are mature (Leelapatra et al. 2000), and a 1 kg mature female may carry 50,000 – 70,000 eggs (Meanakarn 1985).  

**ECOLOGY - Migration type:** Only seems to display Longitudinal migrations.  
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** pelagic  
**ECOLOGY - Resilience:** Medium

**Lobocheilos melanotaenia** (Warren, T.)

**IDENTIFICATION - Family:** Cyprinidae **(Minnows or carps)**  
**IDENTIFICATION - Species name:** Lobocheilos melanotaenia
Longiculter siahi (FAO)

**IDENTIFICATION - Family:** Cyprinidae (Minnows or carps)
**IDENTIFICATION - Species name:** Longiculter siahi
**IDENTIFICATION - Author:** Fowler, 1937
**BIOLOGY - Max. total length (cm):** 25
**BIOLOGY - Max. standard length (cm):** 20
**BIOLOGY - Length at maturity (cm):** 12.9
**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** Kottelat, 1985
**ECOLOGY - All MFD information:** Migration: 0. Spawning: 0. Distribution: It is apparently uncommon or at least localized in distribution (Rainboth 1996). Feeding: Filter-feeder (Rainboth 1996).
**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** pelagic
**ECOLOGY - Resilience:** Medium
**Luciosoma bleekeri** (Baird, I.G.)

**Identification**
- **Family**: Cyprinidae (Minnows or carps)
- **Species name**: Luciosoma bleekeri
- **Author**: Steindachner, 1878
- **Name in Khmer**: រត្តុម្ភ្ព្លូវ ក្តាងមន
- **Name in Khmer (roman)**: Bangkouy/Dorn Darv

**Biology**
- **Max. total length (cm)**: 31
- **Max. standard length (cm)**: 25
- **Length at maturity (cm)**: 15.7
- **Food**: zoobenthos mainly animals
- **Discharge as migration trigger**: no information
- **Water level as migration trigger**: no information
- **Breeds in reservoirs**: No info on breeding in reservoirs

**Ecology**
- **Status**: Native
- **Habitat**: pelagic
- **Resilience**: Medium

**Distribution**
- Recorded from Srepok, and Tonle Sap in Cambodia (Kottelat 1985).
- Collected from Nam Ngum dam site, Tha Ngon, Tha Bo, Sai Fong, Sihan Tay, Pakse and Hatsalao in the Mekong basin (DoF 1987) and in the mainstream at Ban Hang Khone just below the Khone Falls (Ferraris 2001);
- Found in Mekong Delta (Khoa and Huong 1993);
- Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002).

**Feeding**
- **Diet**: includes small crustaceans, fish (Rainboth 1996, Baird et al. 1999) and especially terrestrial insects (Rainboth 1996, Baird et al. 1999); however it is believed, by local people, to be at least an occasional consumer of forest fruits and vegetation (Baird and Phylavanh 1999), and it also eats leaves (Baird et al. 1999).

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**Luciosoma setigerum** (Rainboth W.)

**Identification**
- **Family**: Cyprinidae (Minnows or carps)
- **Species name**: Luciosoma setigerum
- **Author**: Valenciennes, 1842
- **Name in English**: Apollo sharkminnow

**Biology**
- **Max. total length (cm)**: 33
- **Max. standard length (cm)**: 26.5
- **Length at maturity (cm)**: 16.5
- **Food**: Nekton mainly animals
- **Discharge as migration trigger**: no information
- **Water level as migration trigger**: no information
- **Breeds in reservoirs**: No info on breeding in reservoirs

**Ecology**
- **Status**: Native
- **Habitat**: pelagic
- **Resilience**: Medium

**Distribution**
- Collected from Nam Ngum dam site and Tha Ngon (DoF 1987), and at Ban Hang Khone just below Khone falls (Anon
Macrochirichthys macrochirus (Warren, T.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Macrochirichthys macrochirus
IDENTIFICATION - Author: Valenciennes, 1844
IDENTIFICATION - Name in Khmer: Rti dek
IDENTIFICATION - Name in Khmer (roman): Dong khteng
BIOLOGY - Max. total length (cm): 100
BIOLOGY - Length at maturity (cm): 53.5
BIOLOGY - Food: Nekton mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Spawns in rivers (% respondents): 2.4390243902439
REPRODUCTION - Spawns in streams / inlets (% respondents): 97.5609756097561
REPRODUCTION - Date of spawning (% respondents): Jun 3.3%, Feb-Mar 3.3% Jun-Jul 53.3%, May-Jul 3.3%, May-Jun 36.7%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which moves out into the flooded forest during high water and returns to the river as soon as water levels begin to subside. Usually moves on the fourth or fifth day before full moon in October and November (Rainboth 1996). Spawning: It becomes adult at a length of 50 cm (Bardach 1959). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986, Kottelat 2001); It is now very rare in the Mekong River in southern Laos (Baird et al. 1999). Feeding: Juveniles feed on insects, and adults on fishes (Rainboth 1996, Baird et al. 1999).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Very low
GUILD - Grey fish guild (% respondents): 100

Mekongina erythrospila (Warren, T.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Mekongina erythrospila
IDENTIFICATION - Author: Fowler, 1937
IDENTIFICATION - Name in Khmer: Rtey gep
IDENTIFICATION - Name in Khmer (roman): Pase ee
BIOLOGY - Max. total length (cm): 55
BIOLOGY - Max. standard length (cm): 45
BIOLOGY - Length at maturity (cm): 26.5
BIOLOGY - Food: Mainly plants/detritus
BIOLOGY - Notes: Migrates in big schools with several hundred fish, and often together with other species such as Hypsibarbus spp., Scaphognathops spp., Henicorhynchus siamensis and Botia modesta. The juveniles are also migratory (Poulsen and Valbo-Jørgensen 2000).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: South of Khone Falls upstream migrations were generally reported to occur from November to February, while the fish were moving downstream from April to June. Migrates upstream from Pak Lay to Chiang Khong from March to May. Migrations start when the first heavy rains of the rainy season fall, or when the river changes colour from relatively clear to reddish or brown (Poulsen and Valbo-Jørgensen 2000).
In the Mun River, the species migrates upstream from the beginning of the rainy season to the end of August and move back downstream from late September to November (Schouten et al. 2000). Spawning: Spawning take place in the middle of raining season, from June to September (Benjakarn et al. 1979, Poulsen and Valbo-Jørgensen 2000); The eggs are semi-buoyant, and hatching occurs within 16 hours at 27°C. Distribution: Occurs from Chiang Saen to Pak Lay, however from Chiang Khan to Paksan the species was not reported. Occurs again at Thakhek and downstream to Sambor (Poulsen and Valbo-Jørgensen 2000); The southern distribution limit for this species is at Sambor (Roberts and Warren 1994); Also recorded from Xe Bangfai, Nam Theun (Kottelat 1998), and Chi (Leelapatra 1977) Rivers. Feeding: Herbivorous (Pongsirijun et al. 2001, Benjakarn et al. 1979), or algivorous (Singanouvong et al. 1996, Baird and Phylavanh 1999); Feeding on green algae (Baird and Phylavanh 1999), periphyton and phytoplankton (Rainboth 1996, Benjakarn et al. 1979).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Feeds in floodplains (% respondents):
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Mystacoleucus marginatus (Chavalit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Mystacoleucus marginatus
IDENTIFICATION - Author: Valenciennes, 1842
BIOLOGY - Max. total length (cm): 20
BIOLOGY - Length at maturity (cm): 12.9
BIOLOGY - Food: plants/detritus+animals
BIOLOGY - Notes: Always found in schools (Krachangdara 1994).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, M., 1985
ECOLOGY - All MFD information: Migration: 0. Spawning: 0 . Distribution: Occurs in the Xe Bangfai and Nam Theun basins (4832). Feeding: Feeds on plants (Krachangdara 1994).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium
**Osteochilus hasseltii** (Warren, T.)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: *Osteochilus hasseltii*
**IDENTIFICATION** - Author: Valenciennes, 1842

**IDENTIFICATION** - Name in Khmer: ក្រុង
**IDENTIFICATION** - Name in Khmer (roman): Kros
**IDENTIFICATION** - Name in English: Silver sharkminnow

**BIOLOGY** - Max. total length (cm): 40
**BIOLOGY** - Max. standard length (cm): 32
**BIOLOGY** - Length at maturity (cm): 21.7
**BIOLOGY** - Food: zoobenthos plants/detritus+animals
**BIOLOGY** - Notes: Benthopelagic and sometimes bottom dwelling riverine species with a medium to long lifespan (Warren 2000); It is normally diurnally active (NIFI 1993).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Fecundity: 94868
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999
**ECOLOGY** - All MFD information: Migration: It appear to be a species, which mainly lives in smaller tributaries and migrates to flooded areas at the onset of the flood season (Poulsen and Valbo-Jørgensen 2000) in July-August (Baird et al. 1999); It spends the flood season in the floodplain and at the end of the rains, it migrates back to the river habitats in tributaries and, to a lesser extend, the Mekong mainstream (Poulsen and Valbo-Jørgensen 2000); Juveniles are usually first seen in August, they move back to permanent water as flooded lands dry up (Rainboth 1996). Spawning: The peak for occurrence of developed eggs is May-June indicates that the spawning occurs during the period of rising waters at the onset of the floods (Poulsen and Valbo-Jørgensen 2000) but extending into the late rainy season to August and September (Chukajon 1970); Spawning occurs in floodplains (Warren 2000) in areas covered with submerged vegetation and gravel bottom (Pholprasith and Janesirisak 1972); Fish measuring 10.5-17.7 cm have 4,370-13,342 eggs with a diameter of 1.05-1.15 mm (Krachangdara 1994); The eggs are buoyant or semi-buoyant (Warren 2000, Pennapaporn et al. 1991) with a diameter of 1 mm. Hatching occurs around 16 hr at 25.5-27.5°C (Pennapaporn et al. 1991); The larvae measure about 3 mm at hatching (Leelapatra et al. 2000). The fish becomes mature after eight to ten months when it measures around 15 cm (Jaiyen 1976). Distribution: A common species (Rainboth 1996); which is found basin wide in tributaries of the Mekong (Pantulu 1986); Recorded from the Xe Bangfai Basin (Kottelat 1998); It is the most abundant fish in Nam Ngum reservoir (Ukkatawewat 9999). Feeding: It is mainly a herbivorous fish (Krachangdara 1994); It feeds on periphyton, filamentous algae (Warren 2000, Rainboth 1996, Baird et al. 1999), phytoplankton, (Rainboth 1996, Chukajon 1970); roots of plants, unicellular algae and some crustaceans (Ukkatawewat 9999), detritus (Chukajon 1970, Baird et al. 1999) and annelids (Chukajon 1970) and aquatic insects (NIFI 1993); Adults feed on aquatic and terrestrial plants (Yap 1988, NIFI 1993, Baird et al. 1999).

**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High
IDENTIFICATION - Family: *Cyprinidae* (Minnows or carps)
IDENTIFICATION - Species name: *Osteochilus lini*
IDENTIFICATION - Author: Fowler, 1935

IDENTIFICATION - Name in Khmer: រតិរកស
IDENTIFICATION - Name in Khmer (roman): Kros
BIOLOGY - Max. total length (cm): 19
BIOLOGY - Max. standard length (cm): 15
BIOLOGY - Length at maturity (cm): 10
BIOLOGY - Food: Mainly plants/detritus
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Motomura et al. 2002
ECOLOGY - All MFD information: Migration: Moves into flooded forests or open fields, and begins to re-enter rivers in October (Rainboth 1996). Spawning: Spawning season is from May to July (Dumrongtripob et al. 1997), and young of the year are first seen in August (Rainboth 1996). The size at maturity is 9 cm total length in females; Fecundity is reported to be 1,929 eggs in 8.9 cm and 13 g fish, and 34,581 eggs in 17.3 cm and 77.2 g fish; The diameter of the egg is reported to be 0.72 mm (Dumrongtripob et al. 1997). Distribution: Occurs in the Xe Bangfai Basin (Kottelat 1998), in Mun River (Duangsawasdi and Duangsawasdi 1992, Duangsawasdi and Chukajorn 1991.) and Chulabhorn Reservoir (Chantsavang et al. 1991); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on periphyton, phytoplankton algae, and some detritus (Rainboth 1996, Akatawewat et al. 1996).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

*Osteochilus melanopleurus* (Warren, T.)

IDENTIFICATION - Family: *Cyprinidae* (Minnows or carps)
IDENTIFICATION - Species name: *Osteochilus melanopleurus*
IDENTIFICATION - Author: Bleeker, 1852

IDENTIFICATION - Name in Khmer: រតិរកម
IDENTIFICATION - Name in Khmer (roman): Krum
BIOLOGY - Max. total length (cm): 74
BIOLOGY - Max. standard length (cm): 60
BIOLOGY - Length at maturity (cm): 34.1
BIOLOGY - Food: plants mainly plants/detritus
BIOLOGY - Notes: A medium to long-lived riverine species, which also can be found in standing water bodies (Warren 2000).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in streams / inlets (% respondents): 92.5
REPRODUCTION - Spawns in TS permanent lake (% respondents): 7.5
REPRODUCTION - Date of spawning (% respondents): Apr 2.8%, May 2.8% Feb-Mar 2.8% Jun-Jul 55.6%, Mar-Apr 8.3%, May-Jul 2.8%, May-Jun 25%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Migration: A white fish species (Bardach 1959), which moves into seasonally flooded habitats (Rainboth 1996, Baird et al. 1999); Returns to the river from October, with numbers steadily increasing until January, when they begin to decline again (Rainboth 1996). Spawning: Spawning occurs in the rainy season from May to October (Jaiyen 1976, Watanadirokul et al. 1983, Somprasong 1977); It spawns in floodplains (Warren 2000, Baird et al. 1999) and mainstreams of large rivers (Warren 2000); It is a pelagic spawner which produces semi-buoyant eggs (Warren 2000, Watanadirokul et al. 1983, Watanadirokul et al. 1983), with a diameter of 1.45-1.95 mm (Jaiyen 1976), which will be hatch within 14-16 hours at 28°C (Watanadirokul et al. 1983, Watanadirokul et al. 1983); The newly hatched larva is about 6 mm in total length (Watanadirokul et al. 1983, Watanadirokul et al. 1983). Bardach (1959) reported that the fish becomes adult at 50 cm (Bardach 1959), however more recent research indicate that the size at maturity is 26 cm TL in females and 25.7 cm in males (Jaiyen 1976); Females with total length of 26-59 cm carry 67,000 – 750,000 eggs (Jaiyen 1976, Watanadirokul et al. 1983, Watanadirokul et al. 1983). Distribution: A common species (Rainboth 1996); which is found basin wide in tributaries of the Mekong (Pantulu 1986); It also occurs in the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Its preferred diet consists mostly of periphyton (Rainboth 1996, Warren 2000) as well as leafy plants such as aquatic macrophytes (Rainboth 1996, Pothipituk 1970, Somprasong 1977, Jaiyen 1976) and inundated terrestrial plants (Rainboth 1996, Warren 2000, Baird and Phylavanh 1999, Baird et al. 1999); Feeds also on phytoplankton (Rainboth 1996, Warren 2000, Baird and Phylavanh 1999), filamentous algae, and bottom algae (Rainboth 1996, Pothipituk 1970, Somprasong 1977, Jaiyen 1976, Warren 2000, Baird and Phylavanh 1999, Baird et al. 1999) and detritus (Baird and Phylavanh 1999, Warren 2000, Baird et al. 1999).

ECOLOGY - Migration type: Only seems to display Longitudinal migrations.
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low
GUILD - Grey fish guild (% respondents): 100

Osteochilus microcephalus (Chavalit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Osteochilus microcephalus
IDENTIFICATION - Author: Valenciennes, 1842
IDENTIFICATION - Name in Khmer: តូលកស្តែង
IDENTIFICATION - Name in Khmer (roman): Kros
BIOLOGY - Max. total length (cm): 30
BIOLOGY - Max. standard length (cm): 24
BIOLOGY - Length at maturity (cm): 15.2
BIOLOGY - Food: Mainly plants/detritus
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); which migrates upstream for reproduction (Singanouvong et al. 1996); it moves into flooded forests and grasslands during the flood season. It returns to the rivers later, with highest numbers appearing from December to February (Rainboth 1996); The fish species migrate up from Cambodia to southern Lao in January-February (Baird et al. 1999). Spawning: 0. Distribution: A common species (Rainboth 1996). Feeding: Its preferred diet consists mostly of periphyton as well as leafy plants such as aquatic macrophytes and inundated terrestrial plants; It also feeds on phytoplankton,
filamentous algae, and bottom algae (Rainboth 1996, Baird et al. 1999), and detritus (Baird et al. 1999).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

Osteochilus schlegeli (Baird, I.G.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Osteochilus schlegeli
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: រតេញសុខ
IDENTIFICATION - Name in Khmer (roman): Lolouk sor
BIOLOGY - Max. total length (cm): 49
BIOLOGY - Max. standard length (cm): 40
BIOLOGY - Length at maturity (cm): 23.8
BIOLOGY - Food: plants mainly plants/detritus
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which moves into flooded forests and grasslands during the flood season, it returns to the rivers later, with highest numbers appearing from December to February (Rainboth 1996). Spawning: 0 . Distribution: Known from midwater to bottom depths in large and medium-sized rivers. Found in the Great Lake, but apparently not persisting in impoundments (Rainboth 1996). Feeding: Its preferred diet consists mostly of periphyton as well as leafy plants such as aquatic macrophytes and inundated terrestrial plants; It also feeds on phytoplankton, filamentous algae, and bottom algae (Rainboth 1996).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Osteochilus waandersii (Rainboth W.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Osteochilus waandersii
IDENTIFICATION - Author: Bleeker, 1852
IDENTIFICATION - Name in Khmer: រតេញសុខ
IDENTIFICATION - Name in Khmer (roman): Kros chhnout
BIOLOGY - Max. standard length (cm): 20.5
BIOLOGY - Length at maturity (cm): 13.2
BIOLOGY - Food: Mainly plants/detritus
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
Parachela maculicauda (Chavalit Vidthayanon)

**IDENTIFICATION**
- Family: Cyprinidae (Minnows or carps)
- Species name: *Parachela maculicauda*
- Author: Smith, 1934
- Name in Khmer: ចុងតំសាចអាិុយ
- Name in Khmer (roman): Chunteas phluk

**BIOLOGY**
- Max. total length (cm): 6
- Length at maturity (cm): 4.5
- Food: zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**REPRODUCTION**
- Spawns in streams / inlets (% respondents): 97.5
- Spawns in TS permanent lake (% respondents): 2.5
- Date of spawning (% respondents): Feb-Mar 2.6%, Jun-Jul 65.8%, May-Jul 28.9%
- Nurses in floodplain (% respondents): 100

**ECOLOGY**
- Habitat: pelagic
- Resilience: High

**GUILD**
- Grey fish guild (% respondents): 100

Parachela oxygastroides (Chavalit Vidthayanon)

**IDENTIFICATION**
- Family: Cyprinidae (Minnows or carps)
- Species name: *Parachela oxygastroides*
- Author: Bleeker, 1852
- Name in Khmer: ចុងតំសាចអាិុយ
- Name in Khmer (roman): Chunteas phluk
IDENTIFICATION - Name in English: Glass fish
BIOLOGY - Max. total length (cm): 25
BIOLOGY - Max. standard length (cm): 20
BIOLOGY - Length at maturity (cm): 12.9
BIOLOGY - Food: zooplankton mainly animals
BIOLOGY - Notes: This species and P. siamensis seem to be more tolerant of high amounts of suspended solids than P. maculicauda or P. williaminae and are more common in habitats disturbed by farming activities (Rainboth 1996).

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger

REPRODUCTION - Spawns in streams / inlets (% respondents): 97.5
REPRODUCTION - Spawns in TS permanent lake (% respondents): 2.5
REPRODUCTION - Date of spawning (% respondents): Feb-Mar 2.6% Jun-Jul 65.8%, May-Jul 2.6%, May-Jun 28.9%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: Leaves the flooded forest in November as the water levels begin to decline substantially (Rainboth 1996). Spawning: 0 . Distribution: 0. Feeding: Diet includes zooplankton (Rainboth 1996) and insects (Rainboth 1996, Baird et al. 1999).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: Medium
GUILD - Grey fish guild (% respondents): 100

Parachela siamensis (Chavalit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Parachela siamensis
IDENTIFICATION - Author: Günther, 1868
IDENTIFICATION - Name in Khmer: រតីចាម៉ូក
IDENTIFICATION - Name in Khmer (roman): Chunteas phluk
BIOLOGY - Max. total length (cm): 15
BIOLOGY - Max. standard length (cm): 15
BIOLOGY - Length at maturity (cm): 10
BIOLOGY - Food: Mainly animals
BIOLOGY - Notes: Commonly occurs together with P. oxygastroides and P. williaminae (Rainboth 1996).

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in streams / inlets (% respondents): 97.5
REPRODUCTION - Spawns in TS permanent lake (% respondents): 2.5
REPRODUCTION - Date of spawning (% respondents): Feb-Mar 2.6% Jun-Jul 65.8%, May-Jul 2.6%, May-Jun 28.9%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Rainboth, 1996; Kottelat, 1985
ECOLOGY - All MFD information: Migration: At high water it moves into the flooded forest, and probably leaves at the same time as P. oxygastroides (Rainboth 1996). Spawning: 0 . Distribution: This is the most common species of the genus in the Great Lake (Rainboth 1996). Feeding: Feeds on insects (Baird et al. 1999).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
**Parachela williaminae** (Rainboth W.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Parachela williaminae*
**IDENTIFICATION** - Author: Fowler, 1934
**IDENTIFICATION** - Name in Khmer: រតីចូនសេក
**IDENTIFICATION** - Name in Khmer (roman): Chunteas phluk

**BIOLOGY** - Max. standard length (cm): 12
**BIOLOGY** - Length at maturity (cm): 8.2
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Spawns in streams / inlets (% respondents): 97.5
**REPRODUCTION** - Spawns in TS permanent lake (% respondents): 2.5
**REPRODUCTION** - Date of spawning (% respondents): Feb-Mar 2.6%, Jun-Jul 65.8%, May-Jul 2.6%, May-Jun 28.9%
**REPRODUCTION** - Nurses in floodplain (% respondents): 100
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: MFD occurrence map
**ECOLOGY** - All MFD information: Migration: 0. Spawning: 0. Distribution: An apparently uncommon species, known from the main channel of the Mekong from northern Thailand downstream to the Great Lake (Rainboth 1996). Feeding: 0
**ECOLOGY** - Feeds in floodplains (% respondents): 100
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium

**GUILD** - Grey fish guild (% respondents): 100

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**Paralaubuca harmandi** (Chavalit Vidhayananon)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Paralaubuca harmandi*
**IDENTIFICATION** - Author: Sauvage, 1883
**IDENTIFICATION** - Name in Khmer: រតីឈឺសុវត្ថិរ
**IDENTIFICATION** - Name in Khmer (roman): Sleuk russey

**BIOLOGY** - Max. total length (cm): 27
**BIOLOGY** - Max. standard length (cm): 21.9
**BIOLOGY** - Length at maturity (cm): 14
**BIOLOGY** - Food: zooplankton mainly animals
**BIOLOGY** - Notes: Usually found as scattered individuals rather than in large schools like P. barroni and P. typus (Rainboth 1996).
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985
Paralaubuca riveroi (Chavalit Vidhayanon)

**ECOLOGY - All MFD information:**
- **Migration:** A white fish species (Bardach 1959).
- **Spawning:** 0.
- **Distribution:** 0.
- **Feeding:** Feeds on zooplankton and insects of larger size than seen in other members of the genus (Rainboth 1996).

**ECOLOGY - Status:** Native

**ECOLOGY - Habitat:** Benthopelagic

**ECOLOGY - Resilience:** Medium

**IDENTIFICATION - Family:** Cyprinidae (Minnows or carps)

**IDENTIFICATION - Species name:** Paralaubuca riveroi

**IDENTIFICATION - Author:** Fowler, 1935

**IDENTIFICATION - Name in Khmer:** [ឈប្បាសជាស្ថានី]

**IDENTIFICATION - Name in Khmer (roman):** Sleuk russey

**BIOLOGY - Max. total length (cm):** 22

**BIOLOGY - Max. standard length (cm):** 18

**BIOLOGY - Length at maturity (cm):** 11.8

**BIOLOGY - Food:** zooplankton mainly animals

**BIOLOGY - Notes:** Usually occurs as scattered representatives in schools of the other species in this genus (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information

**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs


**Paralaubuca typus** (Roberts, T.R.)

**IDENTIFICATION - Family:** Cyprinidae (Minnows or carps)

**IDENTIFICATION - Species name:** Paralaubuca typus

**IDENTIFICATION - Author:** Bleeker, 1865

**IDENTIFICATION - Name in Khmer:** [ឈប្បាសជាស្ថានី]

**IDENTIFICATION - Name in Khmer (roman):** Sleuk russey

**BIOLOGY - Max. total length (cm):** 22

**BIOLOGY - Max. standard length (cm):** 18

**BIOLOGY - Length at maturity (cm):** 11.8

**BIOLOGY - Food:** zooplankton mainly animals

**BIOLOGY - Notes:** A schooling species (Rainboth 1996), which mainly feeds near the surface (Baird and Phylavanh 1999).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information

**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** Water level variation is a migration trigger

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Thuok, N and L. Sina, 1997
ECOLOGY - All MFD information: Migration: A highly migratory (Roberts and Baird 1995) white fish species (Bardach 1959), which migrates upstream to Kratie and Stung Treng in January-February as part of a group of small non-reproductive fish migrating from downriver (Roberts and Warren 1994); From November to February, a non-reproductive upstream migration is undertaken from Kandal, to the Khone Falls. From May to July, the fish is migrating downstream. At this time, the fish are reported to be in reproductive condition. Above the Khone Falls, an upstream migration occurs from March to July. This migration is apparently triggered by a combination of the first strong rain, rising water, change in water colour/turbidity and the appearance of insects, also reported to migrate around full moon (Poulsen and Valbo-Jørgensen 2000); During the wet season medium sized individuals migrate downstream, adults migrate upstream. The purpose of the migration for both sizes is reproduction (Singanouvong et al. 1996); Migrates up the Mekong and Sekong Rivers in January-February and migrates down to the Cambodian floodplains in July-August (Baird et al. 1999);

Moves out into flooded forests during high water levels and returns to the mainstream after the water levels have already considerably declined (Rainboth 1996); The fish enter the Mekong mainstream from both the Tonle Sap River and from small canals into the mainstream; The species is reported to migrate together with several other species, in particular Henicorhynchus spp., but also Botia modesta, small Pangasius spp. and Micronema spp (Poulsen and Valbo-Jørgensen 2000).

Spawning: It becomes adult at a size of 20 cm (Bardach 1959); Eggs have been observed in the abdomen during the period from April to July with a strong peak in May-June, indicating that spawning occur during this period. Fish have been observed spawning both in the mainstream and in floodplain habitats (Poulsen and Valbo-Jørgensen 2000); Reported to spawn in floodplains (Baird et al. 1999).

Distribution: Occurs from the Mekong Delta to Chiang Saen near the border between Lao PDR, Thailand and Myanmar (Poulsen and Valbo-Jørgensen 2000); Occurs in the Xe Bangfai Basin (Kottelat 1998). Feeding: Feeds on zooplankton (Rainboth 1996) e.g. planktonic crustaceans (Bardach 1959); flying insects (Rainboth 1996, Bardach 1959, Baird et al. 1999) which it catches at the surface in shallow water (Poulsen and Valbo-Jørgensen 2000) in June (Baird and Phylavanh 1999); Rice bran (Baird et al. 1999); May consume seasonally inundated riverine vegetation during the rainy season (Baird and Phylavanh 1999) and plant seeds (Bardach 1959); Is also known to scavenge (Baird et al. 1999).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.

ECOLOGY - Status: Native

ECOLOGY - Habitat: Benthopelagic

ECOLOGY - Resilience: Medium

Poropuntius deauratusm (IFReDI collection)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)

IDENTIFICATION - Species name: Poropuntius deauratus

IDENTIFICATION - Author: Valenciennes, 1842

IDENTIFICATION - Name in Khmer: Kros phnom

IDENTIFICATION - Name in Khmer (roman): Kros phnom

BIOLOGY - Length at maturity (cm): 0.9

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information

ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information

REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs

ECOLOGY - Tonle Sap distribution: From FishBase

ECOLOGY - Migration type: No information on migration type

ECOLOGY - Status: Questionable

ECOLOGY - Habitat: Benthopelagic

ECOLOGY - Resilience: Medium
Probarbus jullieni (IFReDI collection)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Probarbus jullieni
IDENTIFICATION - Author: Sauvage, 1880
IDENTIFICATION - Name in Khmer: ក្តារឈាយដី ក្តារឈាយដី
IDENTIFICATION - Name in Khmer (roman): Tra sork krohom
IDENTIFICATION - Name in English: Iso barb
BIOLOGY - Max. standard length (cm): 150
BIOLOGY - Length at maturity (cm): 76.7
BIOLOGY - Food: plants/detritus+animals
BIOLOGY - Notes: Generally intolerant of habitat alterations, it has disappeared from areas affected by impoundments (Rainboth 1996); Large dams in Stung Treng and Kratie Provinces would eliminate most of the rapids habitat that are important for the spawning of this species (Roberts 1992); The eggs are eaten by P. conchophilus, Hemibagrus nemurus, H. wyckii and Morulius spp. (Roberts and Warren 1994, Baird 1994).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); It migrates upstream for spawning from October to February from Kompong Cham to Chiang Khong (Poulsen and Valbo-Jørgensen 2000) often in association with P. labeamajor (Roberts and Warren 1994, Poulsen and Valbo-Jørgensen 2000); At Khone Falls the migrations take place between October and December, with a peak in November or early December, when water levels begin to go down (Roberts 1993); Or in December to the beginning of January (Baird et al. 1999); It was reported that it migrates up the tributary Nam Ta in Lao PDR to spawn during March-April (Poulsen and Valbo-Jørgensen 2000); The species is further believed to enter flooded streams in the high-water season (Baird and Phylavanh 1999); It is hypothesised to exist as discrete stocks that undertake migrations over relatively short distances (Singanouvong et al. 1996, Baird and Flaherty 2000); Juvenile individuals often migrate downstream in association with small cyprinids for dispersal and feeding (Singanouvong et al. 1996); these trophic migrations by juveniles and sub-adults occur mainly at the onset of the flood season are reported throughout the occurrence range (Poulsen and Valbo-Jørgensen 2000). Spawning: It is a dry season spawner (Singanouvong et al. 1996), which breeds between December and March (Ukkatawewat 1999, Tan et al. 1983, Poulsen and Valbo-Jørgensen 2000, Amatyakul et al. 1995, Phuriphong and Ukkatawewat 1992); Spawning grounds shallow rapids with strong current in the mainstream of large rivers (Roberts and Warren 1994, Tan et al. 1983, Ukkatawewat 1999, Ukkatawewat 1979, Amatyakul et al. 1995) with sand and gravel substrate (Ukkatawewat 1999, Ukkatawewat 1979, Amatyakul et al. 1995, Tan et al. 1983). There are usually deep pools nearby, where the fish stay during the day (Tan et al. 1983); It is apparently incapable of reproducing in reservoirs (Roberts 1992). During the spawning period the fish congregate in large schools of between 30 and 40 individuals (Phuriphong and Ukkatawewat 1992), before spawning, males and females chase one another at the surface of the water (Phuriphong and Ukkatawewat 1992); Spawning takes place at night (Tan et al. 1983, Tan et al. 1983), before the fish moves to the spawning ground in the evening, it starts surfacing in the deep pool where it stays during the day (Tan et al. 1983); Falling water and atmospheric temperatures, together with decreased turbidity, may be important factors in controlling the arrival time of Probarbus to its spawning grounds (Baird and Flaherty 2000); The arrival of P. jullieni at its spawning grounds seem to be associated with low moonlight conditions (Singanouvong et al. 1996); In the Mekong River, spawning grounds have been identified in Nong Kai, Loei, Ubon Ratchathani, Nakhon Phanom, Mukdaharn (Amatyakul et al. 1995); and Champasack Provinces (Roberts and Warren 1994). In the wild only females between four and five kg or heavier have been found in spawning condition (Baird and Phylavanh 1999, Plangchawee et al. 1987), it is however not known at what age wild fish mature, but in captivity both males and females mature when five years old (Rodrarung and
Janesirisak 1990); Mature males usually weigh 5-20 kg, while females weigh 10-50 kg (Amatyakul et al. 1995); Captive brood stock with a weight of 3.0-5.5 kg, have around 45,000 eggs (Leelapatra et al. 2000); A of 14 kg was recorded as producing about 500,000 eggs (Ukkatawewat 1979). The eggs are buoyant (Ukkatawewat 1979) or semi-buoyant, but slightly heavy and adhesive (Amatyakul et al. 1995); The diameter of egg is about 2 mm (Amatyakul et al. 1995, Ukkatawewat 1979); Hatching occurs in 32 hrs (Ukkatawewat 1999, Ukkatawewat 1979); to 72 hr at 23°C (Amatyakul et al. 1995); At hatching, the larvae measure 0.8 – 0.9 cm (Amatyakul et al. 1995). Distribution: Found basin wide in the mainstream of the Lower Mekong (Pantulu 1986, Poulsen and Valbo-Jørgensen 2000); In Cambodia, it occurs in the Mekong from the Lao border to the Great Lake (Rainboth 1996); inhabits parts of the Mekong, Sekong, Sre Pok and Se San Rivers (Baird and Flaherty 2000); Occurs mainly as juveniles up to 40 cm long in the Delta (Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Feeds on aquatic plants (Smith 1945, Ukkatawewat 1999, Amatyakul et al. 1995, Singanouvong et al. 1996, Baird et al. 1999) and invertebrates (Singanouvong et al. 1996, Phuriphong and Ukkatawewat 1992) including molluscs (Ukkatawewat 1999, Amatyakul et al. 1995, Phuriphong and Ukkatawewat 1992, Baird et al. 1999) crabs (Amatyakul et al. 1995, Baird et al. 1999), insects (Ukkatawewat 1999, Baird et al. 1999), aquatic insect larvae, and zooplankton (Amatyakul et al. 1995); Juveniles feed on small gastropod sand snails, fruits, insects, and detritus (Baird and Phylavanh 1999); The species is a night-time feeder (Amatyakul et al. 1995).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Very low

Probarbus labeamajor (Warren, T.)

Identification - Family: Cyprinidae (Minnows or carps)
Identification - Species name: Probarbus labeamajor
Identification - Author: Roberts, 1992
Identification - Name in Khmer: ណង្ហាើ
Identification - Name in Khmer (roman): Tra sork sor
Identification - Name in English: Thicklip barb
Biology - Max. total length (cm): 183
Biology - Max. standard length (cm): 150
Biology - Length at maturity (cm): 76.7
Biology - Notes: probably will not survive in impoundments (Rainboth 1996); Large dams on the mainstream in Stung Treng and Kratie Provinces, would eliminate most of the rapids habitats that are important for its spawning (Roberts 1992).

Ecology vs. Hydrology - Discharge as migration trigger: no information
Ecology vs. Hydrology - Water level as migration trigger: no information
Reproduction - Breeds in reservoirs: Cannot breed in reservoirs
Ecology - Tonle Sap distribution: Hill, and Hill, 1994
Ecology - All MFD information: Migration: It has very similar migrations habits to P. jullieni, and the two species often migrate together (Roberts and Warren 1994, Poulsen and Valbo-Jørgensen 2000); In Southern Lao PDR migrates in December and the beginning of January (Baird et al. 1999); Upstream spawning migrations occur from October to February from Kompong Cham to Chiang Khong. At Chiang Khong, fishermen reported that migrants up the tributary Nam Ta in Lao PDR to spawn during March-April (Poulsen and Valbo-Jørgensen 2000); It is possible that Probarbus does not migrate long distances (Baird and Flaherty 2000). Spawning: Above the Khone Falls, the main spawning period is reported to be January to February, sometimes extending into March-April (Poulsen and Valbo-Jørgensen 2000); To date, the only confirmed spawning site in Laos for this species is just below the Khone Falls (Baird and Flaherty 2000); It used to spawn near Don Hee (Roberts and Warren 1994); Probarbus are apparently incapable of reproducing in
reservoirs (Roberts 1992). Distribution: Occurs throughout the survey area, from the Mekong Delta to the border between Lao PDR, Thailand and Myanmar (Poulsen and Valbo-Jørgensen 2000); Known to inhabit parts of the Mekong, Sekong, Sre Pok and Se San Rivers (Baird 1994); Found in large upland rivers of the middle and Lower Mekong Basin. Probably more common than P. jullieni in Stung Treng, but apparently not found in the Great Lake (Rainboth 1996). Feeding: Feeds on crabs, snails, insects, and aquatic plants (Baird et al. 1999).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Very low

Puntioplites bulu (Chavalit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Puntioplites bulu
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: [ឱក្កជ] កម្ម[ឱក្កជ]
IDENTIFICATION - Name in Khmer (roman): Kuch chreov
BIOLOGY - Max. total length (cm): 35
BIOLOGY - Length at maturity (cm): 21.2
BIOLOGY - Food: plants plants/detritus+animals
BIOLOGY - Notes: Formerly common, but very rare in recent years. It is a candidate for listing by the IUCN (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); Moves into flooded forests when water-levels are high (Rainboth 1996); Returns from the floodplain to the Tonle Sap in October where it formerly was taken in the dai fisheries (Blache and Goossens 1954). Spawning: 0 . Distribution: previously common in the Great Lake where it was an important part of the catch by the large traps (Fily and D'Aubenton 1966). Feeding: Feeds mostly on submerged plants along with some filamentous algae and insects that occur on the plants (Rainboth 1996).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

Puntioplites falcifer (Rainboth W.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Puntioplites falcifer
IDENTIFICATION - Author: Smith, 1929
IDENTIFICATION - Name in Khmer: [ឱក្កជ] កម្ម[ឱក្កជ]
IDENTIFICATION - Name in Khmer (roman): Chra kaeng
BIOLOGY - Length at maturity (cm): 23.8
BIOLOGY - Food: Mainly plants/detritus
BIOLOGY - Notes: It is a riverine species, which seems to avoid standing water (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: The Mekong Basin can be divided into four sections with distinct migration patterns: 1:
Northern Lao PDR and Thailand (from Loei-Chiang Rai Province): Upstream migrations here occur from Feb-May and in July-Aug, but the main period of upstream migration is from March-April. Downstream migration occurs from September-November; 2:
From Champassack to Nakhon Phanom Province: Upstream migrations in this region are concentrated in May-June. Downstream migrations are reported in November-December; 3:
Northern Cambodia (Stung Treng – Kratie): The species migrates upstream in this river stretch from November – December, and downstream in April-June; 4:
The Mekong in Viet Nam: Only one report on upstream migration in Tien Giang Province in July. The fish migrates downstream in October-December. It migrates in large schools often together with a number of other species, in particular Cosmochilus harmandi, Cirrhinus spp., Black sharkminnow (Labeo chrysophekadion), and Bangana sp. (Poulsen and Valbo-Jørgensen 2000);
This species probably enters seasonally inundated areas to feed during the high-water season (Baird and Phylavanh 1999); At the Nam Ngum Reservoir this species is apparently the first to migrate into rivers in April for spawning (Warren et al. Scott and Crossman 1973).
This fish species migrate up from Cambodia to Southern Lao in January-February, and returns to Cambodia to spawn in the flood season in July-August. After spawning the fish migrate to the floodplain and streams, at the end of the rainy season in November-December it returns to large rivers and streams (Baird et al. 1999). Spawning: It is a pelagic spawner, which lays buoyant or semi-buoyant eggs; It spawns in floodplains and mainstreams of large rivers (Warren et al. Scott and Crossman 1973); In July to August (Baird et al. 1999); Although also reported to spawn in small streams and in rice fields; The spawning season is protracted with eggs reported in the period from March-December (with most reports from May-June), and 2 cm long juveniles reported all the year (although in highest occurrence from May to November); Reported to attain sexual maturity, when it weighs about 0.3-0.4 kg (Poulsen and Valbo-Jørgensen 2000). Distribution: A common species in the mainstream Mekong all the way from Chiang Rai Province to the southernmost part of the Mekong Delta (Poulsen and Valbo-Jørgensen 2000); Occurs in the Xe Bangfai and Nam Theun Basins (Kottelat 1998); Common around Stung Treng; It does not seem to occur in the Great Lake (Rainboth 1996); Recorded from the Sekong (Baird et al. 1999). Feeding: Feeds on algae (Baird and Phylavanh 1999, Warren 2000), periphyton, other plant material (Warren 2000, Baird et al. 1999), detritus, bark, leaves (Baird and Phylavanh 1999), earthworms (Baird and Phylavanh 1999, Baird et al. 1999), insects (Baird and Phylavanh 1999, Rainboth 1996, Baird et al. 1999), insect larvae (Rainboth 1996, Baird et al. 1999), ant eggs (Baird et al. 1999); In reservoirs it apparently grazes extensively on the epiphytic growths of filamentous algae found growing on the remains of the drowned forest (Warren 2000).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Puntioplites proctozystron (Jean-Francois Helias / Fishing Adventures Thailand)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Puntioplites proctozystron
IDENTIFICATION - Author: Bleeker, 1865
IDENTIFICATION - Name in Khmer: ច្រេ កំង
IDENTIFICATION - Name in Khmer (roman): Chra kaeng
BIOLOGY - Max. total length (cm): 30
BIOLOGY - Length at maturity (cm): 18.5
BIOLOGY - Food: zoobenthos plants/detritus+animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: Can breed in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); Moves into flooded forests as well as into marshes during high-water periods. It begins to return to the Tonle Sap in October and becomes progressively more abundant until January, when its numbers begin to taper off (Rainboth 1996). Spawning: Spawning occurs in the rainy season (Janesirisak 1971), May to October (Banyen 1988), but the exact timing varies according to environmental factors such as rainfall and water current. In some reservoirs the fish spawns twice a year (Janesirisak 1971) in April-May and September (Duangsawasdi et al. 1988) or in May-August and again in October-November (Janesirisak 1971); Spawning occurs in slow moving water areas with muddy bottom (Watanadiroku and Murada 1985); Females become sexually mature at 12 cm (Duangsawasdi et al. 1988), 23 cm (Janesirisak 1971) or 25 cm (Bardach 1959); The fecundity of 23 cm female is 96,300-100,000 eggs (Janesirisak 1971); Fish of about 17-27 cm body length and of 79.0-278.0 g body weight have approx. 21,500-144,000 eggs. The average number is 62,700 (Duangsawasdi et al. 1988); The eggs are of the semi-buoyant type (Banyen et al. 1989, Banyen et al. 1989, Duangsawasdi et al. 1988, Banyen 1988), with an initial diameter of 0.73 mm (Banyen et al. 1989, Banyen et al. 1989, Duangsawasdi et al. 1988); Hatching occurs 12 hr after fertilization at 28ºC (Banyen et al. 1989, Banyen et al. 1989). . Distribution: Basin wide distribution in main river channel and large rivers. Feeding: Feeds on planktonic crustacea (Bardach 1959, Thoopbucha and Benjakarn 1973) including ostracodes and copepods (Janesirisak 1971), Protozoa (Thoopbucha and Benjakarn 1973), nematodes (Janesirisak 1971), algae, higher plants (Thoopbucha and Benjakarn 1973) and plant detritus (Janesirisak 1971).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Medium

Puntius aurotaeniatus (Chavallit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Puntius aurotaeniatus
IDENTIFICATION - Author: Tirant, 1885
IDENTIFICATION - Remark: puntius aurotaeniatus
BIOLOGY - Max. standard length (cm): 6
BIOLOGY - Length at maturity (cm): 4.5
BIOLOGY - Food: Mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: 0. Spawning: Spawns during the rainy season (Rainboth 1996, Baird et al. 1999) and half-grown young are caught in March (Rainboth 1996). . Distribution: Occurs in the Middle and Lower Mekong (Rainboth 1996); mainly in running waters (Pantulu 1986); Recorded from the Xe Bangfai and Nam Theun basins in Laos (Kottelat 1998). Feeding: Feeds primarily on zooplankton and insect larvae (Rainboth 1996, Baird et al. 1999).
ECOLOGY - Status: No information
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: High
**Puntius brevis** (Baird, I.G.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Puntius brevis*
**IDENTIFICATION** - Author: Bleeker, 1850

**IDENTIFICATION** - Name in Khmer: រត្បុំកប់តៃ
**IDENTIFICATION** - Name in Khmer (roman): Angkot prak

**BIOLOGY** - Max. total length (cm): 15
**BIOLOGY** - Max. standard length (cm): 12
**BIOLOGY** - Length at maturity (cm): 8.2
**BIOLOGY** - Food: zoobenthos mainly animals
**BIOLOGY** - Notes: proliferates in impoundments (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Spawns in floodplain lakes / rice field (% respondents): 95
**REPRODUCTION** - Spawns in streams / inlets (% respondents): 5
**REPRODUCTION** - Date of spawning (% respondents): May 2.7% Jul 5.4% Jun-Jul 59.5% May-Jun 29.7%, May-Sep 2.7%
**REPRODUCTION** - Nurses in floodplain (% respondents): 100

**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985; Lim et al. 1999
**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959); Moves onto newly inundated land during flood season (Rainboth 1996). Spawning: Females with ripe ovaries are found in July (Thiencharoen 1970) and spawning season may be in late rainy season, from July to October (Smith 1945); The fish has adhesive eggs (Thiencharoen 1970) and spawns in newly inundated land (Rainboth 1996); Females reach maturity at 7.6 cm, and males at 4.6 cm (Thiencharoen 1970). Distribution: Recorded from the Nam Theun and Xe Bangfai Basins (Kottelat 1998), Houay Ta Euang and Phapho swamp and Xe Lamphao (Baird et al. 1999); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Eats crustaceans, tubificid worms, zooplankton (Rainboth 1996), algae (Rainboth 1996, Baird et al. 1999), mud (Bardach 1959), terrestrial (Bardach 1959, Pothipituk 1970) and aquatic plants, green algae and diatoms (Pothipituk 1970); Insect larvae, and shrimps (Baird et al. 1999).

**ECOLOGY** - Feeds in floodplains (% respondents): 100
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High

**GUILD** - Black fish guild (% respondents): 100

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**Puntius masyai** (FAO)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Puntius masyai*
**Puntius orphoides** (Warren, T.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Puntius orphoides*
**IDENTIFICATION** - Author: Valenciennes, 1842
**IDENTIFICATION** - Name in Khmer: ១០៩១០៩១០៩១០៩២០៩១០៩៣០៩១០៩៤០៩១០៩៥
**IDENTIFICATION** - Name in Khmer (roman): Ampil tum
**IDENTIFICATION** - Name in English: Javaen barb
**BIOLOGY** - Max. total length (cm): 31
**BIOLOGY** - Max. standard length (cm): 25
**BIOLOGY** - Length at maturity (cm): 15.7
**BIOLOGY** - Food: plants mainly animals
**BIOLOGY** - Notes: Occasionally found in impoundments, but usually stays in the flowing streams leading to the impoundment (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Spawns in floodplain lakes / rice field (% respondents): 97.5
**REPRODUCTION** - Spawns in streams / inlets (% respondents): 2.5
**REPRODUCTION** - Date of spawning (% respondents): Jul 2.7% Jun-Jul 67.6% May-Jun 29.7%
**REPRODUCTION** - Nurses in floodplain (% respondents): 100
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959), which moves into seasonally inundated areas at the onset of the rainy season. Adults leave the floodplains as the water disappears in December or January (Rainboth 1996). Spawning: It breeds in the rainy season (Rainboth 1996, Duangsawasdi et al. 1989.), but the exact timing varies according to local environmental factors such as rainfall and current (Duangsawasdi et al. 1989.); in some rivers it spawns from February to June (Duangsawasdi et al. 1989), in others from March to September (Duangsawasdi et al. 1989.), in southern Lao PDR in June-July (Baird et al. 1999); The young of the year start to appear in streams in July and August; It breeds in floodplains (Rainboth 1996, Baird et al. 1999) in areas covered with vegetation (Leelapatra et al. 2000); The eggs are adhesive with an initial diameter of 0.7 mm (Jitpironsri et al. 1992) and will hatch 18-19 hours after fertilization at 27-28°C (Vongkamonchoon and Chatchavanthathri 1995.); The larva measures about 3 mm at hatching (Vongkamonchoon and Chatchavanthathri 1995.). The fish matures at 10-11 cm (Duangsawasdi et al. 1989., Duangsawasdi et al. 1989); There is considerable variation in fecundity in different environments, in Maeklong River fish of 10-18 cm and 15-80 g contain around 20,000 eggs (Duangsawasdi et al. 1989.); in Tha Chin River fish of 12 cm length contains about 80,000 eggs, and fish of 17 cm about 117,000 eggs (Duangsawasdi et al. 1989); In culture, fish with a total length of 10.9-12.3 cm and a body weight of 18.07-23.36 g contains about 7,300-15,000 eggs (Jitpironsri et al. 1992). . Distribution: Found basin wide in tributaries of the Mekong (Pantulu 1986). Feeding: Feeds on algae, insects and organic detritus (Jitpironsri et al. 1992).
Puntius artipentazona (Baird, I.G.)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Puntius partipentazona
IDENTIFICATION - Author: Fowler, 1934
BIOLOGY - Max. total length (cm): 5
BIOLOGY - Max. standard length (cm): 4
BIOLOGY - Length at maturity (cm): 3.1
BIOLOGY - Food: plants/detritus+animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Known from the Middle and Lower Mekong (Rainboth 1996). Feeding: Feeds primarily on zooplankton, along with some aquatic insect larvae and plant matter (Rainboth 1996, Baird et al. 1999).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: High

Raiamas guttatus (Chavalit Vidthayanon)

IDENTIFICATION - Family: Cyprinidae (Minnows or carps)
IDENTIFICATION - Species name: Raiamas guttatus
IDENTIFICATION - Author: Day, 1870
IDENTIFICATION - Name in English: Burmese trout
BIOLOGY - Max. total length (cm): 37
BIOLOGY - Max. standard length (cm): 30
BIOLOGY - Length at maturity (cm): 18.5
BIOLOGY - Food: zoobenthos mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959). Spawning: 0. Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986); It has been recorded from the Great Lake in Cambodia (Rainboth 1996), and it also occurs in the Xe Bangfai and Nam Theun basins (Kottelat 1998). Feeding: Feeds on fish (Baird and Phylavanh 1999, Rainboth 1996, Baird et al. 1999), insects (Rainboth 1996, Baird et al. 1999), detritus (Baird and Phylavanh 1999) and shrimps (Baird et al. 1999).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
**Rasbora urotaenia** (Baird, I.G.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Rasbora urotaenia*
**IDENTIFICATION** - Author: Tirant, 1885
**IDENTIFICATION** - Name in English: Pale rasbora

**BIOLOGY**
- Max. total length (cm): 19
- Max. standard length (cm): 15
- Length at maturity (cm): 10
- Food: zoobenthos plants/detritus+animals

**ECOLOGY vs. HYDROLOGY**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**REPRODUCTION**
- Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY**
- All MFD information: Migration: Migrates up from Tonle Sap, to Laos in January-February (Baird et al. 1999). Spawning: Spawns in June-July (Baird et al. 1999). Distribution: Recorded from Mekong at Pak Mun (37786); Found in southern Laos (Baird et al. 1999); and around the Tonle Sap river and Great Lake (Thuok, N and L. Sina, 1997). Feeding: probably feeds mostly on terrestrial insects and also on some algae (Rainboth 1996, Baird et al. 1999).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium

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**Rasbora caudimaculata** (Chavallit Vidthayanon)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Rasbora caudimaculata*
**IDENTIFICATION** - Author: Volz, 1903
**IDENTIFICATION** - Name in English: Greater scissortail

**BIOLOGY**
- Max. total length (cm): 21
- Max. standard length (cm): 17
- Length at maturity (cm): 11.2
- Food: zoobenthos mainly animals
- Notes: Not a common species, apparently occurs with only localized populations (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**REPRODUCTION**
- Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY**
- Tonle Sap distribution: Lamberts and Sarath, 1997
- All MFD information: Migration: 0. Spawning: 0. Distribution: 0. Feeding: Feeds primarily on terrestrial insects (Rainboth 1996).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium
**Rasbora daniconius** (Jayasinghe, A.)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: *Rasbora daniconius*
**IDENTIFICATION** - Author: Hamilton, 1822

**IDENTIFICATION** - Name in Khmer: រោយជាច្រូង
**IDENTIFICATION** - Name in Khmer (roman): Changva chnot

**BIOLOGY** - Max. total length (cm): 15
**BIOLOGY** - Length at maturity (cm): 7.2

**ECOLOGY** - Food: zoobenthos mainly animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Reproductive guild: Nonguarders: Open water/substratum egg scatterers
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High

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**Rasbora dusonensis** (JJPhoto)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: *Rasbora dusonensis*
**IDENTIFICATION** - Author: Bleeker, 1851

**IDENTIFICATION** - Name in Khmer: រោយវាយ
**IDENTIFICATION** - Name in Khmer (roman): Changva

**BIOLOGY** - Max. total length (cm): 15
**BIOLOGY** - Max. standard length (cm): 12
**BIOLOGY** - Length at maturity (cm): 9.2

**ECOLOGY** - Food: zoobenthos mainly animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High
**Rasbora hobelmani** (Rainboth W.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Rasbora hobelmani*
**IDENTIFICATION** - Author: Kottelat, 1984

**IDENTIFICATION** - Name in Khmer: រតិក្ខវា
**IDENTIFICATION** - Name in Khmer (roman): Changva
**IDENTIFICATION** - Name in English: Kottelat rasbora

**BIOLOGY** - Max. total length (cm): 8
**BIOLOGY** - Max. standard length (cm): 6
**BIOLOGY** - Length at maturity (cm): 4.5
**BIOLOGY** - Food: zoobenthos mainly animals

**ECOLOGY** - Discharge as migration trigger: no information
**ECOLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999


**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High

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**Rasbora myersi** (Rainboth W.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Rasbora myersi*
**IDENTIFICATION** - Author: Brittan, 1954

**IDENTIFICATION** - Name in Khmer: រតិក្ខវា
**IDENTIFICATION** - Name in Khmer (roman): Changva
**IDENTIFICATION** - Name in English: Siler rasbora

**BIOLOGY** - Max. standard length (cm): 10
**BIOLOGY** - Length at maturity (cm): 7
**BIOLOGY** - Food: plants/detritus+animals

**ECOLOGY** - Discharge as migration trigger: no information
**ECOLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: From FishBase

**ECOLOGY** - All MFD information: Migration: Migrate into small streams and floodplains. Spawning: 0. Distribution: Found in running waters of the Mekong (Pantulu 1986); Recorded from the Mekong Basin in Yunnan (Chu and Chen 1990); Known from the Mekong basin at Luang Prabang, Nam Ngum dam site, Tha Ngon, Hatdokkeo, Tha Bo, Sai Fong, Sithan Tay, Pakse and Pathoum Phon in Laos (DoF 1987); Phnom Penh and Stung Treng in Cambodia (ICLARM 2001); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds mostly on terrestrial insects, as well as some crustaceans and algae (Rainboth 1996, Baird et al. 1999).

**ECOLOGY** - Status: No information
**Rasbora paucisqualis** (FAO)

**IDENTIFICATION** - **Family:** Cyprinidae (Minnows or carps)
**IDENTIFICATION** - **Species name:** Rasbora paucisqualis
**IDENTIFICATION** - **Author:** Ahl, 1935
**IDENTIFICATION** - **Name in English:** Largescaled rasbora

**BIOLOGY** - **Max. total length (cm):** 5
**BIOLOGY** - **Max. standard length (cm):** 4
**BIOLOGY** - **Length at maturity (cm):** 3.1
**BIOLOGY** - **Food:** zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY** - **Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY** - **Water level as migration trigger:** no information

**REPRODUCTION** - **Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY** - **Tonle Sap distribution:** Lim et al. 1999

**ECOLOGY** - **Migration type:** No information on migration type
**ECOLOGY** - **Status:** Native
**ECOLOGY** - **Habitat:** Benthopelagic
**ECOLOGY** - **Resilience:** High

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**Rasbora paviana** (Baird, I.G.)

**IDENTIFICATION** - **Family:** Cyprinidae (Minnows or carps)
**IDENTIFICATION** - **Species name:** Rasbora paviei
**IDENTIFICATION** - **Author:** Tirant, 1885
**IDENTIFICATION** - **Name in Khmer:** RtIcgVaqñÚt
**IDENTIFICATION** - **Name in Khmer (roman):** Changva chnot
**IDENTIFICATION** - **Name in English:** Sidestripe rasbora

**BIOLOGY** - **Max. total length (cm):** 15
**BIOLOGY** - **Max. standard length (cm):** 12
**BIOLOGY** - **Length at maturity (cm):** 8.2
**BIOLOGY** - **Food:** zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY** - **Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY** - **Water level as migration trigger:** no information

**REPRODUCTION** - **Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY** - **Tonle Sap distribution:** Lim et al. 1999.

**ECOLOGY** - **All MFD information:** Migration: 0. Spawning: Spawns in rivers and ponds (Lim et al. 1999) in June-July (Günther 1868); A 12.6 cm individual has about 2,264 eggs with a diameter of 0.74 mm (Krachangdara 1994). Distribution: Occurs in the Xe Bangfai and Nam Theun Basins (Kottelat 1998); Houay Ka Luang, Houay Kuang, Xe Lamphao, Xe Pian and Xe Kamanh (Baird et al. 1999); Found in Tonle Sap and Great Lake (Lim et al. 1999); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Diet...
probably consists of terrestrial insects (Rainboth 1996, Krachangdara 1994, Baird et al. 1999), and aquatic plants (Krachangdara 1994).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: High

**Rasbora rubrodorsalis** (JJPhoto)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: Rasbora rubrodorsalis
**IDENTIFICATION** - Author: Donoso-Büchner and Schmidt, 1997
**BIOLOGY** - Max. total length (cm): 5
**BIOLOGY** - Max. standard length (cm): 3.3
**BIOLOGY** - Length at maturity (cm): 2.6
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** Motomura et al. 2002.
**ECOLOGY - All MFD information:** Migration: 0. Spawning: 0 . Distribution: 0. Feeding: Zooplanktivorous (Rainboth 1996).
**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** High

**Rasbora tornieri** (Rainboth W.)

**IDENTIFICATION** - Family: Cyprinidae (Minnows or carps)
**IDENTIFICATION** - Species name: Rasbora tornieri
**IDENTIFICATION** - Author: Ahl, 1922
**IDENTIFICATION** - Name in Khmer: តូចបូរក្ញម
**IDENTIFICATION** - Name in Khmer (roman): Changva moul
**IDENTIFICATION** - Name in English: Yellowtail rasbora
**BIOLOGY** - Max. total length (cm): 21
**BIOLOGY** - Max. standard length (cm): 17
**BIOLOGY** - Length at maturity (cm): 11.2
**BIOLOGY** - Food: zoobenthos mainly animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** Rainboth, 1996; Lim et al. 1999
**ECOLOGY - Status:** Native
<table>
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<th><strong>ECOLOGY</strong> - Habitat: Benthopelagic</th>
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<tr>
<td><strong>ECOLOGY</strong> - Resilience: Medium</td>
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![Rasbora pauciperforata](image1.jpg)

**Rasbora pauciperforata** *(Noren, M.)*

**IDENTIFICATION**
- **Family:** Cyprinidae (Minnows or carps)
- **Species name:** *Rasbora pauciperforata*
- **Author:** Weber and de Beaufort, 1916
- **Name in Khmer:** ការង៉ាារាយារ្វ្រារ្វ្រ្រារ្រ�
Thryssocypris tonlesapensis (Rainboth W.)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Thryssocypris tonlesapensis*
**IDENTIFICATION** - Author: Roberts and Kottelat, 1984

**BIOLOGY** - Max. total length (cm): 8
**BIOLOGY** - Max. standard length (cm): 6.4
**BIOLOGY** - Length at maturity (cm): 4.7
**BIOLOGY** - Food: zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
**ECOLOGY** - All MFD information: Migration: 0. Spawning: 0. Distribution: A Mekong endemic, found near the water surface from the Tonle Sap to the Mekong Delta. Highest numbers primarily in the tidal zone of large deltaic branches of the Lower Mekong (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Its diet consists of insect larvae (Rainboth 1996).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: pelagic
**ECOLOGY** - Resilience: High

Thynnichthys thynnoides (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: *Cyprinidae* (Minnows or carps)
**IDENTIFICATION** - Species name: *Thynnichthys thynnoides*
**IDENTIFICATION** - Author: Bleeker, 1852
**IDENTIFICATION** - Name in Khmer: [រូបិជ] (RtIlij)
**IDENTIFICATION** - Name in Khmer (roman): Linh

**BIOLOGY** - Max. total length (cm): 25
**BIOLOGY** - Length at maturity (cm): 15.7
**BIOLOGY** - Food: plants mainly plants/detritus

**ECOLOGY** - Food: plants mainly plants/detritus
**ECOLOGY** - Notes: It is a truly pelagic species (Warren 2000, Warren 2000) with a medium to long lifespan; It is a riverine species, which occasionally is found in reservoirs close to sizeable rivers (Warren 2000); Found in small schools (Krachangdara 1994).
**ECOLOGY** - All MFD information: Migration: 0. Spawning: 0. Distribution: A Mekong endemic, found near the water surface from the Tonle Sap to the Mekong Delta. Highest numbers primarily in the tidal zone of large deltaic branches of the Lower Mekong (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Its diet consists of insect larvae (Rainboth 1996).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: pelagic
**ECOLOGY** - Resilience: High
Kadir 1996, Rainboth 1996, Warren 2000), where the eggs are released near submerged macrophytes (Ali and Kadir 1996); It is probably a pelagic spawner producing buoyant or semi-buoyant eggs (Warren 2000); The egg diameter is 0.73-0.83 mm (Krachangdara 1994). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Facultative filter feeder (Warren 2000), which feeds on algae (Bardach 1959) both phytoplankton and periphyton (Rainboth 1996, Warren 2000) and smaller amounts of bottom algae and some small zooplankton (Rainboth 1996, Baird et al. 1999).

**ECOLOGY**
- **Migration type:** Displays longitudinal as well as lateral migrations.
- **Status:** Native
- **Habitat:** Benthopelagic
- **Resilience:** Medium

*Trigonostigma espei* (Åhlander, O.)

**IDENTIFICATION**
- **Family:** Cyprinidae (Minnows or carps)
- **Species name:** *Trigonostigma espei*
- **Author:** Meinken, 1967
- **Name in English:** Lambchop rasbora

**BIOLOGY**
- **Max. standard length (cm):** 2.5
- **Length at maturity (cm):** 2

**ECOLOGY vs. HYDROLOGY**
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**REPRODUCTION**
- **Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY vs. Tonle Sap**
- **Distribution:** Known from southern Laos (Baird et al. 1999). Feeding: 0
- **Status:** Native
- **Habitat:** Benthopelagic
- **Resilience:** High

*Datnioides microlepis* (JJPhoto)

**IDENTIFICATION**
- **Family:** Datnioididae
- **Species name:** *Datnioides microlepis*
- **Author:** Bleeker, 1853
- **Name in English:** Finescale tigerfish

**BIOLOGY**
- **Max. total length (cm):** 55
- **Max. standard length (cm):** 45
- **Length at maturity (cm):** 26.5
- **Food:** Mainly animals

**ECOLOGY vs. Tonle Sap**
- **Distribution:** Kottelat, 1985
- **Status:** Native
- **Habitat:** Benthopelagic
- **Resilience:** High
**Datnioides pulcher** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Datnioididae
**IDENTIFICATION** - Species name: *Datnioides pulcher*
**IDENTIFICATION** - Author: Kottelat, Scott and Crossman 1973

**IDENTIFICATION** - Name in Khmer: прослесец
**IDENTIFICATION** - Name in Khmer (roman): Khla

**BIOLOGY** - Max. standard length (cm): 40
**BIOLOGY** - Length at maturity (cm): 23.8

**BIOLOGY** - Notes: Common as single individuals in freshwaters throughout Cambodia (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: MFD occurrence map

**ECOLOGY** - All MFD information: Migration: A black fish species (Bardach 1959). Spawning: Spawns in March, the eggs are buoyant and approximately 0.8 mm in diameter (Rithcharung and Mahawong 1993). Distribution: 0. Feeding: A voracious predator, feeds on prawns, crabs, worms, insect larvae, and fishes (Rainboth 1996).

**ECOLOGY** - Status: No information

**ECOLOGY** - Habitat: Benthopelagic

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**Datnioides undecimradiatus** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Datnioididae
**IDENTIFICATION** - Species name: *Datnioides undecimradiatus*
**IDENTIFICATION** - Author: Roberts and Kottelat, 1994

**IDENTIFICATION** - Name in Khmer: прослесец
**IDENTIFICATION** - Name in Khmer (roman): Khla

**BIOLOGY** - Max. standard length (cm): 40
**BIOLOGY** - Length at maturity (cm): 23.8

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: From FishBase

**ECOLOGY** - All MFD information: Migration: 0. Spawning: Two females examined in February were full of eggs and two males examined in early March were in spawning condition, including one specimen that weighed only 30 g (Baird and Phylavanh 1999). Distribution: It apparently is restricted to freshwater in the Middle and Lower Mekong Basin (Thailand, Laos, Cambodia and probably Viet Nam) (Roberts and Kottelat 1994, Kottelat 2001). Feeding: Carnivorous: Feeds on fish and shrimps (Baird and Phylavanh 1999).

**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.

**ECOLOGY** - Status: Native

**ECOLOGY** - Habitat: Benthopelagic

**ECOLOGY** - Resilience: No information
**Oxyeleotris marmorata** (Chavalit Vidthayanon)

**IDENTIFICATION - Family:** Eleotridae (Sleepers)
**IDENTIFICATION - Species name:** Oxyeleotris marmorata
**IDENTIFICATION - Author:** Bleeker, 1852
**IDENTIFICATION - Name in Khmer:** រតុណ្ណមានរតុត
**IDENTIFICATION - Name in Khmer (roman):** Domrei
**IDENTIFICATION - Name in English:** Marble goby

**BIOLOGY - Max. standard length (cm):** 65
**BIOLOGY - Length at maturity (cm):** 36.6
**BIOLOGY - Food:** Nekton mainly animals

**BIOLOGY - Notes:** A slow moving predator (Rainboth 1996). Moves around slowly in middle of water but is very quickly at bottom of the water. The species prefer staying in mud or sand. This fish can stop moving immediately and sometimes look as if it is sleeping (Vivatchaiset 1993).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information
**REPRODUCTION - Breeds in reservoirs:** Can breed in reservoirs

**ECOLOGY - Tonle Sap distribution:** MFD occurrence map
**ECOLOGY - All MFD information:** Migration: A black fish species (Bardach 1959). Spawning: The fish has two spawning seasons in March-April, and in October-November (Bardach 1959) or April and September (Vivatchaiset 1993); becomes sexually mature at about 8 cm in length (Duangsawasdi et al. 1992); Fish measuring 15.2-21.5 cm have 6,800-36,300 eggs (Krachangdara 1994); Fish measuring 15-30 cm have 10,000-90,000 eggs. (Vivatchaiset 1993); The eggs are shaped like water drops and measure 0.6 x 2.2 mm (Krachangdara 1994) and are yellow (Vivatchaiset 1993). Distribution: A very common species in the Middle Mekong and often proliferates in reservoirs (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on fish (Rainboth 1986, 1349, Yap 1988, Ukkatawewat 1999, Krachangdara 1994, Duangsawasdi et al. 1992, Vivatchaiset 1993), shrimps, molluscs (Ukkatawewat 1999, Krachangdara 1994, Duangsawasdi et al. 1992, Vivatchaiset 1993), aquatic insects, and crabs (Ukkatawewat 1999); insect larvae, and detritus (Duangsawasdi et al. 1992); According to Bardach (1959) it feeds on planktonic crustaceans (Bardach 1959), however Yap (1988) found that even juveniles feed on fish (Yap 1988).

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Demersal

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**Coilia lindmani** (Rainboth W.)

**IDENTIFICATION - Family:** Engraulidae (Anchovies)
**IDENTIFICATION - Species name:** Coilia lindmani
**IDENTIFICATION - Author:** Bleeker, 1858
**IDENTIFICATION - Name in Khmer:** រតុណ្ណមានរតុត
**IDENTIFICATION - Name in Khmer (roman):** Chunluhngh moan
**IDENTIFICATION - Name in English:** Lindman's grenadier anchovy

**BIOLOGY - Max. total length (cm):** 25
**BIOLOGY - Max. standard length (cm):** 20
**BIOLOGY**

- **Length at maturity (cm):** 12.9
- **Food:** Nekton mainly animals

**COLOGY vs. HYDROLOGY**

- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**REPRODUCTION**

- **Spawns in floodplain lakes / rice field (% respondents):**
- **Spawns in rivers (% respondents):**
- **Spawns in streams / inlets (% respondents):** 97.5
- **Spawns in TS permanent lake (% respondents):** 2.5
- **Date of spawning (% respondents):** Jun-Jul 73.7%, May-Jul 2.6%, May-Jun 23.7%
- **Nurses in floodplain (% respondents):** 100
- **Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY**

- **Tonle Sap distribution:** Rainboth, 1996; Kottelat, M., 1985
- **All MFD information:** Migration: This species seems to have no discernable migratory pattern in the lower Mekong (Blache and Goossens 1954). Spawning: 0 . Distribution: The most common grenadier anchovy in the Cambodian Mekong ranging from the delta to the Great Lake and as far upstream as Stung Treng (Rainboth 1996). Feeding: 0
- **Feeds in floodplains (% respondents):** 100
- **Status:** Native
- **Habitat:** pelagic
- **Resilience:** High
- **Grey fish guild (% respondents):** 100

**IDENTIFICATION**

- **Family:** Engraulidae (Anchovies)
- **Species name:** Coilia macrognathos
- **Author:** Bleeker, 1852
- **Name in Khmer:** Chunlung moan
- **Name in Khmer (roman):** Chunlung moan
- **Name in English:** Longjaw grenadier anchovy
- **Max. total length (cm):** 32
- **Max. standard length (cm):** 26
- **Length at maturity (cm):** 16.3
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information
- **Spawns in streams / inlets (% respondents):** 97.5
- **Spawns in TS permanent lake (% respondents):** 2.5
- **Date of spawning (% respondents):** Jun-Jul 73.7%, May-Jul 2.6%, May-Jun 23.7%
- **Nurses in floodplain (% respondents):** 100
- **Breeds in reservoirs:** No info on breeding in reservoirs
- **Tonle Sap distribution:** Lim et al. 1999; CNM, Scott and Crossman 1973
- **All MFD information:** Migration: A white fish species (Bardach 1959); it does not seem to have any discernable migratory pattern however (Rainboth 1996). Spawning: 0 . Distribution: A common species in the Mekong Delta. Less common though still present in the Tonle Sap and the Great Lake (Rainboth 1996). Feeding: 0
- **Feeds in floodplains (% respondents):** 100
- **Status:** Native
- **Habitat:** pelagic
- **Resilience:** High
- **Grey fish guild (% respondents):** 100
**Lycothrissa crocodilus** (Rainboth W.)

**IDENTIFICATION - Family:** Engraulidae (Anchovies)
**IDENTIFICATION - Species name:** *Lycothrissa crocodilus*
**IDENTIFICATION - Author:** Bleeker, 1851

**IDENTIFICATION - Name in Khmer:** តុងក្រីឆ្លាក់
**IDENTIFICATION - Name in Khmer (roman):** Chhmar krapeu
**IDENTIFICATION - Name in English:** Sabretoothed thryssa

**BIOLOGY - Max. total length (cm):** 37
**BIOLOGY - Max. standard length (cm):** 30
**BIOLOGY - Length at maturity (cm):** 18.5
**BIOLOGY - Food:** Nekton mainly animals

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** Water level variation is a migration trigger

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Rainboth, 1996
**ECOLOGY - All MFD information:** Migration: Rainboth (1996) stated that the species is non-migratory because its numbers remain uniform in the Tonle Sap throughout the fishing season (Rainboth 1996); However Bardach (1959) postulated that it is a white fish species; and it has been found to migrate upstream from the Delta during the dry season from October to March and downstream at the onset of the rainy season, from May to July (Poulsen and Valbo-Jørgensen 2000). Spawning: Developing eggs are mostly found around March to April. This suggests that eggs develop during the dry season and spawning occurs either during late dry season or at the onset of the flood season (Poulsen and Valbo-Jørgensen 2000).
**Distribution:** Occurs from just downstream the Khone Falls to the Mekong Delta (Poulsen and Valbo-Jørgensen 2000, Kottelat 2001); Common in the Mekong Delta up to the Tonle Sap and in the Great Lake (Rainboth 1996).
**Feeding:** Diet consists of crustaceans, small fishes (Vaas 1953, Bardach 1959, Baird et al. 1999) and insects (Vaas 1953, Baird et al. 1999). From FishBase: From the Khone Falls to the Mekong delta, it migrates upstream during the dry season from October to March and downstream at the onset of the monsoon season from May to July (Ferraris 2001). These migrations are reportedly triggered by the receding or rising of the water levels (Ferraris 2001). Feeds on crustaceans, insects and small fishes (Rainboth 1996).

**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.
**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** pelagic
**ECOLOGY - Resilience:** High

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**Setipinna melanochir** (Chavalit Vidthayanon)

**IDENTIFICATION - Family:** Engraulidae (Anchovies)
**IDENTIFICATION - Species name:** *Setipinna melanochir*
**IDENTIFICATION - Author:** Bleeker, 1849

**IDENTIFICATION - Name in Khmer:** ឈុតពិណាដក់កđរាណ
**IDENTIFICATION - Name in Khmer (roman):** Chhma
**IDENTIFICATION - Name in Khmer (roman):** Chhma
**IDENTIFICATION - Name in Khmer (roman):** Chhma
**IDENTIFICATION - Name in English:** Dusky-hairfin anchovy

**BIOLOGY - Max. total length (cm):** 41
**BIOLOGY - Max. standard length (cm):** 33
**Glossogobius aureus** (Murdy, E.O./Ferraris, C.J., Jr.)

**IDENTIFICATION** - Family: **Gobiidae** (Gobies)
**IDENTIFICATION** - Species name: **Glossogobius aureus**
**IDENTIFICATION** - Author: Akihito and Meguro, 1975

**IDENTIFICATION** - Name in Khmer: រត្សីក្រូន
**IDENTIFICATION** - Name in Khmer (roman): Khman
**IDENTIFICATION** - Name in English: Golden tank goby
**BIOLOGY** - Max. total length (cm): 31
**BIOLOGY** - Max. standard length (cm): 25
**BIOLOGY** - Length at maturity (cm): 15.7
**BIOLOGY** - Food: Nekton mainly animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959). Spawning: 0.
Distribution: Common in the Mekong, as far upstream as Thailand (Rainboth 1996); Mekong Basin in Laos downstream of Khone falls, Cambodia and Viet Nam (Kottelat 2001); Becomes abundant in the Middle Mekong when the water levels rise and turbidity increases (Rainboth 1996). Feeding: primarily feeds on insect larvae and small fishes (Vaas 1953, Baird et al. 1999).

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: pelagic
**ECOLOGY** - Resilience: High

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**Gyrinocheilus aymonieri** (Rainboth W.)

**IDENTIFICATION** - Family: **Gyrinocheilidae** (Algae eaters)
**IDENTIFICATION** - Species name: **Gyrinocheilus aymonieri**
**IDENTIFICATION** - Author: Tirant, 1883

**IDENTIFICATION** - Name in English: Chinese algae-eater
**BIOLOGY** - Max. total length (cm): 35
**BIOLOGY** - Max. standard length (cm): 28
**BIOLOGY** - Length at maturity (cm): 17.4
**BIOLOGY** - Food: plants/detritus+animals

**BIOLOGY** - Notes: It holds on to fixed objects with its sucker-like mouth, it breathes by pumping water into the gill cavity through a small spiracle (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Likely (recorded in Cambodia, in Phnom Penh and in floodplains)
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959). Spawning: 0 .
Distribution: Found basin wide in tributaries of the Mekong (Pantulu 1986); Reported from the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Its diet consists largely of mud (Bardach 1959) detritus (Krachangdara 1994), and algae (Bardach 1959, Rainboth 1996, Krachangdara 1994), periphyton, and phytoplankton; but it also feeds on insect larvae and zooplankton (Rainboth 1996).
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: No information

**Hyporhamphus limbatus** (E. D’Antoni in Rainboth)

IDENTIFICATION - Family: Hemiramphidae (Halfbeaks)
IDENTIFICATION - Species name: *Hyporhamphus limbatus*
IDENTIFICATION - Author: Valenciennes, 1847
IDENTIFICATION - Name in Khmer: ឈឺហួរមេស្តី៖
IDENTIFICATION - Name in Khmer (roman): Phitoung
IDENTIFICATION - Name in English: Congaturi halfbeak
BIOLOGY - Max. standard length (cm): 25
BIOLOGY - Length at maturity (cm): 15.7
BIOLOGY - Food: zoobenthos mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in streams / inlets (% respondents): 100
REPRODUCTION - Spawns in TS permanent lake (% respondents):
REPRODUCTION - Date of spawning (% respondents): Jul-Aug 5.3% July-Sep 2.6%, Jun-Jul 63.2% May-Jun 28.9%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: 0. Spawning: 0 . Distribution: Seen in the Mekong as far upstream as Stung Treng, and also found in the Great Lake (Rainboth 1996). Feeding: Insectivorous (Rainboth 1996, Lim et al. 1999, Collette and Su 1986).
ECOLOGY - Migration type: Only seems to display Longitudinal migrations.
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: No information
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: High
GUILD - Grey fish guild (% respondents): 100

**Zenarchopterus ectuntio** (Chavalit Vidthayanon)

IDENTIFICATION - Family: Hemiramphidae (Halfbeaks)
IDENTIFICATION - Species name: *Zenarchopterus ectuntio*
IDENTIFICATION - Author: Hamilton, 1822
BIOLOGY - Max. total length (cm): 18
BIOLOGY - Length at maturity (cm): 11.8
**BIOLOGY** - Food: plants/detritus+animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information

**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985


**ECOLOGY** - Status: Native

**ECOLOGY** - Habitat: pelagic

**ECOLOGY** - Resilience: High

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Macrognathus circumcinctus (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Mastacembelidae (Spiny eels)

**IDENTIFICATION** - Species name: *Macrognathus circumcinctus*

**IDENTIFICATION** - Author: Hora, 1924

**BIOLOGY** - Max. total length (cm): 20.0 SL

**BIOLOGY** - Length at maturity (cm): 12.9

**BIOLOGY** - Food: Mainly animals

**BIOLOGY** - Notes: Nocturnally active (Riehl and Baensch 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information

**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985


**ECOLOGY** - Status: Native

**ECOLOGY** - Habitat: Demersal

**ECOLOGY** - Resilience: High

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Macrognathus maculatus (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: Mastacembelidae (Spiny eels)

**IDENTIFICATION** - Species name: *Macrognathus maculatus*

**IDENTIFICATION** - Author: Cuvier, 1832

**IDENTIFICATION** - Name in Khmer: ំគេង ឈ្ម័ញង

**IDENTIFICATION** - Name in Khmer (roman): Khchoeung

**IDENTIFICATION** - Name in English: Frecklefin eel

**BIOLOGY** - Max. total length (cm): 28

**BIOLOGY** - Length at maturity (cm): 15.9

**BIOLOGY** - Food: zoobenthos mainly animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information

**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999


**ECOLOGY** - Status: Native
<table>
<thead>
<tr>
<th><strong>Macrognathus semiocellatus</strong> (Chavalit Vidthayanon)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECOLOGY</strong> - Habitat: Benthopelagic</td>
</tr>
<tr>
<td><strong>ECOLOGY</strong> - Resilience: Medium</td>
</tr>
</tbody>
</table>

**IDENTIFICATION** - Family: **Mastacembelidae** (Spiny eels)
**IDENTIFICATION** - Species name: *Macrognathus semiocellatus*
**IDENTIFICATION** - Author: Roberts, 1986
**BIOLOGY** - Max. total length (cm): 24
**BIOLOGY** - Max. standard length (cm): 19.2
**BIOLOGY** - Length at maturity (cm): 12.5
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Motomura et al. 2002
**ECOLOGY** - All MFD information: Migration: 0. Spawning: 0. Distribution: Mekong Basin in Laos, Thailand, Cambodia and Viet Nam (Kottelat 2001); Recorded from the Xe Bangfai Basin (Kottelat 1998), Feeding: 0
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High

<table>
<thead>
<tr>
<th><strong>Macrognathus siamensis</strong> (Baird, I.G.)</th>
</tr>
</thead>
</table>
| **IDENTIFICATION** - Family: **Mastacembelidae** (Spiny eels)
**IDENTIFICATION** - Species name: *Macrognathus siamensis*
**IDENTIFICATION** - Author: Günther, 1861
**IDENTIFICATION** - Name in Khmer: ជ្រេងពង | **IDENTIFICATION** - Name in English: Peacock eel
**BIOLOGY** - Max. total length (cm): 37
**BIOLOGY** - Max. standard length (cm): 30
**BIOLOGY** - Length at maturity (cm): 18.5
**BIOLOGY** - Food: zoobenthos mainly animals
**BIOLOGY** - Notes: Spends much of its time buried in the silt, sand, or fine gravel with only a part of its head protruding from the bottom, but it emerges at dusk to forage for food (Rainboth 1996).
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999
**ECOLOGY** - All MFD information: Migration: A black fish species (Bardach 1959). Spawning: 0. Distribution: Recorded in the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on benthic insect larvae, crustaceans, and worms (Rainboth 1996).
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High

| **Macrognathus taeniagaster** (Baird, I.G.) |
**IDENTIFICATION** - Family: Mastacembelidae (Spiny eels)
**IDENTIFICATION** - Species name: Macrognathus taeniagaster
**IDENTIFICATION** - Author: Fowler, 1935
**BIOLOGY** - Max. total length (cm): 20
**BIOLOGY** - Max. standard length (cm): 16
**BIOLOGY** - Length at maturity (cm): 10.6
**BIOLOGY** - Food: zoobenthos mainly animals
**BIOLOGY** - Notes: During the daytime, it spends much of its time buried in silt, sand, or fine gravel with only the snout and eyes protruding from the bottom, but it emerges at night to forage (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Lim et al. 1999
**ECOLOGY - All MFD information:** Migration: 0. Spawning: 0 . Distribution: Very common in the Mekong and often seen in impoundments (Rainboth 1996). Feeding: Feeds on benthic insect larvae, crustaceans, and worms (Rainboth 1996).

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** High

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**IDENTIFICATION** - Family: Mastacembelidae (Spiny eels)
**IDENTIFICATION** - Species name: Mastacembelus armatus
**IDENTIFICATION** - Author: Lacepède, 1800
**IDENTIFICATION** - Name in Khmer: រឿងតូច
**IDENTIFICATION** - Name in Khmer (roman): Khchoeung
**BIOLOGY** - Max. total length (cm): 31
**BIOLOGY** - Length at maturity (cm): 48.8
**BIOLOGY** - Food: zoobenthos plants/detritus+animals
**BIOLOGY** - Notes: Sometimes rests partially buried in fine substrates, and forages at night (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Lim et al. 1999
**ECOLOGY - All MFD information:** Migration: It is a non-migratory (Bardach 1959) or at least relatively stationary species, which performs only short local migrations (Poulsen and Valbo-Jørgensen 2000); however during the flood season part of the population moves to floodplain habitats in the vicinity of the dry season refuges mainly to feed (Poulsen and Valbo-Jørgensen 2000). Spawning: Has developed eggs all the year with a peak in April-June; Was reported to spawn in a whirlpool in April – May, where the eggs stuck to filamentous algae in the whirlpool; It was however also reported to spawn in rice fields (Poulsen and Valbo-Jørgensen 2000). The eggs have a diameter of 1.8-1.9 mm (Krachangdara 1994) . Distribution: The species occurred at all mainstream stations from Chiang Saen to the Lower Mekong Delta, and at many stations it occurs all the year. The level of abundance, however, is very variable, even between closely situated stations. In Cambodia south of Kratie fishers indicate that it is a rare species (Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002); Feeding: Feeds on fishes and insects (Krachangdara 1994), benthic insect larvae, worms, and some submerged plant material (Rainboth 1996).

**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.
**ECOLOGY - Status:** Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High

*Mastacembelus erythrotaenia* (NREB, Sarawak/ DANIDA )

**ID** - Family: *Mastacembelidae* (Spiny eels)
**ID** - Species name: *Mastacembelus erythrotaenia*
**ID** - Author: Bleeker, 1850
**ID** - Name in Khmer: រតីគ្រាត
**ID** - Name in Khmer (roman): Khchoeung pkhar
**ID** - Name in English: Fire eel

**Biology** - Max. total length (cm): 100
**Biology** - Length at maturity (cm): 53.5
**Biology** - Food: zoobenthos plants/detritus+animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs

**Ecology** - Tonle Sap distribution: Lim et al. 1999
**Ecology** - All MFD information: Migration: 0. Spawning: 0. Distribution: Known from the Lower Mekong floodplain, but not yet recorded from upland areas of the Middle Mekong. This species has apparently become rare in recent years (Rainboth 1996). Feeding: Feeds on benthic insect larvae, worms, and some plant material (Rainboth 1996).

**Ecology** - Status: Native
**Ecology** - Habitat: Demersal
**Ecology** - Resilience: Medium

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*Mastacembelus favus* (Warren, T.)

**ID** - Family: *Mastacembelidae* (Spiny eels)
**ID** - Species name: *Mastacembelus favus*
**ID** - Author: Hora, 1924
**ID** - Name in Khmer: រតីគ្រាត
**ID** - Name in Khmer (roman): Khchoeung
**ID** - Name in English: Tire track eel

**Biology** - Max. total length (cm): 86
**Biology** - Max. standard length (cm): 70
**Biology** - Length at maturity (cm): 39.1
**Biology** - Food: zoobenthos plants/detritus+animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs

**Ecology** - Tonle Sap distribution: Lim et al. 1999
**Ecology** - Migration type: No information on migration type
**Ecology** - Status: Native
**Ecology** - Habitat: Demersal
**Ecology** - Resilience: Medium

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No picture available

**ID** - Family: *Nandidae* (Asian leaffishes)
**ID** - Species name: *Nandus nebulosus*
**ID** - Author: Gray, 1835
IDENTIFICATION - Name in English: Bornean leaffish
BIOLOGY - Max. total length (cm): 12
BIOLOGY - Length at maturity (cm): 8.2
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: 0. Feeding: 0
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

Pristolepis fasciata (Jean-Francois Helias / Fishing Adventures Thailand)

IDENTIFICATION - Family: Nandidae (Asian leaffishes)
IDENTIFICATION - Species name: Pristolepis fasciata
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: ត្រនាក់ប្រាសាទ
IDENTIFICATION - Name in Khmer (roman): Kantrob
IDENTIFICATION - Name in English: Catopra
BIOLOGY - Max. total length (cm): 20
BIOLOGY - Length at maturity (cm): 12.9
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: It has upper and lower palatal tooth plates which it uses to grind coarse or shelled food organisms (Warren 2000); Feeding activity peaks at 6 AM and reaches a minimum at 10 PM (Duangsawasdi et al. 1990). It is a demersal or semi-pelagic species and probably short-lived (Warren 2000).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: Can breed in reservoirs
ECOLOGY - All MFD information: Migration: A black fish species (Bardach 1959); Enters smaller streams and floodplains at the onset of the floods. These movements are triggered mainly by changes in water levels (Poulsen and Valbo-Jørgensen 2000). Spawning: Eggs were reported from March to October with a peak from April to June (Poulsen and Valbo-Jørgensen 2000), and it spawns from June to August or September in the Mekong (Bardach 1959, Baird and Phylavanh 1999); and March to September in the Maeklong (Duangsawasdi et al. 1989); In reservoirs it spawns at almost any time of the year with a peak spawning probably takes place in the wet-season months (Warren 2000); May to June (Singhapitukiet and Jermitpong 1980) or from May to August (Dumrongtripob et al. 1997); In reservoirs it spawns at the inlet (Dumrongtripob et al. 1997), and it has a preference for submerged leafy vegetation (Warren 2000).
According to some reports eggs are sticky, large and yolky (Warren 2000), others state that they are floating or pelagic with a diameter of 0.6-0.8 mm (Singhapitukiet and Jermitpong 1980). Hatching occurs after around 22 hr at 28-29°C (Singhapitukiet and Jermitpong 1980, Chumnongsittatham et al. 1992); The size of larvae at hatching is around 2.5 mm in total length (Chumnongsittatham et al. 1992). Females attain sexual maturity around 7-10 cm total length (Dumrongtripob et al. 1997, Duangsawasdi et al. 1989., Warren 2000); Females 10-18 cm long and weighing 15-80 g contain around 20,000 eggs (Duangsawasdi et al. 1989.); Fish measuring 14.0-20.0 cm have 5,476-34,441 eggs with a diameter of 0.85-0.95 mm (Krachangdara 1994). Distribution: Occurs throughout the mainstream from Chiang Saen to the Mekong Delta (Poulsen and Valbo-Jørgensen 2000); and in tributaries (Pantulu 1986); Recorded from the Xe Bangfai Basin...
Chitala chitala (Patzner, R. )

**IDENTIFICATION - Family:** Notopteridae
**IDENTIFICATION - Species name:** Chitala chitala
**IDENTIFICATION - Author:** Hamilton, 1822
**IDENTIFICATION - Name in English:** Clown knifefish
**BIOLOGY - Max. total length (cm):** 149
**BIOLOGY - Length at maturity (cm):** 63.9
**BIOLOGY - Food:** Mainly animals

**ECOLOGY - Tonle Sap distribution:** Kottelat, 1985
**ECOLOGY - Status:** Misidentification
**ECOLOGY - Habitat:** Demersal
**ECOLOGY - Resilience:** No information

Chitala blanci (Warren, T.)

**IDENTIFICATION - Family:** Notopteridae (Featherbacks or knifefishes)
**IDENTIFICATION - Species name:** Chitala blanci
**IDENTIFICATION - Author:** d’Aubenton, 1965
**IDENTIFICATION - Name in Khmer:** ម៉ាសីយុត្តាមួយ (Rom.: Kray)
**IDENTIFICATION - Name in English:** Indochina featherback
**BIOLOGY - Max. total length (cm):** 147
**BIOLOGY - Max. standard length (cm):** 120
**BIOLOGY - Length at maturity (cm):** 62.9
**BIOLOGY - Food:** Nekton mainly animals
**BIOLOGY - Notes:** It was reported that it has habits similar to those of the clown featherback (C. ornata). It was mentioned that it is possible to distinguish between the two species by observing them when they surface, e.g. during spawning (Poulsen and Valbo-Jørgensen 2000); Active during the twilight and at night (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** Water level variation is a migration trigger

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** Lim et al. 1999
ECOLOGY - All MFD information: Migration: Does not migrate extensively (Roberts 1993), it is only undertaking short, local migrations. However it is reported to migrate into smaller tributaries when the water starts to rise, and then return to the main river when it recedes (Poulsen and Valbo-Jørgensen 2000). Spawning: The species carries eggs most of the year, but the main period is from April to May, this indicates that spawning mainly occurs in the late dry season. Spawning takes place within the main river channel in areas with submerged wood and rocks, and the female guards the fry (Poulsen and Valbo-Jørgensen 2000). Distribution: Occurs in the mainstream of the Mekong in Thailand, Laos and Cambodia (Kottelat 1998, Roberts 1992) where it occurs from Xayaboury to Kompong Cham. However, it is rare in Kompong Cham Province (Poulsen and Valbo-Jørgensen 2000); and the main distribution area may be from Khemerat, to Kratie (Rainboth 1996); It also occurs in the lower course of some tributaries including the Xe Bangfai (Kottelat 1998); but it avoids smaller tributaries and swamps (Roberts 1992). Feeding: Feeds on fish (Baird and Phylavanh 1999, Rainboth 1996, Baird et al. 1999), insects (Rainboth 1996, Baird et al. 1999), crustaceans (Rainboth 1996) including shrimps (Baird and Phylavanh 1999, Baird et al. 1999) and crabs, also shell fish, (Baird et al. 1999), earthworms, leaves, snails, and detritus (Baird and Phylavanh 1999).

ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Low

Chitala lopis (Rainboth W.)

IDENTIFICATION - Family: **Notopteridae** (Featherbacks or knifefishes)
IDENTIFICATION - Species name: **Chitala lopis**
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: រត្តវាផ្ញា
IDENTIFICATION - Name in Khmer (roman): Kray
IDENTIFICATION - Name in English: Giant featherback

BIOLOGY - Max. standard length (cm): 150
BIOLOGY - Length at maturity (cm): 76.7
BIOLOGY - Food: Mainly animals (troph. 2.8 and up)
BIOLOGY - Notes: probably has a crepuscular or nocturnal activity pattern (Rainboth 1996).

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information

REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs

ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Found most often in the upland area from Khone Falls to Kratie, and is not known from the Great Lake (Rainboth 1996); but is also known from Thailand (Kottelat 2001). Feeding: piscivorous (Rainboth 1996).

ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Very low

Chitala ornata (Baird, I.G.)

IDENTIFICATION - Family: **Notopteridae** (Featherbacks or knifefishes)
**IDENTIFICATION** - Species name: *Chitala ornata*
**IDENTIFICATION** - Author: Gray, 1831
**IDENTIFICATION** - Name in Khmer: រត្សុក
**IDENTIFICATION** - Name in Khmer (roman): Kray
**IDENTIFICATION** - Name in English: Clown featherback
**BIOLOGY** - Max. total length (cm): 122
**BIOLOGY** - Max. standard length (cm): 100
**BIOLOGY** - Length at maturity (cm): 53.5
**BIOLOGY** - Food: Nekton mainly animals
**BIOLOGY** - Notes: Crepuscular and night active (Rainboth 1996); It was reported that its habits are similar to those of the royal featherback (C. blanchi). It was mentioned that it is possible to distinguish between the two species by observing them when they surface, e.g. during spawning (Poulsen and Valbo-Jørgensen 2000).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999
**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959); Throughout the range, it is reported to migrate locally and move into smaller tributaries and flooded areas (Poulsen and Valbo-Jørgensen 2000) including inundated forest (Rainboth 1996) during the flood season, and return to the main river channel when the water starts to recede (Poulsen and Valbo-Jørgensen 2000). Spawning: Eggs are laid on submerged wood over an extended period from March to July (Poulsen and Valbo-Jørgensen 2000, Smith 1945); In June in Cambodia (Bardach 1959) and in Thailand; It is reported to show parental care by the male (Smith 1945) and the female (Poulsen and Valbo-Jørgensen 2000). Two large specimens (about 700 mm SL) have been observed splashing at the surface of a deep pool upstream of Mahaxai on 6 March 1996 in what could have been spawning or courting behaviour (Kottelat 1998). Distribution: Only known from the mainstream of the Mekong and the lower course of some tributaries (Kottelat 1998); Found basin wide in the mainstream Mekong (Pantulu 1986); Occurs from Chiang Khong to the Mekong Delta, except for the lowermost part (Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002); Also recorded from the Xe Bangfai Basin (Kottelat 1998). Feeding: Feeds on surface-feeding fishes, insects, and crustaceans (Rainboth 1996, Baird et al. 1999) including shrimps, and crabs, and also shellfish (Baird et al. 1999).
**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: pelagic
**ECOLOGY** - Resilience: Low

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**IDENTIFICATION** - Family: *Notopteridae* (Featherbacks or knifefishes)
**IDENTIFICATION** - Species name: *Notopterus notopterus*
**IDENTIFICATION** - Author: pallas, 1769
**IDENTIFICATION** - Name in Khmer: រត្សុក
**IDENTIFICATION** - Name in Khmer (roman): Slat
**IDENTIFICATION** - Name in English: Bronze featherback
**BIOLOGY** - Max. total length (cm): 74
**BIOLOGY** - Max. standard length (cm): 60
**BIOLOGY** - Length at maturity (cm): 34.1
**BIOLOGY** - Food: Nekton mainly animals
**BIOLOGY** - Notes: Most active during the twilight and at night (Rainboth 1996).
Osphronemus exodon (Warren, T.)

**IDENTIFICATION** - Family: Osphronemidae (Gouramies)
**IDENTIFICATION** - Species name: Osphronemus exodon
**IDENTIFICATION** - Author: Roberts, 1994

**IDENTIFICATION** - Name in Khmer: រត្តីរត្តីរត្តីរត្តី
**IDENTIFICATION** - Name in Khmer (roman): Trocheak domrei
**IDENTIFICATION** - Name in English: Elephant ear gourami

**BIOLOGY** - Max. standard length (cm): 60
**BIOLOGY** - Length at maturity (cm): 34.1
**BIOLOGY** - Food: plants/detritus+animals

**BIOLOGY** - Notes: A long living pelagic or semi-pelagic species (Warren 2000); Large individuals, over 40 cm (SL), have enlarged jaw teeth, which lie on the external surface of the jaws entirely outside the mouth when it is shut (Roberts 1994), the extraordinary dentition may facilitate feeding and foraging on roots and other plant matter, and may also be used when it makes its nest out of fine roots (Baird and Phylavanh 1999).

**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: Medium
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Pelagic
ECOLOGY - Resilience: No information

Trichogaster microlepis (Rainboth W.)

IDENTIFICATION - Family: Osphronemidae (Gouramies)
IDENTIFICATION - Species name: Trichogaster microlepis
IDENTIFICATION - Author: Günther, 1861
IDENTIFICATION - Name in Khmer: រំដូចមួយដ៏ធំ ឬ រំដូចមួយ អំពីវីនី
IDENTIFICATION - Name in Khmer (roman): Kamphleanh phluk
IDENTIFICATION - Name in English: Moonlight gourami

BIOLOGY - Max. total length (cm): 16
BIOLOGY - Max. standard length (cm): 13
BIOLOGY - Length at maturity (cm): 8.8
BIOLOGY - Food: zoobenthos mainly animals

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information

REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs


ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium
**Trichogaster pectoralis** (Rainboth W.)

**IDENTIFICATION** - Family: *Osphronemidae* (Gouramies)
**IDENTIFICATION** - Species name: *Trichogaster pectoralis*
**IDENTIFICATION** - Author: Regan, 1910

**IDENTIFICATION** - Name in Khmer: រតាក្សាដាម
**IDENTIFICATION** - Name in Khmer (roman): Kantho
**IDENTIFICATION** - Name in English: Snakeskin gourami

**BIOLOGY** - Max. total length (cm): 25
**BIOLOGY** - Length at maturity (cm): 15.7
**BIOLOGY** - Food: zooplankton mainly animals

**BIOLOGY** - Notes: A hardy, medium to long-lived species (Warren 2000); It has a special air-breathing organ, which allows it to breathe atmospheric air and therefore live in oxygen poor water (1036777, Duangsawasdi et al. 1992), but it can also absorb oxygen from water over the gills (Frimodt 1995); At least one country reports adverse ecological impact after introduction (Welcomme 1988).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs


**ECOLOGY** - All MFD information: Migration: Non migratory (Bardach 1959, Warren 2000); Found in flooded forests and gradually moves back to rivers and the Great Lake as floodwaters recede (Rainboth 1996). Spawning: Spawns throughout the rainy season (Anon 1997, Tongsanga 1958, Phothongkhum 1968) in standing-waters covered with a lot of aquatic vegetation (Tongsanga 1958, Phothongkhum 1968); where the male blows a surface bubble nest (Leelapatra et al. 2000, Xuan 1993) among the plants (Warren 2000); The eggs are buoyant, with an initial size of 0.91-2 mm (Leelapatra et al. 2000); or 0.67 mm (Duangsaawasaki et al. 1992); The eggs hatch after 27 hours 28ºC (Leelapatra et al. 2000), or after 18-20 hours at 28-30ºC (Xuan 1993); the larvae measure 2.7 mm at hatching (Leelapatra et al. 2000).

It reaches maturity at an age of 7-12 months (Leelapatra et al. 2000, Anon 1997) and a body length of 8-10 cm (Leelapatra et al. 2000); Fecundity of the snakeskin gourami is around 18,000-36,000 eggs depending on the size of fish (Thongthai 1968), a 18 cm female can lay around 26,000 eggs (Leelapatra et al. 2000); Fish measuring 10-21 cm have 6,240-26,900 eggs with an average of 16,042 (Duangsaawasaki et al. 1992). Distribution: 0. Feeding: Generally feeds on aquatic plants (Frimodt 1995, Duangsaawasaki et al. 1992), zoo- and phytoplankton, insect larvae (Amatyakul et al. 1995, Frimodt 1995, Duangsaawasaki et al. 1992), periphyton, algae (Amatyakul et al. 1995) and detritus (Daugnsawasaki et al. 1992); The adult fish is a polyphagus species, feeding on vegetable matter (Anon 1997), zooplankton, and crustaceans (Yap 1988); After the yolk sac has been absorbed, the fry feed on zooplankton and phytoplankton (Anon 1997).

**ECOLOGY** - Migration type: Displays longitudinal as well as lateral migrations.
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: Medium

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**Trichogaster trichopterus** (Chavalit Vidthayanon)

**IDENTIFICATION** - Family: *Osphronemidae* (Gouramies)
**IDENTIFICATION** - Species name: *Trichogaster trichopterus*
**IDENTIFICATION - Author:** Pallas, 1770

**IDENTIFICATION - Name in Khmer:** រ៉ុកអាហារក្រម្ម

**IDENTIFICATION - Name in Khmer (roman):** Kamphleanh srae

**IDENTIFICATION - Name in English:** Three spot gourami

**BIOLOGY - Max. total length (cm):** 19

**BIOLOGY - Max. standard length (cm):** 15

**BIOLOGY - Length at maturity (cm):** 10

**BIOLOGY - Food:** Mainly animals

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information

**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Motomura et al. 2002

**ECOLOGY - All MFD information:** Migration: A black fish species (Bardach 1959), which does not undertake longitudinal migrations within the Mekong, but migrates from the main river, or any other permanent water body, to flooded areas during the flood season and returns to the permanent water body at the beginning of the dry season (Poulsen and Valbo-Jørgensen 2000). Spawning: Eggs were reported from March to December with a peak from April to June; It nests in rain-fed paddy fields (Poulsen and Valbo-Jørgensen 2000), during the period June-July (Poulsen and Valbo-Jørgensen 2000, Bardach 1959). Distribution: Occurs from Chiang Saen to the Mekong Delta (Poulsen and Valbo-Jørgensen 2000, Rainboth 1996); Recorded from the Xe Bangfai Basin (Allen 1991); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on zooplankton, crustaceans, and insect larvae (Rainboth 1996).

**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.

**ECOLOGY - Status:** Native

**ECOLOGY - Habitat:** Benthopelagic

**ECOLOGY - Resilience:** High

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**Trichopsis schalleri** (Chavalit Vidthayanon)

**IDENTIFICATION - Family:** Osphronemidae (Gouramies)

**IDENTIFICATION - Species name:** Trichopsis schalleri

**IDENTIFICATION - Author:** Ladiges, 1962

**IDENTIFICATION - Name in Khmer:** រ៉ុកអាហារក្រម្ម

**IDENTIFICATION - Name in Khmer (roman):** Kreum

**IDENTIFICATION - Name in English:** Threestripe gourami

**BIOLOGY - Max. total length (cm):** 7

**BIOLOGY - Max. standard length (cm):** 5

**BIOLOGY - Length at maturity (cm):** 3.8

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information

**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY - Tonle Sap distribution:** Motomura et al. 2002

**ECOLOGY - All MFD information:** Migration: 0. Spawning: Females are sexually mature at 4.3 cm SL (Kottelat 1998). Distribution: Known from the Mekong Basin in Laos, Yunnan and Thailand, and also recorded from the Lower, Middle and Upper Nam Theun (not collected on the Nakay Plateau) (Kottelat 1998). Feeding: Feeds on zooplankton (Rainboth 1996) and aquatic insects (Rainboth 1996, Kottelat 1998).

**ECOLOGY - Status:** Native

**ECOLOGY - Habitat:** Benthopelagic

**ECOLOGY - Resilience:** No information
**Trichopsis vittata** (Chavalit Vidthayanon)

IDENTIFICATION - Family: *Osphronemidae* (Gouramies)
IDENTIFICATION - Species name: *Trichopsis vittata*
IDENTIFICATION - Author: Cuvier, 1831
IDENTIFICATION - Name in Khmer: រុុមវិតាតា ៖ ៧២២
IDENTIFICATION - Name in Khmer (roman): Kreum
IDENTIFICATION - Name in English: Croaking gourami

**Biology**

Max. total length (cm): 7
Max. standard length (cm): 7
Length at maturity (cm): 5.1
Food: Mainly animals

**Ecology vs. Hydrology**

Discharge as migration trigger: No information
Water level as migration trigger: No information

**Reproduction**

Breeds in reservoirs: No info on breeding in reservoirs

**Ecology**

Tonle Sap distribution: From FishBase
All MFD information: Migration: 0. Spawning: 0. Distribution: Common throughout the Middle and Lower Mekong (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on zooplankton, crustaceans (Rainboth 1996), and insect larvae (Rainboth 1996, Krachangdara 1994).
Status: Native
Habitat: Demersal
Resilience: No information

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**Helicophagus waandersii** (Warren, T.)

IDENTIFICATION - Family: *Pangasiidae* (Shark catfishes)
IDENTIFICATION - Species name: *Helicophagus waandersii*
IDENTIFICATION - Author: Bleeker, 1858
IDENTIFICATION - Name in Khmer: រុុមវៃដែល ៖ ៧៣识
IDENTIFICATION - Name in Khmer (roman): Pra kandorl

**Biology**

Max. total length (cm): 70
Length at maturity (cm): 39.1
Food: Mainly animals

**Ecology vs. Hydrology**

Discharge as migration trigger: No information
Water level as migration trigger: No information

**Reproduction**

Breeds in reservoirs: No info on breeding in reservoirs

**Ecology**

Tonle Sap distribution: Kottelat, 1985
All MFD information: Migration: Above the Khone Falls migrates upstream during late dry season and/or early flood season (Rainboth 1996, Singanouvong et al. 1996, Poulsen and Valbo-Jørgensen 2000); these migrations are relatively short (Ref. Poulsen and Valbo-Jørgensen 2000), and the purpose seem to be spawning (Poulsen and Valbo-Jørgensen 2000), although they may also involve migrations for dispersal and feeding by sub-adults (Singanouvong et al. 1996, Poulsen and Valbo-Jørgensen 2000). The fish moves downstream as water clears at the end of the flood season (Rainboth 1996).
Below the Falls the pattern is opposite with a downstream migration at the onset of the flood season and an upstream migration from the during the dry season (Poulsen and Valbo-Jørgensen 2000).
Some populations migrate into major tributaries (e.g. Nam Ngum River and Songkhram River (Poulsen and Valbo-Jørgensen 2000); In Mun River, the species migrates upstream from the beginning of the rainy season to the end of August and move back downstream from late September to November (Schouten et al. 2000). Spawning: Eggs occur from March to July with a peak in May June, which probably is the main spawning season is during the period May to June (Poulsen and Valbo-Jørgensen 2000), but may extend until September - October (Singanouvong et al. 1996); However the species has also been reported to spawn in January to April (NFFS 1988). 2-4 cm juveniles have been reported both below (down stream to Can Tho and Dong Thap) and above Khone Falls (upstream to Nong Khai Province) (Poulsen and Valbo-Jørgensen 2000).


Biology - Max. total length (cm): 300
Biology - Length at maturity (cm): 141.4
Biology - Food: plants mainly plants/detritus
Biology - Notes: At present, there are reports of the Mekong giant catfish being caught in reservoirs every year, with body weights exceeding 100 kg. This indicates that the Mekong giant catfish can grow to their normal size in reservoirs. However, at present none of the fish caught in the reservoir has mature gonads. It is not known if the fish can mature in this type of environment (Leelapatra et al. 2000).

Ecology vs. Hydrology - Discharge as migration trigger: no information
Ecology vs. Hydrology - Water level as migration trigger: no information
Reproduction - Breeds in reservoirs: No info on breeding in reservoirs
Ecology - All MFD information: Migration: A white fish species (Bardach 1959); the actual distances and destinations of individuals moving through different parts of the river are poorly known (Rainboth 1996); Spawning migration has been observed in the northern part of the Mekong Basin (Vidthayanon 2001) where it migrates upstream during April-May. This migration is triggered by the first rain and increasing turbidity (Poulsen and Valbo-Jørgensen 2000). Spawning: Carries eggs from March to July (Singanouvong et al. 1996) and the main spawning season is between April and May (Leelapatra et al. 2000, Vidthayanon and Roongthongbaisuree 1993) at Chiang Rai, however in Mun River it spawns in June-July (Vidthayanon and Roongthongbaisuree 1993). The eggs are adhesive, yellowish in colour with a diameter of 1.7 mm (Leelapatra et al. 2000) and hatches 42 hours after fertilization at 25°C (Pholprasith and Tavarutmaneegul 1997); The larvae measure 7 mm at hatching (Pholprasith and Tavarutmaneegul 1997); Based on the occurrence of juveniles Durand (1940) suggested that it may spawn in the delta or mouth of the Mekong, and perhaps in the adjacent brackish coastal waters of Cambodia (Durand 1940); Other spawning grounds have been identified in the mainstream of the Mekong River near Chiang Rai (Pholprasith and Tavarutmaneegul 1997, Vidthayanon and Roongthongbaisuree 1993), and in Mun River at
Ubon Ratchathani (Vidthayanon and Roongthongbaisuree 1993); Juveniles measuring 12.5-15.0 cm SL have been found in the Great Lake of Cambodia (Vidthayanon and Roongthongbaisuree 1993); Fish caught with ripe eggs were estimated to be 6-8 years old with a body weight of 150-250 kg (Pholprasith and Tavarutmaneegul 1997), while a 14-year old fish permanently cultured in an earthy pond still had immature gonads (Leelapatra et al. 2000); A 178-kg female was found contain 10.8 million eggs (Pholprasith and Tavarutmaneegul 1997). Distribution: Found basin wide in the mainstream of the Lower Mekong (Pantulu 1986) Burma, Laos, Thailand, Cambodia and Viet Nam (NFFS 1988); Although it apparently used to be relatively common in different areas along the Lao-Thai border (e.g. around Nong Khai), the giant catfish is now extremely rare along most of this stretch (Poulsen and Valbo-Jørgensen 2000). Feeding: Feeds only on vegetation in the river (Davidson 1975); filamentous algae (Leelapatra et al. 2000, Vidthayanon and Roongthongbaisuree 1993) and detritus (Vidthayanon and Roongthongbaisuree 1993); The food of the fish consists largely, perhaps exclusively, of algae cropped from stones on the bottom and sides of the river. The frequent presence of stones in its stomach, up to the size of a mans fist is easily accounted for by the supposition that thy have been inadvertently swallowed in efforts to detach the algae (Smith 1945, Rainboth 1996); It probably also eats insect larvae and periphyton attached to the stones (Rainboth 1996, Leelapatra et al. 2000). The fry feed mainly on zooplankton (Leelapatra et al. 2000, NFFS 1988) for 1-2 months (NFFS 1988), but is also cannibalistic (Leelapatra et al. 2000). ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.

Pangasius bocourti (Warren, T.)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius bocourti
IDENTIFICATION - Author: Sauvage, 1880
IDENTIFICATION - Name in Khmer: ក្រវ៉ាពូសី
IDENTIFICATION - Name in Khmer (roman): Pra khchao
BIOLOGY - Max. total length (cm): 147
BIOLOGY - Max. standard length (cm): 120
BIOLOGY - Length at maturity (cm): 62.9
BIOLOGY - Food: plants/detritus+animals
BIOLOGY - Notes: Similar in appearance and behaviour to P. kunyit (Poulsen and Valbo-Jørgensen 2000).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Suvatti, 1981
ECOLOGY - All MFD information: Migration: From just below the Khone Falls to Chiang Saen in the north there is an upstream migration from the onset of the flood season (Singanouvong et al. 1996, Rainboth 1996, Poulsen and Valbo-Jørgensen 2000); this migration coincides with an increase in turbidity (Rainboth 1996); the fish passes Khone Falls through some of the largest canals (Baird 1998, Singanouvong et al. 1996). Further below the Khone Falls to the Mekong Delta, the fish migrates in the opposite direction: Downstream in the beginning of the rainy season or in the late dry season and upstream migration when the water level in the river is decreases in November, and continuing well into the dry season until at least February (Poulsen and Valbo-Jørgensen 2000). Spawning: Mature eggs occur from March to August (Poulsen and Valbo-Jørgensen 2000), and a 2,500 g individual was full of eggs in September (Baird and Phylavanh 1999); The young are first seen in June, averaging about 5 cm by mid-June (Rainboth 1996); However the spawning period uncertain (Singanouvong et al. 1996) and may extend from the onset of flood season (Rainboth 1996) to August or even October (Singanouvong et al. 1996). Distribution: Known from large rivers in the Lower and Middle Mekong (Roberts and Vidthayanon 1991, Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002); There are probably
two different populations in the Mekong. One occur from the Mekong Delta in Viet Nam to the Mukdahan-Savannakhet area upstream from the Khone Falls. Another population occurs from around Boulikhamxay-Nong Khai provinces to around Chiang Rai - Bokeo provinces in the north (Poulsen and Valbo-Jørgensen 2000). Feeding: In the rainy season it consumes mainly plant material such as fruits (Baird and Phylavanh 1999, Singanouvong et al. 1996) and leaves; In the dry season it feeds on fish, molluscs, algae and shrimps (Baird and Phylavanh 1999); Juveniles feed on insects. Adults feed on plants, insects and molluscs (Vidthayanon and Roongthongtairesree 1993).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

**Pangasius conchophilus**

**IDENTIFICATION - Family:** Pangasiidae (Shark catfishes)
**IDENTIFICATION - Species name:** *Pangasius conchophilus*
**IDENTIFICATION - Author:** Roberts and Vidthayanon, 1991
**IDENTIFICATION - Name in Khmer:** រតេក
**IDENTIFICATION - Name in Khmer (roman):** Pra kae
**BIOLOGY - Max. standard length (cm):** 120
**BIOLOGY - Length at maturity (cm):** 62.9
**BIOLOGY - Food:** Mainly animals
**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** Water level variation is a migration trigger
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** MFD occurrence map
**ECOLOGY - All MFD information:** Migration: A white fish species (Bardach 1959); From just upstream Khone Falls to Chiang Saen it migrates upstream when the Mekong River rises quickly with the beginning of the monsoon season around May (Baird and Phylavanh 1999, Singanouvong et al. 1996, Rainboth 1996, Poulsen and Valbo-Jørgensen 2000), it mainly moves in large schools at night (Baird and Phylavanh 1999); and the migration continues until August; However this migration of 40 - 90 cm sexually mature fish seem to be preceded by a migration of 10 to 40 cm sub-adults in the period March to May (Poulsen and Valbo-Jørgensen 2000); Migrates up the Mun river to spawn in the rainy season (Ref.Schouten et al. 2000). Spawning: Based on eggs reports from March to August with a strong peak in May-July (Poulsen and Valbo-Jørgensen 2000) and the presence of females in spawning condition in March, June and August (Baird and Phylavanh 1999); and juveniles of 6 to 7 cm by late June (Rainboth 1996); it seems likely that the species spawn at various times of the year (Baird and Phylavanh 1999) although it probably mainly reproduces early in the flood season (Rainboth 1996, Poulsen and Valbo-Jørgensen 2000) the spawning period may extend to October (Singanouvong et al. 1996). An important spawning ground appears to be in the Mekong mainstream somewhere between Kompong Cham and Khone Falls (Poulsen and Valbo-Jørgensen 2000); and in rapids and riffles of the Mun river (Schouten et al. 2000). Distribution: The distribution range is from the Mekong Delta all the way along the Mekong to Chiang Saen. In the Mekong Delta in Viet Nam, mainly juveniles less than 30 cm are reported (Poulsen and Valbo-Jørgensen 2000); There seem to be one population below Khone Falls and one (to several) above the Falls (Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on molluscs (Singanouvong et al. 1996, Roberts and Vidthayanon 1991) primarily gastropods (Rainboth 1996, Baird and Phylavanh 1999) but also some bivalves (Rainboth 1996), insects (Rainboth 1996, Roberts and Vidthayanon 1991); crabs, and algae (Singanouvong et al. 1996), filamentous green algae, leaves (Baird and Phylavanh 1999) forest fruits (Baird and Phylavanh 1999, Singanouvong et al. 1996, Roberts 1993).
Juveniles feed on prawns and insects; sub adults and adults on prawns, insects and particularly molluscs which are more predominant in stomach contents than in any other Pangasius species (Roberts and Vidthayanon 1991, Vidthayanon and Roongthongbaisuree 1993) and also small fish and crabs (Vidthayanon and Roongthongbaisuree 1993); Adults feed mainly on shellfish, crab, and fruit seeds (Vidthayanon and Roongthongbaisuree 1993).

Snails are an especially important source of food in the low-water season between January and May. Dense green algae appear to be an important source of food between January and March, when algae floats down the Mekong River in abundance. Leaves (Baird and Phylavanh 1999) and forest fruits are the dominant food sources for this catfish between late April and September (Baird and Phylavanh 1999, Roberts 1993).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Identification - Family: Pangasiidae (Shark catfishes)
Identification - Species name: Pangasius hypophthalmus
Identification - Author: Sauvage, 1878
Identification - Name in Khmer: ខ្មែរ (Pra thom)
Identification - Name in English: Sutchi catfish

Biology - Max. total length (cm): 159
Biology - Max. standard length (cm): 130
Biology - Length at maturity (cm): 67.5
Biology - Food: plants mainly animals
Biology - Notes: Swims at the surface early in the morning during its upstream migration (Poulsen and Valbo-Jørgensen 2000). It requires a great deal of space and is not suited to small aquaria although it shows a generally non-aggressive behaviour. (Rainboth 1996).

Ecology vs. Hydrology - Discharge as migration trigger: no information
Ecology vs. Hydrology - Water level as migration trigger: Water level variation is a migration trigger.

Reproduction - Breeds in reservoirs: No info on breeding in reservoirs
Ecology - Tonle Sap distribution: Motomura et al. 2002
Ecology - All MFD information: Migration: A white fish species (Bardach 1959), which migrates upstream for reproduction (Singanouvong et al. 1996); From Nong Khai to Chiang Khong it appears to be migrating upstream from May to July. South of the Khone Falls, there is a pronounced upstream migration from October to February (with a peak in November-December). It probably spawns in deep pools in the Mekong mainstream somewhere between Kratie to Khone Falls at the beginning of the flood season (Poulsen and Valbo-Jørgensen 2000, Bardach 1959) before it migrates downstream migration towards Kandal and the Mekong Delta in Vietnam from May to August; When the eggs hatch, the larvae drift downstream until they are swept out onto floodplain areas in southern Cambodia and Vietnam. At this time, the current in the Tonle Sap River has reversed resulting in a proportion of the larvae drifting up the Tonle Sap and out into flooded areas along the Tonle Sap River and the Great Lake (Poulsen and Valbo-Jørgensen 2000). Spawning: Eggs are reported during March to August with a strong peak in June-July (Poulsen and Valbo-Jørgensen 2000) or July (NFFS 1988, Vidthayanon and Roongthongbaisuree 1993), which is the main spawning season (Khanh 1996); Spawns in July (Vidthayanon and Roongthongbaisuree 1993); It probably spawns in deep pools in the Mekong mainstream somewhere between Kratie and Khone Falls (Poulsen and Valbo-Jørgensen 2000); The eggs are adhesive eggs (Singanouvong et al. 1996, Khanh 1996), and hatch after 22-24 hours at 30°C (Khanh 1996); The larvae are approximately 3 mm long when they hatch (Pham Van Khanh et al. 2000). The species reaches maturity when three and four years old in males and females respectively, with a
corresponding body weight of 3-4 kg (Khanh et al. 1999.). Distribution: The distribution range is from the Mekong Delta to Chiang Khong and Bokeo - it was not reported at Chiang Saen. In general, this species appear to be very rare above the Khone Falls (Poulsen and Valbo-Jørgensen 2000), but common in the Lower Mekong (Rainboth 1996); Recorded from Tien and Hau Rivers (Yen et al. 1992); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002), fingerlings are found in the Tien River. Mature fish however are nearly only found in culture ponds, being very rare in natural habitats in the Mekong Delta (Pham Van Khanh et al. 2000). Feeding: Omnivorous (Ukkatawewat 1999, NFFS 1988): Feeds on fishes and crustaceans, vegetable debris (Rainboth 1996), small fruits and probably forest vegetation during the rainy season (Baird and Phylavanh 1999).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Pangasius larnaudii (Warren, T.)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius larnaudii
IDENTIFICATION - Author: Bocourt, 1866
IDENTIFICATION - Name in Khmer: រីបោស
IDENTIFICATION - Name in Khmer (roman): Pra po
IDENTIFICATION - Name in English: Spot pangasius
BIOLOGY - Max. total length (cm): 159
BIOLOGY - Max. standard length (cm): 130
BIOLOGY - Length at maturity (cm): 67.5
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: Can sometimes be seen at the surface (Poulsen and Valbo-Jørgensen 2000).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Hill, and Hill, 1994
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); which from around the Khone Falls and upstream migrates up-river from April to July with most activity from late May until the end of June; This migration is for both feeding and reproduction (Singanouvong et al. 1996); At Ubon Ratchatani, it was reported to be the last species to undertake upstream migrations just after the upstream migration of P. krempfi (Poulsen and Valbo-Jørgensen 2000); However, compared to P. conchophilus migratory activity for this species is spread out over a much longer time period with regular smaller runs of fish taking place over a number of weeks (Singanouvong et al. 1996); The main trigger of these migrations seems to be a combination of changes in water levels and changes in water colour (Poulsen and Valbo-Jørgensen 2000); Further below the Falls and towards the Delta the species migrates downstream at the onset of the rainy season (Poulsen and Valbo-Jørgensen 2000); and upstream at the beginning of the dry season, triggered by receding water levels. This migration is reported on the stretch from Dong Thap Province in Vietnam to the Khone Falls (Poulsen and Valbo-Jørgensen 2000); From Kratie and downstream, it is reported that it moves between the Mekong and smaller streams (Poulsen and Valbo-Jørgensen 2000), it is also known to migrate into floodplains (Rainboth 1996). Spawning: Eggs and/or milt were reported to occur over a long period from March to September with most reports from May to July (Poulsen and Valbo-Jørgensen 2000), which explains why the species has been reported to spawn both at the beginning of the flood season (Rainboth 1996) and in August-October (Singanouvong et al. 1996); Rainboth (1996) suggests that it migrates into floodplains to spawn (Rainboth 1996), while Bardach (1959) suggests a mainstream spawning ground near Stung Treng from where the larvae drift to the Bassac region in six to eight days (Bardach 1959). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986, Poulsen and

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

Pangasius macronema (Chavalit Vidthayanon)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius macronema
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: រត្តុក្កត
IDENTIFICATION - Name in Khmer (roman): Pra chveat
BIOLOGY - Max. total length (cm): 37
BIOLOGY - Max. standard length (cm): 30
BIOLOGY - Length at maturity (cm): 18.5
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: Often found in large schools (Rainboth 1996); Can live in reservoirs (Vidthayanon and Roongthongbaisuree 1993).

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: Discharge variation is a migration trigger
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); It migrates upstream to spawn in the beginning of the rainy season (Schouten et al. 2000); Many fishers correlate the occurrence of this species with the emergence of insects especially dragonflies. From Boulikhamxay Province and northwards the species is mainly migrating upstream in May to June. In Cambodia there is an upstream migration from November until January/February. The fish go downstream in May-June (Poulsen and Valbo-Jørgensen 2000); Migrates upstream in May-June. In 1994, migratory activity was concentrated around early to mid-June when water flow volume was increasing rapidly. In 1996, migratory activity was concentrated over two periods; late May/early June and again towards the end of June. Some specimens with moderate fat deposits during the time of migration. Migration is for dispersal and feeding (Singanouvong et al. 1996); Passes the Khone Falls in April-May (Roberts and Baird 1995); During the period from late April to early May its numbers increase substantially by migrants coming from downstream. As the water transparency decreases it moves into tributary streams and flooded forests along with many species of cyprinids and other species of visually oriented catfishes such as P. pleurotaenia (Rainboth 1996). Spawning: Eggs have been observed in the abdomen of this fish all year round except for February, but most often reported from April to June (Poulsen and Valbo-Jørgensen 2000); A female with ripe eggs has been found in September (Baird and Phylavanh 1999); Spawns from February to April (NFFS 1988); It spawns in rapids in the beginning of the rainy season.
Schouten et al. 2000); It spawns in June in Cambodia where larvae are present in July (Bardach
1959); In Viet Nam it was reported to spawn in August to September in the main river (Poulson and
Valbo-Jørgensen 2000). Females are sexually mature at 13 cm and 25g (Baird and Phylavanh
1999). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986) except for
a short stretch from Nakhon Phanom and Mukdaharn Provinces (Poulson and Valbo-Jørgensen
2000); Rarely caught at Hoo Som Yai at the Khone Falls (Singanouvong et al. 1996); Found in
many reservoirs in Thailand (Vidhayanon and Roongthongbaisuree 1993); Larvae/juveniles have
been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al.
2002). Feeding: Feeds on aquatic insect larvae (Rainboth 1996), insects (Baird and Phylavanh
1999, NFFS 1988, Vidhayanon and Roongthongbaisuree 1993), earthworms (Baird and Phylavanh
1999, NFFS 1988), miscellaneous fruits (Baird and Phylavanh 1999, Vidhayanon and
Roongthongbaisuree 1993), leaves, pulsed wood, mushrooms, detritus (Baird and Phylavanh
1999), mud, plant fragments (Bardach 1959), and plant seeds (NFFS 1988); and also scavenges
(Vidhayanon and Roongthongbaisuree 1993).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

Pangasius micronemus (IFReDI collection)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius micronemus
IDENTIFICATION - Author: Bleeker, 1847
IDENTIFICATION - Name in English: Shortbarbel pangasius
BIOLOGY - Max. total length (cm): 107
BIOLOGY - Max. standard length (cm): 100
BIOLOGY - Length at maturity (cm): 53.5
BIOLOGY - Food: plants/detritus+animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Relatively uncommom in
the Mekong (Rainboth 1996). Feeding: Feeds on animal and plant matter including detritus
(Rainboth 1996); Feeds on algae in the Great Lake, but on molluscs in the Tonle Sap River
(Bardach 1959); Smaller P. micronema mainly feed on small fish but larger feed on fruit seed, fruit
and insects (Vidhayanon and Roongthongbaisuree 1993).
ECOLOGY - Migration type: Only seems to display Longitudinal migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

Pangasius nasutus (www.xyac.edu.cn)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius nasutus
IDENTIFICATION - Author: Bleeker, 1863
BIOLOGY - Max. total length (cm): 90
BIOLOGY - Length at maturity (cm): 48.8
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Migration type: No information on migration type
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

Pangasius pleurotaenia (Warren, T.)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius pleurotaenia
IDENTIFICATION - Author: Sauvage, 1878
BIOLOGY - Max. total length (cm): 43
BIOLOGY - Max. standard length (cm): 35
BIOLOGY - Length at maturity (cm): 21.2
BIOLOGY - Food: plants/detritus+animals
BIOLOGY - Notes: High occurrence of this species in the Mekong mainstream coincides with emergence of certain insects, in particular dragonflies. Some fishers had seen the fish come to the surface to catch these insects, confirming that the species relies on vision to catch its prey (Poulsen and Valbo-Jørgensen 2000). Before the flood season it is found in the lower reaches of tributary streams along with most of the cyprinids that would be found in the main stream of the Mekong when the water is clear. This species prefer greater water clarity than most species of river catfishes (Pangasiidae) (Rainboth 1996);
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Chao, and Trewavas, 1981
ECOLOGY - All MFD information: Migration: Along the stretch from Khone Falls and up to Chiang Rai Province, the first heavy rains marking the end of the dry season, triggers this species to migrate upstream. Along the stretch from Khone Falls to Loei, Thailand, this migration occur over a relatively short period, typically during May-June (Poulsen and Valbo-Jørgensen 2000, Singanouvong et al. 1996). Further upstream, from Xayaboury to Chiang Rai, migration tend to occur over a longer period, from March to August. Below the Khone Falls it migrates upstream at the beginning of the dry season, a migration that continues in waves well into the dry season (until March). These migrations are triggered by receding/low water levels. Late in the dry season, probably triggered by the first rain showers, the species migrates downstream from the Khone Falls, at least until Kandal Province - migratory behaviour in the Mekong Delta appear to be less clear (Poulsen and Valbo-Jørgensen 2000). Spawning: Eggs were reported to occur from March to December with most reports from May-June (Poulsen and Valbo-Jørgensen 2000); A 23 cm female weighing 70 g examined in November was full of eggs (Baird and Phylavanh 1999); Spawning period uncertain - possibly February-March (Singanouvong et al. 1996). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986, Poulsen and Valbo-Jørgensen 2000), Most common in the Middle Mekong (Rainboth 1996) rare both in the far north and far south (Poulsen and Valbo-Jørgensen 2000); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Diet consists of terrestrial and aquatic insects along with small amounts of plant matter (Rainboth 1996, Vidthayanon and Roongthongbaisuree 1993), fruits (Singanouvong et al. 1996, Vidthayanon and Roongthongbaisuree 1993), leaves, aquatic chlorophytes (Singanouvong et al. 1996), and seeds (Vidthayanon and Roongthongbaisuree 1993); This species feeds on large quantities of the flowers. It sometimes wait under flowering shrubs for flowers to drop into the water (Baird and Phylavanh 1999).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information
Pangasius polyuranodon (Rainboth W.)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius polyuranodon
IDENTIFICATION - Author: Bleeker, 1852
IDENTIFICATION - Name in Khmer: [រត្តច្រថារ]
IDENTIFICATION - Name in Khmer (roman): Pra chveat
BIOLOGY - Max. standard length (cm): 80
BIOLOGY - Length at maturity (cm): 44
BIOLOGY - Food: plants/ detritus + animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurrence map
ECOLOGY - All MFD information: Migration: Upstream from Khone Falls, the species migrates upstream at the onset of the flood season. This migration is triggered by a combination of the first rain and changes in water level and turbidity. From Kandal to Khone Falls upstream migrations are mainly triggered by receding water at the end of the flood season. Downstream migrations during the onset of the flood season are triggered by a combination of rain and rising water levels. Many fishers use the appearance of certain insects, in particular dragonflies, as an indication that migrations are underway; It was reported to migrate upstream in schools together with other species. However, the downstream migrations are undertaken more sporadic and not together with other species (Poulsen and Valbo-Jørgensen 2000); It probably moves out onto the floodplain during high water (Rainboth 1996). Spawning: Females with eggs were seen in June to August and in October, the eggs of the specimen examined in June appeared to be less developed than the ones examined in October (Baird and Phylavanh 1999); Spawns from May to August (Poulsen and Valbo-Jørgensen 2000); The smallest individual with eggs was 27 cm long and weighed 160 g (Baird and Phylavanh 1999). Distribution: Occurs from Xayaboury to the Mekong Delta. However it is rare in the Middle Mekong, from the Khone Falls and upstream (Poulsen and Valbo-Jørgensen 2000); More common from Stung Treng and downstream (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: It is known to feed on insect larvae, bottom dwelling worms, and submerged land plants, including flowers and fruits (Rainboth 1996); Feeds on forest leaves, fruits and insects in the high-water season between June and October. Apart from consuming large quantities of flooded forest fruits and vegetation, presumably as they float down river, this fish is a heavy consumer of dense green algae in the low-water season. It also feeds on fish, snails, crabs, shrimp, and frogs, but not in large quantities (Baird and Phylavanh 1999); Feeds on crab, shrimp, and shellfish (Vidthayanon and Roongthongbaisuree 1993). Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: No information
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: Low

Pangasius sanitwongsei (Rainboth W.)

IDENTIFICATION - Family: Pangasiidae (Shark catfishes)
IDENTIFICATION - Species name: Pangasius sanitwongsei
IDENTIFICATION - Author: Smith, 1931
IDENTIFICATION - Name in Khmer: ប្រុសស្មុគស្ថាន
IDENTIFICATION - Name in Khmer (roman): Pra po pruy
IDENTIFICATION - Name in English: Giant pangasius
BIOLOGY - Max. total length (cm): 366
BIOLOGY - Max. standard length (cm): 300
BIOLOGY - Length at maturity (cm): 141.4
BIOLOGY - Food: Mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); From Kompong Cham to the Khone Falls, the species migrates upstream during receding water from October to February and then downstream during rising water from June to August. The main trigger of these migrations is changes in water level (Poulsen and Valbo-Jørgensen 2000); It does not appear to migrate over the Khone Falls. Spawning: Spawns just before the rainy season, and the young of the year reach a length of about 10 cm by mid-June (Rainboth 1996). Distribution: Found basin wide in the mainstream (Pantulu 1986, Poulsen and Valbo-Jørgensen 2000); Upper and Middle Mekong (NFFS 1988); Seen in Stung Treng, and used to be common upstream from Khone Falls in the Middle Mekong along the Thai-Lao border (Rainboth 1996), however it is now rare in most of its distribution range (Poulsen and Valbo-Jørgensen 2000); Occasionally caught at Ban Hang Khone just downstream from the Falls (Baird 1998 ); Recorded from Mun River (NFFS 1988); Juvenile individuals were caught by hook and line in Vientiane in 1999 (Valbo-Jørgensen 2001); and in Songkram River in 2000 (Suntornratana 2001). Feeding: Adult and young feed mainly on fishes (Vidthayanon 2001, Rainboth 1996, Roberts and Vidthayanon 1991, Vidthayanon and Roongthongbaisuree 1993) and crustaceans (Rainboth 1996), but it sometimes scavenges (Vidthayanon 2001, Vidthayanon and Roongthongbaisuree 1993), larger individuals have for example been known to feed on carcasses of fowl (Roberts and Vidthayanon 1991) or dog (Smith 1945, Roberts and Vidthayanon 1991); It may also consume floating forest fruits and vegetation in the mainstream Mekong River (Baird and Phylavanh 1999) and detritus (NFFS 1988); Juveniles feed on insects and leaves (Baird and Phylavanh 1999).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

No picture available
IDENTIFICATION - Family: Polynemidae
IDENTIFICATION - Species name: Polynemus melanochir dulcis
IDENTIFICATION - Author: Motomura and Sabaj, 2002
IDENTIFICATION - Name in English: Lake blackhand paradise fish
BIOLOGY - Max. total length (cm): 17
BIOLOGY - Max. standard length (cm): 13.5
BIOLOGY - Length at maturity (cm): 9.1
ECOLOGY - Tonle Sap distribution: Motomura et al. 2002; Motomura 2004
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: High

No picture available
IDENTIFICATION - Family: Polynemidae (Threadfins)
IDENTIFICATION - Species name: Polynemus aquilonaris
IDENTIFICATION - Author: Motomura, 2003
IDENTIFICATION - Name in English: Northern paradise fish
BIOLOGY - Max. total length (cm): 20
BIOLOGY - Max. standard length (cm): 15.8
BIOLOGY - Length at maturity (cm): 10.5
Polynemus melanochir melanochir (CSIRO)

IDENTIFICATION - Family: Polynemidae (Threadfins)
IDENTIFICATION - Species name: Polynemus melanochir melanochir
IDENTIFICATION - Author: Valenciennes, 1831
IDENTIFICATION - Name in English: Blackhand paradise fish
BIOLOGY - Max. total length (cm): 31
BIOLOGY - Max. standard length (cm): 25
BIOLOGY - Length at maturity (cm): 15.7
BIOLOGY - Food: zoobenthos mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Migration type: No information on migration type
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High

Polynemus paradiseus (FAO)

IDENTIFICATION - Family: Polynemidae (Threadfins)
IDENTIFICATION - Species name: Polynemus paradiseus
IDENTIFICATION - Author: Linnaeus, 1758
IDENTIFICATION - Name in Khmer: ត្រីព្រៃ
IDENTIFICATION - Name in Khmer (roman): Trey priem
IDENTIFICATION - Name in English: Paradise threadfin
BIOLOGY - Max. total length (cm): 23
BIOLOGY - Length at maturity (cm): 14.6
BIOLOGY - Food: Mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Common in muddy waters of the Mekong tidal zone and upstream in freshwater reaches of the Tonle Sap (Rainboth 1996); Found at least as far as upstream as Can Tho and from the Bassac River at least as far as My Tho (5978); Never found above the Khone Falls (Roberts 1993). Feeding: Feeds on crustaceans (Rainboth 1996).
ECOLOGY - Status: Misidentification
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High

Boesemania microlepis (Jean-Francois Helias / Fishing Adventures Thailand)

IDENTIFICATION - Family: Sciaenidae (Drums or croakers)
IDENTIFICATION - Species name: Boesemania microlepis
IDENTIFICATION - Author: Bleeker, 1858
IDENTIFICATION - Name in Khmer: ខ្លែ មូម៉ោល៖ ១
IDENTIFICATION - Name in Khmer (roman): Prama
IDENTIFICATION - Name in English: Boeseman croaker
BIOLOGY - Max. total length (cm): 122
BIOLOGY - Max. standard length (cm): 100
BIOLOGY - Length at maturity (cm): 53.5
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: The adults are strong, fast swimming and probably wide ranging competitors and predators of other fishes and aquatic fauna. It is possibly very sensitive to polluted water, like the other euryhaline fishes mentioned earlier. Its extinction from many freshwater habitats, especially in the lower courses of the rivers, is foreseen (Wongratana 1985).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959); The species is reported to undertake short and sporadic migrations, these are normally solitary rather than in schools possibly in order to follow its prey; Below the Falls, these short distance upstream movements are usually seen at receding water at the end of the flood season (Poulsen and Valbo-Jørgensen 2000); However the species is rather sedentary in the river (CESVI 1998, Baird and Phylavanh 1999), and is an important inhabitant of certain deep-water pools in the Mekong mainstream River in southern Laos (Baird and Phylavanh 1999). Spawning: Eggs were reported only in the period April to July (Poulsen and Valbo-Jørgensen 2000); Spawning occurs during the height of the dry season between March and early May in southern Laos (Baird and Phylavanh 1999); and in May-June in Cambodia (Bardach 1959). The species spawns in deep-water sections of the Mekong River in southern Laos and north-eastern Cambodia (CESVI 1998, Baird and Phylavanh 1999); Seven spawning grounds, associated with deep pools are situated in Khong District, just above the Khone Falls (Baird and Phylavanh 1999); The identified spawning areas are characterized by being over 20 m deep, with hard rock or pebble and silt or sand substrate, and having slow to moderate counter-current eddies in the dry-season, and with steep rock sides descending into the pools (Baird et al. 2001). It makes loud croaking vocalisations during its spawning period (Baird and Phylavanh 1999).
A fish of about 73 cm body length and 3,800 g body weight has approx. 20,500 eggs with a diameter of about 0.5 mm (Duangsawasdi et al. 1988). Distribution: Found in the Mekong River (Hiranwatana 1970, Hiranwatana 1968, Serene 1951) and its effluents (Serene 1951, Rainboth 1996); above and below Khone Falls (Rainboth 1996); The main distribution area is from the Mekong Delta to Paksan with a single report from Xayabouri (Poulsen and Valbo-Jørgensen 2000);
where it used to occur but have not been seen for many years (Bouakhamvongsa 2001); Recorded from the mainstream at Nong Khai (Anonymous 1968); Vientiane, Pakse (Wongratana 1985, Taki 1968), Hat Salao (Taki 1968); and Loei (Wongratana 1985); and the Mekong Delta of Viet Nam (Kawamoto et al. 1972); and further from the Tonle Sap (1632); and the Great Lake (1037478). Feeding: Feeds mainly on prawns and shrimps (Wongratana 1985, Baird and Phylavanh 1999, Baird et al. 2001, Bothipitak 1970); but also on fishes (Baird and Phylavanh 1999, Baird et al. 2001, Bothipitak 1970, Rainboth 1996), and some insects (Baird et al. 2001, Baird and Phylavanh 1999), bark, leaves, and snails (Baird and Phylavanh 1999).

**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.

**ECOLOGY - Status:** Native

**ECOLOGY - Habitat:** Benthiopelagic

**ECOLOGY - Resilience:** Medium

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**Kryptopterus hexapterus (IFReDI collection)**

**IDENTIFICATION - Family:** Siluridae  
**IDENTIFICATION - Species name:** Kryptopterus hexapterus  
**IDENTIFICATION - Author:** Bleeker, 1851  
**IDENTIFICATION - Remark:** Formerly Kryptopterus hexapterus  
**BIOLOGY - Max. total length (cm):** 24  
**BIOLOGY - Length at maturity (cm):** 15.2  
**BIOLOGY - Food:** Mainly animals  
**ECOLOGY - Tonle Sap distribution:** Likely (above Khone Falls and in the delta)  
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Benthiopelagic  
**ECOLOGY - Resilience:** High

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**No picture available**

**IDENTIFICATION - Family:** Siluridae  
**IDENTIFICATION - Species name:** Ompok pinnatus  
**IDENTIFICATION - Author:** Ng, 2003  
**BIOLOGY - Max. total length (cm):** 29  
**BIOLOGY - Length at maturity (cm):** 0.9  
**ECOLOGY - Tonle Sap distribution:** Eschmeyer, Editor, 2004  
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Demersal  
**ECOLOGY - Resilience:** No information

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**Belodontichthys dinema (Roberts, T.R.)**

**IDENTIFICATION - Family:** Siluridae (Sheatfishes)  
**IDENTIFICATION - Species name:** Belodontichthys dinema  
**IDENTIFICATION - Author:** Bleeker, 1851  
**IDENTIFICATION - Name in Khmer:** ឈឺញ ចាស់ ឈឺញ មើ ន  ឈឺញមើន  
**IDENTIFICATION - Name in Khmer (roman):** Khlang hay  
**BIOLOGY - Max. total length (cm):** 100  
**BIOLOGY - Length at maturity (cm):** 53.5  
**BIOLOGY - Food:** Nekton mainly animals
<table>
<thead>
<tr>
<th>Topic</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td><strong>ECOLOGY vs. HYDROLOGY</strong></td>
<td>Discharge as migration trigger: no information</td>
</tr>
<tr>
<td></td>
<td>Water level as migration trigger: no information</td>
</tr>
<tr>
<td><strong>REPRODUCTION</strong></td>
<td>Spawns in streams / inlets (% respondents): 100</td>
</tr>
<tr>
<td></td>
<td>Date of spawning (% respondents): Jun 2.6%, Jun-Jul 71.1%, May-Jul 2.6%, May-Jun 23.7%</td>
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<tr>
<td></td>
<td>Nurses in floodplain (% respondents): 100</td>
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<td></td>
<td>Breeds in reservoirs: No info on breeding in reservoirs</td>
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<td><strong>ECOLOGY</strong></td>
<td>Tonle Sap distribution: Thuok, N and L. Sina, 1997</td>
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<tr>
<td><strong>ECOLOGY</strong></td>
<td>Migration type: No information on migration type</td>
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<tr>
<td><strong>ECOLOGY</strong></td>
<td>Feeds in floodplains (% respondents): 100</td>
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<td><strong>ECOLOGY</strong></td>
<td>Status: Native</td>
</tr>
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<td><strong>ECOLOGY</strong></td>
<td>Habitat: Demersal</td>
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<td><strong>ECOLOGY</strong></td>
<td>Resilience: No information</td>
</tr>
<tr>
<td><strong>GUILD</strong></td>
<td>Grey fish guild (% respondents): 100</td>
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</tbody>
</table>

### IMAGE

**No picture available**

**IDENTIFICATION** - Family: *Siluridae* (Sheatfishes)
**IDENTIFICATION** - Species name: *Hemisilurus heterorhynchus*
**IDENTIFICATION** - Author: Bleeker, 1853
**BIOLOGY** - Max. total length (cm): 80
**BIOLOGY** - Length at maturity (cm): 44
**ECOLOGY** vs. **HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY** vs. **HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Kottelat, 1985
**ECOLOGY** - Migration type: No information on migration type
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: Medium

### IMAGE

**Hemisilurus mekongensis** (Rainboth W.)

**IDENTIFICATION** - Family: *Siluridae* (Sheatfishes)
**IDENTIFICATION** - Species name: *Hemisilurus mekongensis*
**IDENTIFICATION** - Author: Bornbusch and Lundberg, 1989
**IDENTIFICATION** - Name in Khmer: ខោត្រី មួក
**IDENTIFICATION** - Name in Khmer (roman): Kromorm
**BIOLOGY** - Max. total length (cm): 80
**BIOLOGY** - Length at maturity (cm): 44
**BIOLOGY** - Food: plants/detritus+animals
**ECOLOGY** vs. **HYDROLOGY** - Discharge as migration trigger: Discharge variation is a migration trigger
**ECOLOGY** vs. **HYDROLOGY** - Water level as migration trigger: Water level variation is a migration trigger
**REPRODUCTION** - Spawns in streams / inlets (% respondents): 100
**REPRODUCTION** - Date of spawning (% respondents): Jun-Jul 71.8%, Jun-Oct 2.6%, May-Jun 23.1%, May-Sep 2.6%
**REPRODUCTION** - Nurses in floodplain (% respondents): 100
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: MFD occurrence map
**ECOLOGY** - All MFD information: Migration: Migrates upstream in April-July. The migratory activity seems to be strongly associated with river discharge. Generally speaking, when water flow increases, migratory activity intensifies, while falling discharge leads to a decrease in migratory activity in most cases. The purpose of the migration is for dispersal and feeding (Singanouvong et al. 1996). Spawning: Spawning period uncertain - probably August - October (Singanouvong et al.
Distribution: Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Browses along the bottom, where it feeds on worms, plants, animal debris (Rainboth 1996), insects (Rainboth 1996, Baird and Phylavanh 1999), shrimp/prawn, fish (Singanouvong et al. 1996, Baird and Phylavanh 1999) and crabs (Baird and Phylavanh 1999). It appears that its feeding habits do not differ considerably according to season (Baird and Phylavanh 1999).

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: No information
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: Medium
GUILD - Grey fish guild (% respondents): 100

**Kryptopterus apogon** (Rainboth W.)

IDENTIFICATION - Family: **Siluridae** (Sheatfishes)
IDENTIFICATION - Species name: **Kryptopterus apogon**
IDENTIFICATION - Author: Bleeker, 1851
BIOLOGY - Max. total length (cm): 159
BIOLOGY - Max. standard length (cm): 130
BIOLOGY - Length at maturity (cm): 67.5
BIOLOGY - Food: Nekton mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959), which moves into flooded riparian forests and probably into floodplains during high water levels. Young of the year begin to move back to the rivers in October, where they remain common until January (Rainboth 1996). Spawning: Spawns from just before water levels begin to rise (Rainboth 1996) in May to November (Bardach 1959); The young of the year are first seen in July (Rainboth 1996). Distribution: Found basin wide in the mainstream of the Mekong (Pantulu 1986); Recorded from the Xe Bangfai Basin (Kottelat 1998). Feeding: Feeds on pelagic fishes in midwater to upper depths (Rainboth 1996, Bardach 1959) and large crustaceans (Bardach 1959).
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

**Kryptopterus bicirrhis** (Baird, I.G.)

IDENTIFICATION - Family: **Siluridae** (Sheatfishes)
IDENTIFICATION - Species name: **Kryptopterus bicirrhis**
IDENTIFICATION - Author: Valenciennes, 1840
IDENTIFICATION - Name in Khmer: ខូក្ីព្រក
IDENTIFICATION - Name in Khmer (roman): Kes prak
IDENTIFICATION - Name in English: Glass catfish
BIOLOGY - Max. standard length (cm): 15
**BIOLOGY - Max. total length (cm):** 35
**BIOLOGY - Length at maturity (cm):** 21.2
**BIOLOGY - Food:** Mainly animals
**BIOLOGY - Notes:** Always found in the water surface in schools of about 10-20 individuals (1038315). By some authors said to be diurnally active (Mills and Vevers 1989) others state that it is nocturnal (1038315).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Spawns in streams / inlets (% respondents):** 100
**REPRODUCTION - Date of spawning (% respondents):** Jun 5.4%, Jun-Jul 70.3%, May-Jul 2.7%, May-Jun 21.6%
**REPRODUCTION - Nurses in floodplain (% respondents):** 100
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** Likely (above Khone Falls and in the delta)
**ECOLOGY - All MFD information:** Migration: 0. Spawning: Spawns around October to November (1038315). Distribution: Occurs in the Xe Bangfai Basin (Kottelat 1998). Feeding: Feeds on worms, crustaceans (Mills and Vevers 1989), insects (Mills and Vevers 1989, 1038315), and zooplankton (1038315).
**ECOLOGY - Feeds in floodplains (% respondents):** 100
**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** High

**GUILD - Grey fish guild (% respondents):** 100

**Kryptopterus cheveyi** (Baird, I.G.)

**IDENTIFICATION - Family:** Siluridae (Sheatfishes)
**IDENTIFICATION - Species name:** Kryptopterus cheveyi
**IDENTIFICATION - Author:** Durand, 1940
**IDENTIFICATION - Name in Khmer:** រតេក្រូវម៉ោះខ្យាពីវ
**IDENTIFICATION - Name in Khmer (roman):** Kamphleav stung

**BIOLOGY - Max. total length (cm):** 35
**BIOLOGY - Length at maturity (cm):** 21.2
**BIOLOGY - Food:** Mainly animals
**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Spawns in streams / inlets (% respondents):** 100
**REPRODUCTION - Date of spawning (% respondents):** Jun 5.1%, Jun-Jul 69.2%, May-Jul 2.6%, May-Jun 23.1%
**REPRODUCTION - Nurses in floodplain (% respondents):** 100
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY - Tonle Sap distribution:** Kottelat, 1985; Motomura et al. 2002
**ECOLOGY - All MFD information:** Migration: 0. Spawning: 0. Distribution: Reported from the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles have been recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Feeds on larvae of chironomids and ephemeropterans as well as zooplankton and fishes. The mouth and gill cavity often contain sand when the fish is removed from the water (Rainboth 1996).
**ECOLOGY - Migration type:** Displays longitudinal as well as lateral migrations.

**ECOLOGY - Feeds in floodplains (% respondents):** 100
**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Benthopelagic
**ECOLOGY - Resilience:** No information
**GUILD - Grey fish guild (% respondents):** 100
**Kryptopterus cryptopterus** (JJPhoto)

**Identification**
- Family: **Siluridae** (Sheatfishes)
- Species name: **Kryptopterus cryptopterus**
- Author: Bleeker, 1851
- Name in Khmer: ភ្លូវបែនមាពារ
- Name in Khmer (roman): Kamphleav khlanh

**Biology**
- Max. total length (cm): 25
- Max. standard length (cm): 20
- Length at maturity (cm): 12.9
- Food: Nekton mainly animals

**Ecology vs. Hydrology**
- Discharge as migration trigger: no information
- Water level as migration trigger: no information

**Reproduction**
- Spawns in streams / inlets (% respondents): 100
- Date of spawning (% respondents): Jun 5.1%, Jun-Jul 69.2%, May-Jul 2.6%, May-Jun 23.1%
- Nurses in floodplain (% respondents): 100
- Breeds in reservoirs: No info on breeding in reservoirs

**Ecology**
- Tonle Sap distribution: Kottelat, 1985
- All MFD information:
  - Migration: The young move into seasonally flooded habitats and are first seen in August (Rainboth 1996). Spawning: According to Rainboth (1996) it spawns in the early part of the rainy season (Rainboth 1996); However females measuring 21-22 cm (40-45 g) were full of eggs in August (Baird and Phylavanh 1999). Distribution: Found basin wide in the mainstream of the Lower Mekong (Pantulu 1986); Recorded from the Xe Bangfai Basin (Kottelat 1998) and the Great Lake (Rainboth 1996); Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds mostly on fish, along with prawns, insects, and their larvae (Rainboth 1996); small insects, earthworms and detritus (Baird and Phylavanh 1999).
- Migration type: Only seems to display Longitudinal migrations.
- Feeds in floodplains (% respondents): 100
- Status: Native
- Habitat: Benthopelagic
- Resilience: No information

**Guild**
- Grey fish guild (% respondents): 100

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**No picture available**
- Family: **Siluridae** (Sheatfishes)
- Species name: **Kryptopterus geminus**
- Author: Ng, 2003
- Max. total length (cm): 21
- Max. standard length (cm): 17.1
- Length at maturity (cm): 11.2
- Discharge as migration trigger: no information
- Water level as migration trigger: no information
- Breeds in reservoirs: No info on breeding in reservoirs
- Tonle Sap distribution: From FishBase
- Migration type: No information on migration type
- Status: Native
- Habitat: Demersal
- Resilience: No information
**Kryptopterus micronema** (Baird, I.G.)

**IDENTIFICATION** - Family: **Siluridae** (Sheatfishes)
**IDENTIFICATION** - Species name: **Kryptopterus micronema**
**IDENTIFICATION** - Author: Bleeker, 1846

**BIOLOGY** - Max. total length (cm): 41
**BIOLOGY** - Max. standard length (cm): 33
**BIOLOGY** - Length at maturity (cm): 20.1
**BIOLOGY** - Food: Mainly animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999.

**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: No information

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**Kryptopterus schilbeides** (Rainboth W.)

**IDENTIFICATION** - Family: **Siluridae** (Sheatfishes)
**IDENTIFICATION** - Species name: **Kryptopterus schilbeides**
**IDENTIFICATION** - Author: Bleeker, 1858

**IDENTIFICATION** - Name in Khmer: ṭeɪ mɛpøóv
**IDENTIFICATION** - Name in Khmer (roman): Kamphleav

**BIOLOGY** - Max. total length (cm): 12
**BIOLOGY** - Length at maturity (cm): 8.2
**BIOLOGY** - Food: Mainly animals

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Spawns in streams / inlets (% respondents): 100
**REPRODUCTION** - Date of spawning (% respondents): Jun 5.1%, Jun-Jul 69.2%, May-Jul 2.6%, May-Jun 23.1%

**REPRODUCTION** - Nurses in floodplain (% respondents): 100
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: MFD occurrence map

**ECOLOGY** - All MFD information: Migration: A white fish species (Bardach 1959); Moves into flooded forests during high water periods and returns to rivers in November, where they remain common at least until March (Rainboth 1996). Spawning: probably spawns in inundated forest June-October; 10 cm fingerlings collected in January (Bardach 1959). Distribution: Found in the Lower Mekong (Rainboth 1996). Feeding: Feeds on small fishes, prawns, and insect larvae (Rainboth 1996).

**ECOLOGY** - Feeds in floodplains (% respondents): 100
**ECOLOGY** - Status: No information
**ECOLOGY** - Habitat: Benthopelagic
**ECOLOGY** - Resilience: High

**GUILD** - Grey fish guild (% respondents): 100
**Micronema bleekeri** (Chavalit Vidthayanon)

**Identification** - Family: **Siluridae** (Sheatfishes)
**Identification** - Species name: **Micronema bleekeri**
**Identification** - Author: Günther, 1864
**Identification** - Name in Khmer: រត្បម្រាបរបាយ
**Identification** - Name in Khmer (roman): Kes krohorm

**Biology** - Max. total length (cm): 74
**Biology** - Max. standard length (cm): 60
**Biology** - Length at maturity (cm): 34.1
**Biology** - Food: Nekton mainly animals

**Ecology vs. Hydrology** - Discharge as migration trigger: no information
**Ecology vs. Hydrology** - Water level as migration trigger: Water level variation is a migration trigger

**Reproduction** - Spawns in streams / inlets (% respondents): 100
**Reproduction** - Date of spawning (% respondents): Jun 5.4%, Jun-Jul 70.3%, May-Jul 2.7%, May-Jun 21.6%
**Reproduction** - Nurses in floodplain (% respondents): 100
**Reproduction** - Breeds in reservoirs: No info on breeding in reservoirs
**Ecology** - Tonle Sap distribution: Kottelat, M., 1985; Lim et al. 1999
**Ecology** - All MFD information: Migration: Migrates upstream May - July; migration activity peaks in late May and continues at a comparatively low level until the end of June. The purpose of the migration is mainly for reproduction (Singanouvong et al. 1996); It also undertakes lateral migrations from the main river into smaller tributaries and inundated riverine habitats at the onset of the flood season (Baird and Phylavanh 1999, Poulsen and Valbo-Jørgensen 2000). The first rains at the end of the dry season trigger these migrations, as well as water level changes. (Poulsen and Valbo-Jørgensen 2000); It returns to the main river channel when water starts to recede at the beginning of the dry season. (Poulsen and Valbo-Jørgensen 2000); in Cambodia it was reported to migrate towards the river on, or immediately before, full moon. Below the Khone Falls, these lateral migrations are followed by a longitudinal migration within the mainstream. The purpose of this upstream migration is reportedly to find a deep pool where it can spend the dry season (Poulsen and Valbo-Jørgensen 2000). Spawning: It mainly carries egg in May and June (Poulsen and Valbo-Jørgensen 2000); corresponding to a spawning period in May- July/August (Singanouvong et al. 1996); A 320 g female has been reported to have eggs (Baird and Phylavanh 1999). Distribution: Found in the mainstream of the Mekong (Pantulu 1986) from Chiang Saen in to the Mekong Delta (Poulsen and Valbo-Jørgensen 2000). Feeding: Feeds on small fishes (Ukkatawewat 9999, Singanouvong et al. 1996, Baird and Phylavanh 1999), shrimps (Ukkatawewat 9999, Singanouvong et al. 1996), aquatic insect larvae (Ukkatawewat 9999) and leaves (Baird and Phylavanh 1999).

**Ecology** - Migration type: Displays longitudinal as well as lateral migrations.
**Ecology** - Feeds in floodplains (% respondents): 100
**Ecology** - Status: Native
**Ecology** - Habitat: Demersal
**Ecology** - Resilience: No information
**Guild** - Grey fish guild (% respondents): 100
**Ompok bimaculatus** (MNHN)

**IDENTIFICATION** - **Family:** Siluridae (Sheatfishes)
**IDENTIFICATION** - **Species name:** *Ompok bimaculatus*
**IDENTIFICATION** - **Author:** Bloch, 1794

**IDENTIFICATION** - **Name in Khmer:** ឈូតរីតោន
**IDENTIFICATION** - **Name in Khmer (roman):** Ta aon
**IDENTIFICATION** - **Name in English:** Butter catfish

**BIOLOGY** - **Max. total length (cm):** 55
**BIOLOGY** - **Max. standard length (cm):** 45
**BIOLOGY** - **Length at maturity (cm):** 26.5
**BIOLOGY** - **Food:** Nekton mainly animals
**BIOLOGY** - **Notes:** A slow-moving and stealthy predator, (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - **Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY** - **Water level as migration trigger:** no information
**REPRODUCTION** - **Breeds in reservoirs:** No info on breeding in reservoirs
**ECOLOGY** - **Tonle Sap distribution:** Kottelat, 1985; Lim et al. 1999

**ECOLOGY** - **All MFD information:** Migration: A white fish species (Bardach 1959), which migrates upstream during the wet season; the purpose of the migration is mainly reproduction (Singanouvong et al. 1996). In the high-water season the fish enters freshly inundated areas small seasonal streams (Rainboth 1996, Baird and Phylavanh 1999); where it is often caught in large numbers (Singanouvong et al. 1996). Spawning: It probably spawns from May to October (Bardach 1959); Females (including a 39 g individual) with developed ovaries were found in May-June (Singanouvong et al. 1996), and in July (Baird and Phylavanh 1999); Eggs are yellow and measure 1.2-1.5 mm diameter (1038319). Distribution: Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: It is mainly a carnivorous fish (Ref Krachangdara 1994) that feeds on crustaceans, fishes, molluscs (Rainboth 1996); earthworms, detritus (Baird and Phylavanh 1999), insects (Singanouvong et al. 1996), vegetable matter and fish (Pethiyagoda 1991).

**ECOLOGY** - **Migration type:** Displays longitudinal as well as lateral migrations.
**ECOLOGY** - **Status:** Native
**ECOLOGY** - **Habitat:** Demersal
**ECOLOGY** - **Resilience:** No information

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**Ompok eugeneiatus** (MNHN)

**IDENTIFICATION** - **Family:** Siluridae (Sheatfishes)
**IDENTIFICATION** - **Species name:** *Ompok eugeneiatus*
**IDENTIFICATION** - **Author:** Vaillant, 1893

**BIOLOGY** - **Max. total length (cm):** 16.5
**BIOLOGY** - **Length at maturity (cm):** 10.9
**ECOLOGY vs. HYDROLOGY** - **Discharge as migration trigger:** no information
<table>
<thead>
<tr>
<th><strong>ECOLOGY vs. HYDROLOGY</strong></th>
<th>Water level as migration trigger: no information</th>
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<tbody>
<tr>
<td><strong>REPRODUCTION</strong></td>
<td>Breeds in reservoirs: No info on breeding in reservoirs</td>
</tr>
<tr>
<td><strong>ECOLOGY</strong></td>
<td>Tonle Sap distribution: Lim et al. 1999</td>
</tr>
<tr>
<td><strong>ECOLOGY</strong></td>
<td>Migration type: No information on migration type</td>
</tr>
<tr>
<td><strong>ECOLOGY</strong></td>
<td>Status: Native</td>
</tr>
<tr>
<td><strong>ECOLOGY</strong></td>
<td>Habitat: Demersal</td>
</tr>
<tr>
<td><strong>ECOLOGY</strong></td>
<td>Resilience: No information</td>
</tr>
</tbody>
</table>

| **Ompok hypophthalmus** (Baird, I.G.) |
| **IDENTIFICATION** | Family: *Siluridae* (Sheatfishes) |
| **IDENTIFICATION** | Species name: *Ompok hypophthalmus* |
| **IDENTIFICATION** | Author: Bleeker, 1846 |
| **IDENTIFICATION** | Name in Khmer: ២៤ តារាងាណ |
| **IDENTIFICATION** | Name in Khmer (roman): Ta aon |
| **BIOLOGY** | Max. total length (cm): 37 |
| **BIOLOGY** | Max. standard length (cm): 30 |
| **BIOLOGY** | Length at maturity (cm): 18.5 |
| **BIOLOGY** | Food: Nekton mainly animals |
| **ECOLOGY vs. HYDROLOGY** | Discharge as migration trigger: no information |
| **ECOLOGY vs. HYDROLOGY** | Water level as migration trigger: no information |
| **REPRODUCTION** | Breeds in reservoirs: No info on breeding in reservoirs |
| **ECOLOGY** | Tonle Sap distribution: Thuok, N and L. Sina, 1997 |
| **ECOLOGY** | Migration type: No information on migration type |
| **ECOLOGY** | Status: Native |
| **ECOLOGY** | Habitat: Demersal |
| **ECOLOGY** | Resilience: No information |

| **No picture available** |
| **IDENTIFICATION** | Family: *Siluridae* (Sheatfishes) |
| **IDENTIFICATION** | Species name: *Ompok urbaini* |
| **IDENTIFICATION** | Author: Fang and Chaux, 1949 |
| **BIOLOGY** | Max. total length (cm): 23 |
| **BIOLOGY** | Max. standard length (cm): 18.1 |
| **BIOLOGY** | Length at maturity (cm): 11.8 |
| **ECOLOGY vs. HYDROLOGY** | Discharge as migration trigger: no information |
| **ECOLOGY vs. HYDROLOGY** | Water level as migration trigger: no information |
| **REPRODUCTION** | Breeds in reservoirs: No info on breeding in reservoirs |
| **ECOLOGY** | Tonle Sap distribution: Ng, 2003 |
| **ECOLOGY** | Migration type: No information on migration type |
| **ECOLOGY** | Status: Native |
| **ECOLOGY** | Habitat: Demersal |
| **ECOLOGY** | Resilience: No information |

| **Wallago attu** (Rainboth W.) |
| **IDENTIFICATION** | Family: *Siluridae* (Sheatfishes) |
| **IDENTIFICATION** | Species name: *Wallago attu* |
| **IDENTIFICATION** | Author: Bloch and Schneider, 1801 |

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IDENTIFICATION - Name in Khmer: រត់ស៊ូក កញ្ចក់
IDENTIFICATION - Name in Khmer (roman): Sanday
IDENTIFICATION - Name in English: Wallago
BIOLOGY - Max. total length (cm): 240
BIOLOGY - Length at maturity (cm): 116.1
BIOLOGY - Food: Nekton mainly animals
BIOLOGY - Notes: A nocturnally active (Rainboth 1996), large, voracious and predatory catfish (Pethiyagoda 1991).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Reproductive guild: Guarders; Nesters
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: No information

Wallago leerii (JJPhoto)

IDENTIFICATION - Family: Siluridae (Sheatfishes)
IDENTIFICATION - Species name: Wallago leerii
IDENTIFICATION - Author: Bleeker, 1851
IDENTIFICATION - Name in Khmer: រត់ស៊ូក កញ្ចក់
IDENTIFICATION - Name in Khmer (roman): Stuok
BIOLOGY - Max. total length (cm): 220
BIOLOGY - Max. standard length (cm): 180
BIOLOGY - Length at maturity (cm): 90
BIOLOGY - Food: Nekton mainly animals
BIOLOGY - Notes: It is not as common as W. attu (Rainboth 1996).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: Water level variation is a migration trigger
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: Enters the flooded forest in high water and stays near the edge of the forest in low water (Roberts 1993); In Cambodia downstream migrations start in May and end in July. In Lao PDR and one in Thailand it was reported to migrate downstream in groups in October–November (Poulsen and Valbo-Jørgensen 2000). The schooling behaviour has also been observed outside the Mekong basin in the Kapuas River where it used to form large...
migratory schools in the mainstream (Roberts 1989); it apparently migrates into smaller streams to
spawn when the water level starts rising, especially after strong rain (Poulsen and Valbo-Jørgensen
2000). Spawning: Eggs in the abdomen of the fish have been observed from April to October, with
the majority of observations between May and July; it was reported that it spawns in flooded
grassland in July, it was further maintained that the species spawns at night, and that it breeds in
deep water than Wallago attu; During the spawning performance the fish swim in pairs, and the
eggs are spawned near the surface (Poulsen and Valbo-Jørgensen 2000).

Distribution: Occurs from about 50 km from the river mouth in Viet Nam to the northernmost Chiang Saen, but is less
common than Wallago attu (Poulsen and Valbo-Jørgensen 2000). Feeding: piscivorous (Rainboth

ECOLOGY - Migration type: Displays longitudinal as well as lateral migrations.
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: No information

Glyptothorax lampris (CAFS)

IDENTIFICATION - Family: Sisoridae (Sisorid catfishes)
IDENTIFICATION - Species name: Glyptothorax lampris
IDENTIFICATION - Author: Fowler, 1934

BIOLOGY - Max. total length (cm): 15
BIOLOGY - Max. standard length (cm): 12.1
BIOLOGY - Length at maturity (cm): 8.3
BIOLOGY - Food: Mainly animals

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information

REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs

ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: 0. Spawning: 0. Distribution: Found in running waters
of the Mekong Basin (Pantulu 1986). Feeding: Its diet consists of aquatic insect larvae (Rainboth
1996).

ECOLOGY - Status: Native
ECOLOGY - Habitat: Benthopelagic
ECOLOGY - Resilience: No information

Achiroides leucorhynchos (Rainboth W.)

IDENTIFICATION - Family: Soleidae (Soles)
IDENTIFICATION - Species name: Achiroides leucorhynchos
IDENTIFICATION - Author: Bleeker, 1851

IDENTIFICATION - Name in Khmer: Andat chhkae
IDENTIFICATION - Name in Khmer (roman): Andat chhkae

BIOLOGY - Max. standard length (cm): 8
BIOLOGY - Length at maturity (cm): 5.8
BIOLOGY - Food: Mainly animals

ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in rivers (% respondents): 97.5
REPRODUCTION - Spawns in streams / inlets (% respondents): 2.5
REPRODUCTION - Date of spawning (% respondents): May 14.3%, Jun 57.1%, Jun-Jul 28.6%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: IFReDI identification
ECOLOGY - All MFD information: Migration: 0. Spawning: 0 . Distribution: 0. Feeding: Feeds primarily on benthic invertebrates (Rainboth 1996).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: No information
GUILD - White fish guild (% respondents): 100

Brachirus harmandi (Baird, I.G.)

IDENTIFICATION - Family: Soleidae (Soles)
IDENTIFICATION - Species name: Brachirus harmandi
IDENTIFICATION - Author: Sauvage, 1878
IDENTIFICATION - Name in Khmer: ពត្តាប្រីពស់នព្យូ
IDENTIFICATION - Name in Khmer (roman): Andat chhkae
BIOLOGY - Max. total length (cm): 13
BIOLOGY - Max. standard length (cm): 10
BIOLOGY - Length at maturity (cm): 7
BIOLOGY - Food: zoobenthos mainly animals
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Spawns in rivers (% respondents): 97.5
REPRODUCTION - Spawns in streams / inlets (% respondents): 2.5
REPRODUCTION - Date of spawning (% respondents): May 14.3%, Jun 57.1%, Jun-Jul 28.6%
REPRODUCTION - Nurses in floodplain (% respondents): 100
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: MFD occurence map
ECOLOGY - All MFD information: Migration: 0. Spawning: 0 . Distribution: Reported from the Xe Bangfai Basin (Kottelat 1998); Larvae/juveniles recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds primarily on benthic invertebrates (Rainboth 1996).
ECOLOGY - Feeds in floodplains (% respondents): 100
ECOLOGY - Status: Native
ECOLOGY - Habitat: Demersal
ECOLOGY - Resilience: High
GUILD - White fish guild (% respondents): 100

Brachirus orientalis (Randall, J.E.)
**Identification**
- **Family:** Soleidae (Soles)
- **Species name:** Brachirus orientalis
- **Author:** Bloch and Schneider, 1801
- **Name in Khmer:** ខ្មៅស្វាយស្រួយ
- **Name in Khmer (roman):** Andat chhkae
- **Name in English:** Oriental sole

**Biology**
- **Max. standard length (cm):** 30
- **Length at maturity (cm):** 18.5
- **Food:** zoobenthos mainly animals

**Ecology vs. Hydrology**
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**Reproduction**
- **Spawns in rivers (% respondents):** 97.5
- **Spawns in streams / inlets (% respondents):** 2.5
- **Date of spawning (% respondents):** May 14.3%, Jun 57.1%, Jun-Jul 28.6%
- **Nurses in floodplain (% respondents):** 100
- **Breeds in reservoirs:** No info on breeding in reservoirs

**Ecology**
- **Tonle Sap distribution:** MFD occurrence map
- **All MFD information:** Migration: A white fish species (Bardach 1959). Spawning: 0. Distribution: 0. Feeding: Feeds mainly on bottom-dwelling invertebrates, (Rainboth 1996, Günther 18683) especially small crustaceans (Günther 18683).
- **Feeds in floodplains (% respondents):** 100
- **Status:** Native
- **Habitat:** Demersal
- **Resilience:** Low

**Guild**
- **White fish guild (% respondents):** 100

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**Identification**
- **Family:** Soleidae (Soles)
- **Species name:** Brachirus panoides
- **Author:** Bleeker, 1851

**Biology**
- **Max. total length (cm):** 20
- **Length at maturity (cm):** 12.9
- **Food:** zoobenthos mainly animals
- **Notes:** An euryhaline species (Kottelat 1989).

**Ecology vs. Hydrology**
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**Reproduction**
- **Breeds in reservoirs:** No info on breeding in reservoirs

**Ecology**
- **Tonle Sap distribution:** MFD occurrence map
- **All MFD information:** Migration: 0. Spawning: 0. Distribution: The species is common just below the falls (Baird et al. 1999); Larvae/juveniles recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al. 2002). Feeding: Feeds on benthic invertebrates (Rainboth 1996) and earthworms (Baird and Phylavanh 1999).
- **Status:** Native
- **Habitat:** Demersal
- **Resilience:** Medium
**Monopterus albus** (CAFS)

**Identification**
- **Family:** Synbranchidae (Swamp-eels)
- **Species name:** *Monopterus albus*
- **Author:** Zuiew, 1793
- **Name in Khmer:** រឿងខ្មៅ
- **Name in Khmer (roman):** Antong
- **Name in English:** Swamp eel

**Biology**
- **Max. total length (cm):** 122
- **Max. standard length (cm):** 100
- **Length at maturity (cm):** 52.2
- **Food:** zoobenthos mainly animals
- **Notes:** Can burrow up to 1.5 m down into the mud where it survives dry periods (Rainboth 1996, Davidson 1975).

**Ecology vs. Hydrology**
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**Reproduction**
- **Reproductive guild:** Guarders: Nesters
- **Breeds in reservoirs:** No info on breeding in reservoirs

**Ecology**
- **Tonle Sap distribution:** Motomura et al. 2002
- **All MFD information:** Migration: 0. Spawning: A bubble nest builder at the water surface near the shoreline during the rainy season (Rainboth 1996, Talwar and Jhingran 1992).
- **Distribution:** Larvae/juveniles recorded from the drift in the Mekong River in An Giang (Nguyen et al. 2002). Feeding: Feeds on small animals (Krachangdara 1994), crustaceans, and molluscs (Rainboth 1996), and detritus (Talwar and Jhingran 1992, Krachangdara 1994).
- **Status:** Native
- **Habitat:** Demersal
- **Resilience:** Medium

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**Doryichthys boaja** (Chavalit Vidthayanon)

**Identification**
- **Family:** Syngnathidae (Pipefishes and seahorses)
- **Species name:** *Doryichthys boaja*
- **Author:** Bleeker, 1851
- **Name in English:** Long-snouted pipefish

**Biology**
- **Max. total length (cm):** 51
- **Max. standard length (cm):** 41
- **Length at maturity (cm):** 24.4
- **Food:** Mainly animals
- **Notes:** Moves about in bottom debris (Rainboth 1996).

**Ecology vs. Hydrology**
- **Discharge as migration trigger:** no information
- **Water level as migration trigger:** no information

**Reproduction**
- **Breeds in reservoirs:** No info on breeding in reservoirs

**Ecology**
- **Tonle Sap distribution:** Kottelat, 1985; CNMC 1998, Scott and Crossman 1973
- **All MFD information:** Migration: A white fish species (Bardach 1959). Spawning: 0.
- **Distribution:** This species has been seen as far upstream as the Great Lake (Rainboth 1996). Feeding:
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Benthopelagic  
**ECOLOGY - Resilience:** Medium

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**Auriglobus nefastus**  
*(Chavalit Vidthayanon)*

**IDENTIFICATION - Family:** Tetraodontidae (Puffers)  
**IDENTIFICATION - Species name:** *Auriglobus nefastus*  
**IDENTIFICATION - Author:** Roberts, 1982  
**IDENTIFICATION - Name in English:** Greenbottle pufferfish  
**BIOLOGY - Max. total length (cm):** 16  
**BIOLOGY - Max. standard length (cm):** 13  
**BIOLOGY - Length at maturity (cm):** 8.8  
**BIOLOGY - Food:** Mainly animals  
**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information  
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information  
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs  
**ECOLOGY - Tonle Sap distribution:** Kottelat, 1985  
**ECOLOGY - All MFD information:** Migration: 0. Spawning: 0. Distribution: Found in flowing waters of rivers and streams in the Middle and Lower Mekong Basin (Rainboth 1996). Feeding: Feeds on fish scales and fins (Rainboth 1996).  
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Demersal  
**ECOLOGY - Resilience:** High

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**Carinotetraodon lorteti**  
*(Chavalit Vidthayanon)*

**IDENTIFICATION - Family:** Tetraodontidae (Puffers)  
**IDENTIFICATION - Species name:** *Carinotetraodon lorteti*  
**IDENTIFICATION - Author:** Tirant, 1885  
**IDENTIFICATION - Name in English:** Redeye puffer  
**BIOLOGY - Max. total length (cm):** 8  
**BIOLOGY - Max. standard length (cm):** 6  
**BIOLOGY - Length at maturity (cm):** 4.5  
**BIOLOGY - Food:** Mainly animals  
**BIOLOGY - Notes:** Said to be able to change colours depending on the surroundings (Rainboth 1996).  
**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information  
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information  
**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs  
**ECOLOGY - Tonle Sap distribution:** Kottelat, 1985  
**ECOLOGY - All MFD information:** Migration: 0. Spawning: 0. Distribution: Found in flowing waters of rivers and streams in the Middle and Lower Mekong Basin (Rainboth 1996). Feeding: Feeds on molluscs, crustaceans, and other invertebrates and zooplankton (Rainboth 1996).  
**ECOLOGY - Status:** Native  
**ECOLOGY - Habitat:** Benthopelagic  
**ECOLOGY - Resilience:** High
**Tetraodon cochinchinensis** (www.exomarc.com)

**IDENTIFICATION** - Family: **Tetraodontidae** (Puffers)
**IDENTIFICATION** - Species name: **Tetraodon cochinchinensis**
**IDENTIFICATION** - Author: Steindachner, 1866

**BIOLOGY** - Max. total length (cm): 9
**BIOLOGY** - Max. standard length (cm): 7
**BIOLOGY** - Length at maturity (cm): 5.1

**BIOLOGY** - Notes: Known to be a quarrelsome and aggressive fish (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information

**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Motomura, Tsukawaki and Kamiya, 2002

**ECOLOGY - All MFD information: Migration:** A white fish species (Bardach 1959). Spawning: 0.
**Distribution:** Occurs in the Lower Mekong as far upstream as the Great Lake (Rainboth 1996).
**Feeding:** Feeds on fish (Bardach 1959), large crustaceans (Bardach 1959, Rainboth 1996), molluscs, and other invertebrates as well as some plant matter (Rainboth 1996); Small individuals feed on planktonic crustaceans (Bardach 1959).

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Demersal
**ECOLOGY - Resilience:** High

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**Tetraodon fluviatilis** (Randall, J.E.)

**IDENTIFICATION** - Family: **Tetraodontidae** (Puffers)
**IDENTIFICATION** - Species name: **Tetraodon fluviatilis**
**IDENTIFICATION** - Author: Hamilton, 1822
**IDENTIFICATION** - Name in English: Green pufferfish

**BIOLOGY** - Max. total length (cm): 17
**BIOLOGY** - Length at maturity (cm): 11.2
**BIOLOGY** - Food: zoobenthos mainly animals

**BIOLOGY** - Notes: Adults are pugnacious and aggressive against other fishes (Rainboth 1996).

**ECOLOGY vs. HYDROLOGY - Discharge as migration trigger:** no information
**ECOLOGY vs. HYDROLOGY - Water level as migration trigger:** no information

**REPRODUCTION - Breeds in reservoirs:** No info on breeding in reservoirs

**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999

**ECOLOGY - All MFD information:** Migration: 0. Spawning: 0.
**Distribution:** Found in the Mekong Delta and may occur in Cambodia (Rainboth 1996). Feeding: Feeds on molluscs, crustaceans, and other invertebrates as well as vascular plants and detritus. May occasionally eat fish scales or fins (Rainboth 1996).

**ECOLOGY - Status:** Native
**ECOLOGY - Habitat:** Demersal
**ECOLOGY - Resilience:** High
**Tetraodon leiurus** (Baird, I.G.)

**IDENTIFICATION** - Family: *Tetraodontidae* (Puffers)
**IDENTIFICATION** - Species name: *Tetraodon leiurus*
**IDENTIFICATION** - Author: Bleeker, 1851
**BIOLOGY** - Max. total length (cm): 19
**BIOLOGY** - Max. standard length (cm): 16
**BIOLOGY** - Length at maturity (cm): 10.6
**BIOLOGY** - Food: plants/detritus+animals
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Rainboth, 1996;
**ECOLOGY** - All MFD information: Migration: 0. Spawning: 0. Distribution: Mekong Basin in Laos, Thailand and Cambodia (Kottelat 2001). Feeding: Feeds on molluscs, crustaceans and other invertebrates as well as some plant matter and detritus (Rainboth 1996).
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: High

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**Tetraodon nigroviridis** (Liu, K.H.)

**IDENTIFICATION** - Family: *Tetraodontidae* (Puffers)
**IDENTIFICATION** - Species name: *Tetraodon nigroviridis*
**IDENTIFICATION** - Author: Marion de Procé, 1822
**IDENTIFICATION** - Name in English: Spotted green pufferfish
**BIOLOGY** - Max. total length (cm): 17
**BIOLOGY** - Length at maturity (cm): 11.2
**BIOLOGY** - Food: zoobenthos mainly animals
**BIOLOGY** - Notes: Aggressive with other fishes (Rainboth 1996).
**ECOLOGY vs. HYDROLOGY** - Discharge as migration trigger: no information
**ECOLOGY vs. HYDROLOGY** - Water level as migration trigger: no information
**REPRODUCTION** - Breeds in reservoirs: No info on breeding in reservoirs
**ECOLOGY** - Tonle Sap distribution: Lim et al. 1999
**ECOLOGY** - All MFD information: Migration: 0. Spawning: 0. Distribution: 0. Feeding: Feeds on molluscs, crustaceans, and other invertebrates, as well as some plant matter. May eat fish scales and fins (Rainboth 1996).
**ECOLOGY** - Status: Native
**ECOLOGY** - Habitat: Demersal
**ECOLOGY** - Resilience: High
Toxotes chatareus (Aland, G.)

IDENTIFICATION - Family: Toxotidae (Archerfishes)
IDENTIFICATION - Species name: Toxotes chatareus
IDENTIFICATION - Author: Hamilton, 1822
IDENTIFICATION - Name in Khmer: រត្ប័ត្បុកកោស៊ុត
IDENTIFICATION - Name in Khmer (roman): Kanhchak slar/Khla
IDENTIFICATION - Name in English: Largescale archerfish
BIOLOGY - Max. total length (cm): 49
BIOLOGY - Max. standard length (cm): 40
BIOLOGY - Length at maturity (cm): 22.9
BIOLOGY - Food: Nekton mainly animals
BIOLOGY - Notes: Feeds at the surface during the day. Renowned for their habit of spitting to dislodge their insect prey from tree branches above the water; maximum shooting range is about 150 cm (Allen 1991).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Kottelat, 1985
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959). Spawning: Breeds in both fresh and brackish water (Allen 1991); It lays 20,000 to 150,000 eggs, measuring about 0.4 mm in diameter (Pethiyagoda 1991). Distribution: Found from the estuary up to Thailand and Laos (Rainboth 1996). Feeding: Diet consists of terrestrial insects (Rainboth 1996, Bardach 1959, Allen 1991), aquatic insect larvae (Bardach 1959, Rainboth 1996); zooplankton, rotifers, cladocerans (Rainboth 1996), vegetable matter (Allen 1991), and fish (Salini et al Scott and Crossman 1973).
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: Medium

Toxotes microlepis (Baird, I.G.)

IDENTIFICATION - Family: Toxotidae (Archerfishes)
IDENTIFICATION - Species name: Toxotes microlepis
IDENTIFICATION - Author: Günther, 1860
IDENTIFICATION - Name in Khmer: រត្ប័ត្បុកកោស៊ុត
IDENTIFICATION - Name in Khmer (roman): Kanhchak slar / Khla
IDENTIFICATION - Name in English: Smallscale archerfish
BIOLOGY - Max. total length (cm): 19
BIOLOGY - Max. standard length (cm): 15
BIOLOGY - Length at maturity (cm): 10
BIOLOGY - Food: zoobenthos mainly animals
BIOLOGY - Notes: Because this fish likes to stay under overhanging branches, it is certainly reliant on flooded and riparian forests for habitat (Baird and Phylavanh 1999).
ECOLOGY vs. HYDROLOGY - Discharge as migration trigger: no information
ECOLOGY vs. HYDROLOGY - Water level as migration trigger: no information
REPRODUCTION - Breeds in reservoirs: No info on breeding in reservoirs
ECOLOGY - Tonle Sap distribution: Lim et al. 1999
ECOLOGY - All MFD information: Migration: A white fish species (Bardach 1959). Spawning: 0.
Distribution: Occurs well upstream from the estuary (Rainboth 1996) and has been recorded from
the Xe Bangfai Basin (Kottelat 1998). Feeding: Diet consists of terrestrial insects (Rainboth 1996,
Baird and Phylavanh 1999), zooplankton, crustaceans, and aquatic insect larvae (Rainboth 1996),
and pulverised wood (Baird and Phylavanh 1999).
ECOLOGY - Status: Native
ECOLOGY - Habitat: pelagic
ECOLOGY - Resilience: High

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"BAYFISH-TONLE SAP", A MODEL OF THE TONLE SAP FISH RESOURCE

Prepared by

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1 INTRODUCTION

As demand for freshwater steadily increases, decision makers at a national as well as at basin level require information on the role of river flow in sustaining environmental benefits and tools to assess the necessary trade-offs between different water uses. River and floodplain fisheries are one of these benefits, and in the case of Cambodia are assets of remarkably high importance for the country.

Inland fisheries amounted to 360,000 tons in 2002 according to the Department of Fisheries, contributing up to 16% of the GDP (Van Zalinge et al. 2004). Depending upon years, this catch is equal or superior to that of the inland fisheries in the whole Northern America. However, detailed scientific monitoring shows that this annual catch varies a lot from year to year, depending among others on the flood characteristics (Ngor Peng Bun 2000, Baran et al. 2001a and b). Recent studies have also shown that the fish production in the Mekong Basin is dependant upon a number of hydrological, environmental and ecological factors (Baran 2001c). A modelling approach is the only possible way to integrate all these states (Baran and Cain 2001; Baran and Baird 2003), as the global trend resulting from intricacy of factors is beyond the reach of individual experts and the number of interacting variables would require decades of data for a standard statistical approach. For example, 60 annual cycles would be required to test all the interactions of four environmental variables on the annual fish production with a non parametric method, the least data-hungry approach (Sokal and Rohlf, 1981).

Reviews of modelling approaches and tools for tropical floodplain rivers management have also demonstrated the interest of Bayesian networks (Baran 2002; Arthington et al. 2004) as they allow the integration of quantitative as well of qualitative information (databases or expert knowledge), and they are intuitive, flexible and powerful.

In 2001-2002 a decision support tool based on Bayesian networks was developed to integrate the 25 variables that drive the Mekong fish production (Baran et al. 2003a). The paucity of data available at this time at the scale of the whole basin led to a rather crude model, whose parameterization was based on expert knowledge only. Lessons learnt from this undertaking were that:

a) the usefulness of Bayesian networks as a management tool would be better demonstrated if undertaken at a smaller scale, at which sufficient data would be available and variables could be more precisely described;

b) the expert consultation process was a crucial step in building a model that would be recognized as relevant by stakeholders, balancing simplification and accuracy, sophistication and uptake.

Learning from these lessons, in 2003 the WorldFish Center, in collaboration with IFReDI, undertook the development of a model of the Tonle Sap fish production. The objectives of this study were to identify relationships between river hydrology, floodplain habitats and fish production; to raise awareness among stakeholders and decision-makers about the dependency of fish production upon environmental factors; and to predict the relative abundance of the fish groups dominant in the Great Lake fisheries. An additional objective was also to train IFReDI counterparts in modelling approaches.

This report describes the progressive building of this model named BayFish – Tonle Sap (Bay- stands for Bayesian, and Fish- for fisheries). After having introduced the principles of Bayesian networks (section 2) and the process of stakeholders consultation for model building (section 3), we detail the creation of the
model framework by selection of relevant variables (section 4), and the characterization of these variables (section 5). Then the parametrization of the variables is described in sections 6 and 7; the integration of data sets in the model, briefly addressed here, is extensively detailed in a companion report by Jantunen (2006). The model obtained is tested and validated, before scenario analyses are run (section 8). The conclusion of this study are presented in the final section.

2  BAYESIAN NETWORKS AS INFORMATION INTEGRATORS

A Bayesian network consists in defining the system studied as a network of variables linked by probabilistic interactions (Jensen 1996). Bayesian networks are also called Bayes nets or Bayesian belief networks (BBN). These methods based on the calculation of dependant probabilities (Bayes theorem) were originally developed in the mid-90s as Decision Support Systems (DSS) for medical diagnostic. Their principles and application to environmental management have been detailed in Charniak (1991), Ellison (1996), Cain (2001) and Reckhow (2002).

Variables representing the modelled environment can be quantitative (e.g. “Number of fishers”) or qualitative (e.g. “Fishing strategy”). For each variable a small number of classes are defined. One of the challenges, when building a network, consists in defining enough but not too many variables.

Probabilities are attached to connected variables, based on what is known about the system represented (Figure 1).

Figure 1: Mini-network of 3 connected variables representing a hypothetical fishery (left). The probabilities of the first two driving variables are detailed in the central section, and the justification is detailed in the right part of the figure.

In a driven variable all the possible combinations of driving variables are integrated (Figure 2).
Bayesian networks have been used since the mid-nineties (e.g. Lee and Rieman 1997, Kuikka et al. 2000, Soncini-Sessa et al. 2004). Ultimately the computer calculates, based on the Bayes formula of combined probabilities, the probability of having a certain state in a driven variable given all the states defined in all driving variables.

The possible integration of expert knowledge (an expert being any person having a first hand experience of having a certain state in a driven variable given all the states defined in all driving variables.) into a modelling framework contributed significantly to the success of the Bayesian approach; such consultations are nowadays being more and more broadly used (e.g. McKendrick et al. 2000, Soncini-Sessa et al. 2002, Hahn et al. 2002, Bertorelle et al. 2004). In the field of fisheries, Bayesian networks have been used since the mid-nineties (e.g. Lee and Rieman 1997, Kuikka et al. 1999,}

Figure 2: Mini-network of 3 connected variables representing a hypothetical fishery (continued). The probability table of the driven variable is detailed and in the middle of the figure, and the resulting probabilistic computation is given in the right part of the figure.

Thus the major tasks in building the model are:

a) **Network development:**
   - To identify the major variables of the system studied;
   - To arrange them into a meaningful network.

b) **Variables definition:**
   - To define a few relevant states for each variable.

c) **Parameterization:**
   - To define the probability of each state of each driving variable (action named "elicitation of prior probabilities");
   - To define for each driven variable the probabilities of each combination of driving variables.

If data is available, then the quantified relationship between two variables can be automatically converted into probabilities. If data is not available, then expert knowledge can be used to express in terms of probabilities the known relationship between two variables.

Ultimately the computer calculates, based on the Bayes formula of combined probabilities, the probability of having a certain state in a driven variable given all the states defined in all driving variables.

**Bayes formula**

\[
P(a|b) = \frac{P(b|a) \times P(a)}{P(b)} \quad \text{i.e.} \quad \text{Probability of a knowing b} = \frac{(\text{Probability of b knowing a}) \times (\text{Probability of a})}{\text{Probability of b}}
\]

In other words

\[
\text{Posterior} = \frac{\text{Conditional likelihood} \times \text{Prior}}{\text{Likelihood}}
\]

The possible integration of expert knowledge (an expert being any person having a first hand experience of the system studied) into a modelling framework contributed significantly to the success of the Bayesian approach; such consultations are nowadays being more and more broadly used (e.g. McKendrick et al. 2000, Soncini-Sessa et al. 2002, Hahn et al. 2002, Bertorelle et al. 2004). In the field of fisheries, Bayesian networks have been used since the mid-nineties (e.g. Lee and Rieman 1997, Kuikka et al. 1999,}
Borsuk et al. 2002) and are being increasing used, for instance for stock assessment (Hoggarth et al. 2006).

Different software applications are available to build and run Bayesian networks (review in Arthington et al. 2004) although some teams prefer to develop their own (Varis 2003). We chose for the development of this model the Netica software developed by Norsys (www.norsys.com) as it is intuitive, user friendly (it does not require to master a computer language) and is easily accessible on Internet, where a freeware version allows the development of small models and the running of any big model such as BayFish – Tonle Sap.

3 THE STAKEHOLDERS CONSULTATION PROCESS

In using Bayesian networks for environmental management, the consultation of experts and stakeholders is acknowledged as being of critical importance (Borsuk et al. 2001; Cain et al. 2003; Ravnborg and Westermann 2002). The experts or stakeholders consultation has been described with more or less details in almost all studies using Bayesian networks. However for modelling approaches touching up on societal issues such as natural resources management, studies focusing on consultation processes and methodologies are very few (Reckhow 2002). Some authors have addressed specific aspects of consultations, in particular on the formal side (Beierle 2002, Gregory et al. 2003, Wilkins et al. 2002, Seidel et al. 2003), whereas others have highlighted the psychological pitfalls inherent to consultation of individuals or stakeholders (Anderson 1998, De Bruin et al. 2002, Fenton 2004). On the practical side, the recommendations provided by Cain (2001) and Ravnborg and Westermann (2002) for stakeholders consultations are among the most detailed; however the lack of concise and pragmatic methodological framework led Baran and Jantunen (2004) to propose guidelines for stakeholders consultation for Bayesian modelling in environmental management.

The Tonle Sap model has been built from scratch following the recommendations of 38 stakeholders overall, met during four one-day workshops, (Hort et al. 2004). The meetings were attended by a majority of stakeholders pertaining to the fisheries sector, from national agencies (IFReDI, DoF) but also from local organizations (community fisheries, farmers-fishers organizations). Environmental and socio-economic disciplines were also represented, in particular hydrology, water quality and environmental valuation. Among other disciplines, managers (MRC Basin Development Plan) and policy-makers (Cambodian National Mekong Committee) were also present. In term of origin of the stakeholders, governmental agents were a majority, which is coherent with the target of the tool developed. The presence of independent scientists and representatives from fisher organizations balanced the number of specialists from the governmental agencies.

Several consultations were necessary so that the modellers could progressively convert the information provided by stakeholders into a computer model. This back-and-forth process also permitted to identify missing notions, incoherencies and mistakes. The model presented below is the final accepted one, and the intermediate steps have not been detailed.
The three main steps of the consultation consisted in:
   a) building the model framework;
   b) defining the model variables, and;
   c) parameterizing the variables.
A report following each major step has been produced and served as a basis of the following consultation.

4 BUILDING THE MODEL FRAMEWORK

The model framework is based on contributions from stakeholders, as detailed in Hort et al. (2004). By convention the variables of the network are represented in a box and the states of each variable are in “Italics”. In this section, description starts from the driven variables, moving up towards their driving variables.

4.1 Fish production variables

- Tonle Sap fish production is expressed as **Total fish catch** (Figure 3):
  - Fish stock depends on hydrology, habitat available, and amount of fish migrations;
  - Fish catch depends on fish stock and on the efficiency of the fishing sector.

![Figure 3: Main variables contributing to Tonle Sap fish production.](image)

4.1.1 Components of the fish catch

- **Total fish catch** results from **Catch of Mekong migrants**, **Catch of Tonle Sap migrants** and **Catch of residents**.
- “Resident fish” is a term considered here as synonym of “Black fish”; this ecological category is that of species with limited lateral migrations and no longitudinal migrations, able to survive in swamps and ponds all year round. These fish are mostly carnivorous and detritus feeders. The group of “resident fish” includes: Channidae (Snakeheads), Clariidae, Bagridae (Mystus sp.) and Anabantidae (Van Zalinge et al. 2004).
- “Mekong migrants” is synonym here of “White fish”; i.e. the ecological group of species showing long distance migrations, in particular back to the Mekong mainstream. This group includes many cyprinids (e.g. “Trey riel” Henicorhynchus spp. and Cirrhinus sp.) but also most Pangasidae.
• “Tonle Sap migrants” is synonym of Grey fish, as defined by Welcomme (2001). This ecological category corresponds to fishes that do not spend the dry season in floodplain ponds, but do not undertake long distance migrations either. They tend to spend the dry season in Tonle Sap tributaries and their ecological and physiological characteristics are intermediate between those of black and white fish. This guild includes species such as Belodontichthys dinema (trey khlang hay in Khmer), Mystus albolineatus (trey kanhchos bai) or Kryptopterus cheveyi (Trey kamphleav stung).

The terms “resident” and “migrant” have been preferred to the classical terms “black fish”, “white fish” or “grey fish” as the latter are not familiar to stakeholders who do not see the point of a classification based on colour, although it is actually based on ecology and behaviour. It is also acknowledged that “resident” fishes also move laterally between different habitats in the floodplain and thus qualify as migrants, but this feature is considered minor by stakeholders when compared to the migrations undertaken over much longer distances by white or grey fishes. Stakeholders also decided not to detail fish groups further, as classifying into more detailed and significant ecological groups the 296 species or so that constitute the Tonle Sap fish community seemed to be impossible at this point of time.

![Figure 4: Variables contributing to Tonle Sap fish catch.](image)

• As catch results from a fishing pressure on a fish stock, Catch of Mekong migrants is dependant on Stock of Mekong migrants and of Pressure on Mekong migrants. The same applies to Tonle Sap migrants and resident fish.

![Figure 5: Variables contributing to catch of resident fish.](image)

4.1.2 Components of the fish stock

• Stock of Mekong migrants depends on the annual flooding pattern (Flooding for fish), on the available options for migrations (Migrations of Mekong migrants), and on the quality of the environment used (Habitat for Mekong migrants). The same applies to Tonle Sap migrants and Resident fish (figure 6).
Thus these fish stock nodes serve as the combination point for hydrological, environmental and fishing sections of the model.

4.2 Hydrology variables

4.2.1 Quality of flooding

- Flooding for fish is understood as a combination of the Flood beginning (date of beginning of the flood in the floodplain), of the Flood duration and of the Flood level. At the same time Flood duration is affected by Flood beginning and Flood level, i.e. earlier and higher flood causes duration to extend.

4.2.2 Details of hydrological variables

- Flood level results from Tonle Sap water level as measured in a reference site. Flood level is also affected by Flood beginning as earlier floods have a higher possibility to cause higher floods.

- Tonle Sap water level results from Tonle Sap runoff (water originating from rainfall over the Tonle Sap Basin), from the Mekong inflow (water coming from the Mekong River via the Tonle Sap River) and from the Overland flow (Mekong River water spilling over the land, in particular between Kompong Cham and Phnom Penh, hence not contributing to discharge measurements at Prek Kdam). Justifications can be found in Jantunen (2006).
• **Tonle Sap runoff** results directly from **Tonle Sap rainfall** over the basin, as seen in figure 9.

![Figure 9: Variables contributing to Tonle Sap water level.](image)

4.3 **Habitat variables**

• **Habitat for Mekong migrants**, **Habitat for residents** and **Habitat for Tonle Sap migrants** are understood as the quality of the environment used by these fishes. Stakeholders and recent studies show that the states of critical importance to all fish groups are the oxygen level in the floodplain (\(O_2\) for resident fish, \(O_2\) for Mekong migrants and \(O_2\) for Tonle Sap migrants) and the nature of the vegetation in the floodplain (\(\text{Flooded vegetation}\)). Incidentally dissolved oxygen (DO) is the only indicator of scientifically proven importance to fish production as that of other chemical variables could not be ascertained. In general the lake is well oxygenated due to wind and wave induced aeration, but parts of the floodplain are largely anoxic due to the decaying of vegetation and lack of wind induced mixing (Sarkkula and Koponen 2003).

• \(O_2\) for residents is the concentration of **Floodplain oxygen** biologically acceptable for black fishes used to living in the floodplain. The same applies to \(O_2\) for Mekong migrants and \(O_2\) for Tonle Sap migrants (a distinction was made as the three groups do not have the same requirements, black fishes being the least demanding, white fish the most demanding in oxygen and grey fish having intermediate requirements).

• **Floodplain dissolved oxygen** depends upon **Tonle Sap water level** and upon the nature of **Flooded vegetation**. Usually the higher the water level the higher the dissolved oxygen levels. Vegetation type affects DO through the amount of organic matter produced (leaves and branches absorb oxygen when they decompose in the water) as well as vegetation height (high vegetation such as flooded forest reduces wave formation, water stirring and the subsequent mixing of oxygen in the water column).

• **Flooded vegetation** is a function of the **Tonle Sap water level**, the amount of vegetation flooded being directly dependant on the surface area covered by the flood.

![Figure 10: Variables contributing to Habitat for migrant and resident fish.](image)
4.4 Fish migration variables

- **Migrations of resident fish** is understood as the possibility for fish to migrate within the floodplain and to have access to refuges in the dry season. This variable is thus driven by two factors: the availability of **Floodplain refuges** and the presence of **Built structures** that reduce access to floodplain habitats and increase fish catchability and mortality. **Migrations of Mekong migrants** and **Migrations of TS migrants** depend upon the same factors, although there is more emphasis on longitudinal migrations and larval drift between the Mekong or Tonle Sap tributaries and the Lake.

- **Floodplain refuges** describe temporary and perennial ponds in the Tonle Sap floodplain that have the potential to offer dry season refuges for fish (mainly for residents and Tonle Sap migrants). Any pond (temporal) that completely dries up at some point of the year is not considered as a refuge. For this reason irrigation channels, most of which dry up, are not considered as refuges (Cambodian irrigated rice fields produce only two crops per year, hence they dry up at some point).

- **Built Structures** depend upon Tonle Sap water level. The higher the water level the more the built structures affect the flow and especially extent of the flood. Larger area of flood provides wider habitat for fish, therefore built structures have a negative impact on fisheries. The only built structures considered here were National Roads 5 and 6 due to lack and quality of data.

4.5 Fishery variables

4.5.1 Components of the fishing pressure

- **Pressure on residents**, **Pressure on Tonle Sap migrants** as well as **Pressure on Mekong migrants** all depend on the fishing pressure of three major components of the overall fishery: the small scale (SS), middle scale (MS) and large scale (LS) fisheries (DoF 2001; figure 11)

![Figure 11: Variables contributing to fishing pressure.](image)

4.5.2 Components of each fishery

- In absence of significant and quantified alternative information, it is considered that the **Pressure from large-scale fishery** is primarily a reflection of the length of fences constituting the large scale fishing lots.
The fishing pressure from small-scale fishery depends on the gear size of small-scale fishers, on the activity of small-scale fishers (i.e., their intensity of fishing), and on the number of small-scale fishers. The number of small-scale fishers is a combination of the number of Khmer small-scale fishers and of the number of Vietnamese/Cham small-scale fishers. As a matter of fact, it is believed by stakeholders that the expertise and impact of Vietnamese and Cham specialized fishers are superior to that of Khmer fishers, who consider themselves mainly as rice farmers (Nettleton and Baran 2004).

The "gear size" variable illustrates the fact that the dominant gear of the small scale fishery is the nylon gill net, whose size has been increasing over years from the 10 meters allowed by law to an average of 300m (Nettleton and Baran 2004).

The activity of small-scale fishers depends on the Tonle Sap water level since subsistence farmers-fishers spend their time either fishing or farming, depending upon the flooding conditions.

Figure 12: Variables contributing to fishing pressure from the small-scale fishery.

The pressure from middle-scale fishery depends on the number of middle-scale fishers and on the middle-scale gear efficiency. The number of fishers is the variable easiest to assess (relatively speaking), and can be a proxy of the total fishing effort; however, the gear efficiency has also been evolving, in particular since the fishery reform in 2000, with, for instance, the spreading of electric fishing, the introduction of the "Boh" gear and the electrification of certain dragnets. These technical evolutions towards more efficiency are well known from fisheries specialists but it remains difficult to quantify them and their impact, and there is currently no monitoring system allowing a quantification of these changes.

The number of middle-scale fishers is a combination of the number of Vietnamese/Cham middle-scale fishers, the number of Khmer middle-scale fishers and of the number of migrant middle-scale fishers, as detailed in Nettleton and Baran (2004). The difference between Vietnamese/Cham or Khmer fishers reflects the fact that the former are considered to operate intensely, whereas the pressure exerted by the latter is believed to be of lesser intensity. Migrant fishers also play a role considered important as they are said to harvest exhaustively and indiscriminately a few months a year.

Figure 13: Variables contributing to fishing pressure from middle-scale fishers.
Figure 14: Overview of the model variables
5 DEFINING THE MODEL VARIABLES

Once the model framework built, a second stakeholders consultation led to the definition of the relevant states for each variable (Hort and Baran 2004). Several of these variables had to be qualified in vague terms, such as “Abundant” or “Scarce”, which illustrates the absence of reliable quantified data for these variables. From this perspective, this modelling study is useful in highlighting the areas that require more research, and shows in particular how little quantitative knowledge exists about the fish resource. The states defined for some other variables can also seem vague (e.g. Flooding for fish “Good” or “Bad”) but in that case this is normal and inherent to the integrative nature of these variables, that represent a status indicator (this is reflected in sayings such as “this year the fish production was good”).

5.1 Fish production variables

- Total fish catch is defined as “High” or “Low”. Quantitative estimates would be possible IF reliable fishery statistics were available to feed the model, but at the moment such data do not exist (Coates 2002).

- Catch of Mekong migrants, Catch of Tonle Sap migrants as well as Catch of residents are defined as “High” or “Low” as no detailed catch statistics are available; therefore more precise states were impossible to define.

- Stock of resident fish, Stock of Tonle Sap migrants and Stock of Mekong migrants are simply defined as “Abundant” and “Scarce”, in absence of any quantitative stock assessment.

5.2 Hydrology variables

- Flooding for fishes is purposely qualified as “Good” or “Bad”, which synthetically describes the quality of a hydrological year from a fishery perspective. All variables seen as essential by stakeholders for fish are taken into account, i.e. flood maximum level, duration and date of beginning.

- The Flood beginning has been defined as “the date of spill-over from the river to the floodplain”; stakeholders have considered, after extensive debates opposing memorized experience to recorded data and people from different locations, that a flood can be considered as “early” when it starts “Before mid-July”, “normal” when it starts from “Mid-July to mid-August”, and “late” when it begins “After mid-August”. In data analysis this ‘spill-over’ was defined as occurring when the water level at Kompong Loung exceeded 4 metres (due to highly fluctuating nature of the water level two reference dates were used: 15th July and 15th August).

- Variable Flood duration has been defined as the time span between Flood beginning and date of end of the flooding; the “end of flooding” being defined by the flow reversal towards Mekong in Tonle Sap River at Prek Kdam. In the second stakeholders consultation, flood duration was expressed in terms of dates; this was later converted into a number of weeks. This consultation also identified states as “Long” (over 13 weeks), “Medium” (5-13 weeks) and “Short” (less than 5 weeks) but data analysed showed that no
flood was longer than 13 weeks or shorter than 5 weeks in records. Ultimately states were defined as “Less than 6 weeks” (short flood), “Around 8 weeks” (6 to 11 weeks, normal flood) and “More than 11 weeks” (long flood).

- **Flood level** was characterized as being “Low” or “High”, and these values are closely associated to the [Tonle Sap water level](#). This simplicity is also required to allow easier elicitation in the probability table of the [Flooding for fish](#) child variable that has three parent variables.

- The definition of the [Tonle Sap water level](#) in a reference place has been subject to several revisions, due to the complexity of this notion. Kompong Chhnang was initially proposed by stakeholders as a reference site but the analysis of datasets revealed that Kompong Chhnang had 34 gaps (2526 days in total) over 37 years of data whereas Kompong Loung had only 8 gaps (819 days in total) in 20 years of data; subsequently Kompong Loung was chosen as reference site for Tonle Sap Lake water level. Thresholds set for water level in 2nd stakeholders consultation were “Above 11m”, “10-11m” and “Below 10m” for Kompong Chhnang; however these thresholds were invalid for Kompong Loung (where water level never reach 11m and rarely 10m). Thus in the 4th stakeholders consultation the thresholds were set at “Below 8m”, “From 8 to 10m” and “Above 10m” (Hort et al. 2004). This correlates with the natural system, i.e. “Below 8m” being considered bad for fish production (dry year), “From 8 to 10m” good and “Above 10m” as moderately good for fish production (a high water level favouring the abundance of fish in water but reducing the catchability of these fish by fishers) and bad for agriculture. Jantunen (2006) gives detailed justifications for the final choice, i.e. Kompong Loung as a reference site for gauging and “Below 8m”, “Between 8 and 10m” and “Above 10m” as reference marks of low, normal or high water levels.

- [Tonle Sap rainfall](#), [Tonle Sap runoff](#), [Mekong inflow](#) and [Overland flow](#) were calculated based on existing databases (Jantunen 2006) and are simply expressed in terms of a state “Above” or “Below” of their respective average after several rainy seasons. Given existing knowledge it was impossible to define the states more meaningfully, and defining more states would have generated a non-manageable complexity in probability tables, with impossible combinations and unrealistic data requirements (e.g. 3 driving variables with 3 states each = 27 combination of states; when related to 3 states in the driven variables, this would correspond to 27 x 3 = 81 probabilities to be set or calculated into the probability table).

### 5.3 Habitat variables

- [Habitat for residents](#), [Habitat for TS migrants](#) as well as [Habitat for Mekong migrants](#) have been described as “Good” or “Bad”, as this describes the quality of the habitat from a fish perspective. Only two variables define the habitat quality: dissolved oxygen concentration and vegetation type. A lot of other variables were mentioned and discussed during the stakeholder consultations, but these two variables are the only ones whose role vis-à-vis fish production could be substantiated and states defined. Vegetation in particular provides feed and protection from predators for juvenile fishes, but also plays a negative role by reducing dissolved oxygen concentrations through decomposition of organic material at the beginning of the flood.
• O₂ for residents has been simply expressed in terms of "Acceptable" or "Impossible"; this variable is linked to Floodplain Dissolved Oxygen. The same applies to O₂ for Mekong migrants. See Floodplain Dissolved Oxygen below for more detailed description.

• The essential states of Floodplain Dissolved Oxygen has been defined, after a review of literature using FishBase (2004), as "Above 4 mg/l" (value acceptable to almost all fishes), "Between 2 and 4 mg/l" (values acceptable by resident black fishes and most grey fish but too low for migrant white fishes) and "Below 2 mg/l" (values too low for any fish species). This rough classification was confirmed by a consultation of local aquaculturists.

• Flooded vegetation is defined in terms of surface of "Grass", "Shrub" and of "Forest" as these variables has been acknowledged to be the ecologically significant ones by stakeholders, as well as in scientific studies (Baran et al. 2001c).

• Floodplain refuges are defined from JICA (1999) data as “Perennial” (an actual dry season refuge for fish) or “Temporal” (non-refuge because dry in the dry season). Refuges play an important role for resident and Tonle Sap migrant fishes during the dry season providing habitat, shelter and food on the driest months of the year.

• Built Structures are defined for now as structures that prohibit the extent (area) of the flood. Therefore the structures can be either “Blocking” or “Open”.

5.4 Fish migration variables

• Migrations of resident fish : it is likely that the hydrological and environmental requirements of larvae and juveniles (feeding migrations) are different from those of the adults (breeding migrations), but the paucity of knowledge in that field did not allow the stakeholders to be more specific. In absence of any other information, Migrations of resident fish is qualified as "Free" or "Blocked" (by unfavourable hydrological conditions or built structures).

• Having to define the Migrations of migrant fish highlighted the knowledge gaps about most of these species (the migration status being known for only one fourth of Mekong fish species; Baran et al. 2005), and the difficulty of quantifying migrations on a large scale. As a consequence the status defined were simply “Free” or “Blocked”, the elicitation of probabilities allowing a full range of situations between these two extremes.

• The (mainly lateral) Migration of resident fish was defined with the same states.
5.5 Fishery variables

In view of developing a model that matches the approach of the Department of Fisheries, the description of the Cambodian fishery sector has been based on the official classification of the Ministry of Agriculture, Forestry and Fisheries (DoF 2001): large scale fishing (fishing lot operations, barrages fishing and bag net fishing), medium-scale fishing (gill nets longer than 10 m, seine net, fishing traps not longer than 500m of bamboo fence, hook lining, etc); and small-scale or subsistence fishing (simple small gears).

From the data we gathered on the field, it appeared that small-scale fishers categories harvest around 3,000 kg/fisher/year, as compared to middle scale fishers yielding more than 20,000 kg/year/fisher. It was also felt necessary to disaggregate fishers according to their ethnicity, as the fishing activity (methods, efficiency and pressure on the resource) is quite different depending upon the ethnic group. As put by Luco (1997): “traditionally, important fishermen on the lake are of Cham or Vietnamese descent. The Khmer are farmers first, becoming fishermen in the dry season” The Vietnamese, like the Muslim Chams, are reported to be excellent fishers, and are always consulted by fishing lot operators (Degen & Thuok 1998). As noted by Keskinen (2003), “ethnic minorities are significantly concentrated in the areas close to the lake and particularly in the floating villages where they are involved in fishing and fishing-related activities. One of the main reasons for this is that often ethnic minorities do not own any agricultural land”.

• As all stakeholders agreed that the fishing pressure was unlikely to decrease in the coming years because of population growth, Pressure on resident fish, Pressure on Mekong migrant fish and Pressure on Tonle Sap migrant fish were defined as “Increasing” or “Stable”, even though no quantitative assessment of this fishing pressure is available nor in progress. The on-going reforms of the fisheries sector also justified the need to differentiate between fishing pressure on resident black fish (valuable species targeted in particular by the lot fisheries) and fishing pressure on migrant white fish (mainly small cyprinids, caught in particular with gill nets and by the dai fishery).

• The large-scale fishery was the one that could be best quantified; Pressure from large-scale fishery has been described as varying between “Blockage” and “Nil”. This describes the effect of fences at the end of the flooding period (blockage of the migration routes) or during the rainy season (lots are not in operation, fences have been removed, pressure is nil).

• Considering the Fisheries Reform that opened access to more small-scale fishers than in the past and the recent suppression of licence fees in the middle-scale fishery sector, the Pressure from small-scale fishery has been described as “Increasing” or “Stable”. The lack of assessments does not allow a quantification of this fishing pressure, but a reduction is not expected in a near future.
• The Activity of small-scale fishers, who are also part-time farmers when they are ethnic Khmers, varies depending on the benefits perceived: they may shift to “More fishing” or “More farming” depending upon environmental conditions. It is considered that when the water level is high (above 10m), farmer-fishers shift towards more fishing because of relative fish abundance and high value of the catch relatively to rice. When the water level is low (below 8m), fish stock is relative scarce and farmer-fishers tend to shift toward more farming.

• According to Keskinen’s study (2003), with 12,000 persons the Vietnamese represent 3% of the population of the Lake’s basin, and Chams 2.2%. However the Vietnamese concentrate around the borders of the permanent water body, where they fish and make up to 14% population. The Number of Vietnamese/Cham small-scale fishers is considered to increase moderately. In absence of studies on the demography and migrations of ethnic minorities, field interviews have led to the conclusion that natural population growth in these minorities is largely offset by a push away from the lake and emigration towards booming cities. The state of this variable was thus defined as “Decreasing” or “Stable”.

• With about 1.2 million persons living around the lake and 94.8% of them being Khmer (Keskinen 2003), the Number of Khmer small-scale fishers was considered significant by stakeholders. At the scale of the country, the population growth rate amounts to 1.8%; however Haapala (2003) has shown that the difficult conditions of living and insufficient natural resources around the lake result in emigration towards cities and borders, and that four out of five of the lake provinces actually lose inhabitants. Subsequently the states of the above variable were defined as “Decreasing” or “Stable”. It should be noted however that this does not integrate temporary migrants from the upper parts of the Tonle Sap basin that seasonally come to the lake to exploit it, and whose dynamics and impact have never been quantified.

• The Gear size of small-scale fishers was defined as “Increasing” or “Stable”, because the size of the small scale fishing gears of subsistence family fishers has increased over time, but it is said to have stabilized to a maximum manageable size in recent years. Small-scale gear efficiency is a complementary variable that should be present in the model but that is simply impossible to quantify; therefore it has not been taken into account.

• Considering the Fisheries Reform that opened access to more small-scale fishers than in the past and the recent suppression of licence fees in the middle-scale fishery sector, the Pressure from middle-scale fishery have been described as “Increasing” or “Stable”. The lack of assessments does not allow a quantification of this fishing pressure, but a reduction is not expected in a near future.

• Depending upon technological improvements, Middle -scale gear efficiency may increase. A common trend is increased motorization and use of smaller mesh sizes that make nets more efficient. Although it is almost impossible to quantify the efficiency of a multi-gear fishery, we consider it is either “Stable” or “Increasing”.

• The Number of middle-scale fishers is the sum of Number of Vietnamese/Cham, Khmer and migrant fishers. States for this node are defined as “Stable” or “Increasing".
Middle scale fishers consist of Vietnamese, Cham, Khmer commercial fishers, and migrant fishers who come from the surroundings of the basin and exert a temporary but intense pressure on the resources (Nettleton & Baran 2004). For the same reasons as those detailed for the number of subsistence fishers, it was considered that the states of the variables \textit{Number of Vietnamese/Cham middle-scale fishers}, \textit{Number of Khmer middle-scale fishers} and \textit{Number of migrant middle-scale fishers} should be "Stable" or "Increasing".

Overall the extreme and unrealistic simplicity of the states of the fishery variables sadly reflects the absence of scientific knowledge about the status of the Cambodian inland fishery, and the subsequent weakness of the Fishery module in the overall model. Because of this fact, the BayFish Tonle Sap model can be considered strongly underpinned by best available information down to the Stock level, but not down to the Catch level.

Figure 15 summarizes all the states defined for each variable of the network.
Figure 15: States defined for each variable of the network.
6 INTEGRATING DATABASES

A significant effort was put in the integration of databases to the model. These data consist in hydrological (rainfall, runoff, Mekong inflow, overland flow, flood beginning, and flood duration), water quality (dissolved oxygen), land use for the Tonle Sap Lake and floodplain and built structures (opposing flow, refuges and fishing lots). In addition scenarios of the model are based on output data of MRCS/WUP_FIN hydrological model. Special attention in analysis was given to data accuracy, reliability and suitability for the model. A specific report has been dedicated to this study (Jantunen 2006), and the reader might want to refer to this companion report.

The databases gathered and used in the model are summarized in table 1.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Area and period</th>
<th>Description</th>
<th>Format</th>
<th>Obtained from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall data</td>
<td>MRCS</td>
<td>Tonle Sap catchment 1980-2003</td>
<td>Average rainfall data over each of the subcatchments</td>
<td>Numerical</td>
<td>MRCS/JICA &amp; TSLV Flow Reversal Project</td>
</tr>
<tr>
<td>Land use, road network, ponds and administrative data</td>
<td>JICA</td>
<td>Tonle Sap catchment</td>
<td>1999 JICA Land use map simplified for Tonle Sap floodplain</td>
<td>GIS layer 1:100 000</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Land use data</td>
<td>WUP_FIN</td>
<td>Tonle Sap floodplain</td>
<td>Calculated percentages of land use types depending on elevation</td>
<td>Numerical</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Dissolved oxygen data</td>
<td>WUP_FIN and MRCS</td>
<td>Tonle Sap Lake and floodplain</td>
<td>Measurements by MOWRAM and MRCS/WUP_FIN</td>
<td>Numerical</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>MRCS/WUP_FIN model output data</td>
<td>WUP_FIN</td>
<td>Tonle Sap Lake and floodplain</td>
<td>Average dissolved oxygen levels and anoxic conditions prevalent in the lake and floodplain</td>
<td>Numerical and bitmap</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Certeza survey contour data</td>
<td>MRCS</td>
<td>Tonle Sap floodplain</td>
<td>Digital contour lines based on 1964 levelling survey</td>
<td>GIS layer 1m contour lines</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Water balance data</td>
<td>JICA &amp; TSLV Flow Reversal Project and MRCS/WUP_FIN</td>
<td>Tonle Sap catchment</td>
<td>Calculated water balance to Tonle Sap catchment</td>
<td>Numerical</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Fishing lots</td>
<td>MRC</td>
<td>Tonle Sap catchment</td>
<td>Location, extent and state of fishing lots</td>
<td>GIS layer</td>
<td>MRCS/WUP_FIN</td>
</tr>
</tbody>
</table>
7 PARAMETERIZING THE VARIABLES

Parameterizing the variables in the model consists in attributing probabilities to variables; more specifically attributing probabilities to each state of a driving variable and, to each combination of states of a driven variable. This process is the one described in section 2 and illustrated in Figures 1 and 2. Parameterization is detailed in the reports of the third and fourth stakeholders consultations (Hort et al. 2004; Baran 2004). In this section, description starts from the driving variables, that combine into driven variables. In the BayFish model all probability tables are open to viewing and to modification by the user if this is felt necessary. For a detailed explanation of the computations in case of variables based on databases it is recommended to refer to the Netica manual (available online at http://www.norsys.com/download.html).

7.1 Fish production variables

- **Total fish catch**

  The Tonle Sap total fish catch results from the yielding of white, grey and black fish. However the creation of a grey fish category is new, and has never been reflected in catch statistics so far. It is therefore impossible to date to quantify the contribution of grey fish to the Tonle Sap total catch. Since grey fish used to be previously considered as white fish (they leave the floodplain when the flood recedes, and do not spend the dry season in ponds), grey fish have been assimilated below by default to white fish. This approximation allows using available statistics regarding white fish and black fish to parametrize the last node of the model.

  According to Van Zalinge et al. (2000), Black fish harvest represents only 17.5% in biomass while the rest is represented by White fish harvest (See Table 2).

<table>
<thead>
<tr>
<th>CATCH of residents</th>
<th>CATCH of Mekong migrants</th>
<th>CATCH of TS migrants</th>
<th>Total fish catch</th>
<th>Justifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>100</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>(Low)</td>
<td>Low</td>
<td>100</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>(High)</td>
<td>17.5</td>
<td>82.5</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>17.5</td>
<td>82.5</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>82.5</td>
<td>17.5</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>(Low)</td>
<td>82.5</td>
<td>17.5</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>(High)</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
• **Catch of residents**
The Catch of residents results from the combination of a stock of resident fish and a fishing pressure on these black fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of residents.

• **Catch of Tonle Sap migrants**
The Catch of Tonle Sap migrants results from the combination of a stock of resident fish and a fishing pressure on these grey fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of residents.

• **Catch of Mekong migrants**
The Catch of Mekong migrants results from the combination of a stock of Mekong migrants and a fishing pressure on these white fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of Mekong migrants.

• In absence of specific information, the **Stock of Mekong migrants** is considered to result equally from a proper habitat, recruitment from migrations and adequate hydrology; hence 33%-33%-34% chances attributed to each variable.

• In absence of specific information, the **Stock of Tonle Sap migrants** is also considered to result equally from a proper habitat, possible migrations to local tributaries and adequate hydrology; hence 33%-33%-34% chances attributed to each variable.

• For the **Stock of resident fish**, less importance is given to migrations (20% only) because of the short homerange of this guild; the size of the stock is considered to also result from a proper habitat (50%, in particular since dry season refuges are required) and adequate hydrology (30%).

### 7.2 Hydrology variables

• The parameterization of variables **Tonle Sap rainfall**, **Tonle Sap runoff**, **Mekong inflow** and **Overland flow** is described in detail in Jantunen (2006). Basically the databases provided several years long time series (1985-2003) from which average values for each variable were calculated. Then the modelling software used the data table generated (average per variable per period of time) to fill in the probability table of having an annual value above or below the average. Parameterization was changed for **Mekong inflow** and **Overland flow** when hydrological scenarios were made available through ADB Built Structures Project (WUP_FIN) as upstream development only affects inflow originating from Mekong. However, the WUP_FIN model could only process years 1996-2000, thus severely reducing the amount of data available for producing probabilities for the nodes. Changes are described shortly below, and data analysis is detailed in Jantunen (2006).

For **Tonle Sap rainfall**, data used was the data checked and edited by MRCS/WUP-JICA & TSLV project. For this data no sophisticated spatial weighting were used for rain gauge network due to its non-uniform
distribution. In addition, rainfall on the open lake was not accounted for, as it is equal to evaporation. Also, only post-1996 data were used due to inconsistencies before this date. Standard deviation of rainfall data showed that most variation in rainfall amounts takes place between August and November, and thus only half a year of data (from June to December) was used for each hydrological year.

For **Tonle Sap runoff**, MIKE11 model output data from the MRCS/WUP-JICA & TSLV project was used, whereas **Mekong inflow** and **Overland flow** are derived from WUP_FIN model output data. The water balance of the Tonle Sap Lake depends on these three components and deriving them from one and the same dataset ensures compatibility of data in their common child node **Tonle Sap water level** at Kompong Loung. Even though two parent nodes for **Tonle Sap water level** were changed with new data, the parameterization of **Tonle Sap water level** was not changed. The MRCS/WUP-JICA & TSLV project data provides much more comprehensive range of combinations for generating probabilities.

- The reference average value for **Tonle Sap rainfall** is 1000 mm of rain during the June-December period (45% above average and 55% below average).
- The reference average value for **Tonle Sap runoff** is 30,000 million cubic meters (MCM) of water during the June-December period (43% above average and 57% below average when TS rainfall is below 1000mm and 67% above average and 33% below average when TS rainfall is above 1000mm).
- The reference average value for **Mekong inflow** was 37,000 MCM of water during the June-December period (48% above average and 52% below average). This was changed into 34,000 MCM with WUP_FIN data. The resulting probabilities for baseline are 60% above average and 40% below average. This shows a general increase in likelihood of above average floods, but the change is due to lowered threshold level from 37388 to 34363 (average of total time series), shorter time series and generally lower flows of WUP_FIN output data.
- The reference average value for **Overland flow** is 7,600 MCM of water during the June-December period (43% above average and 57% below average). This was changed into 6,400 MCM with WUP_FIN data. The resulting probabilities for baseline are 60% above average and 40% below average. See scenarios (section 8) for full explanation. Similarly there is a general increase in likelihood of above average floods, but the change is due to lowered threshold level from 7800 to 6400 (average of total time series), shorter time series and generally lower flows of WUP_FIN output data.

- For **Tonle Sap water level**, the reference is the annual maximum water level at Kompong Loung; Parameterization is derived from the simulation outputs of the MRCS/WUP-JICA & TSLV MIKE11 model for the 1985-2003 period. Measured data were not used because of unexplained daily shifts (+/- 1m per day) and because of approximately 2.5m difference between pre-1965 and post-1996 datasets. Furthermore using the MIKE11 model output data provided a longer dataset (1985-2003). It has an excellent correlation with MRCS/Hymos corrected data (restricted to 1996-2003). In addition MIKE11 model output data was also used for parameterization of some of **Tonle Sap water level** parent nodes, therefore using the same dataset increases compatibility. Baseline of the node changed a little due to incorporation of hydrological scenarios from WUP_FIN from 25.4/49.8/24.8 to 29.6/47.8/22.6 (Above 10m/Between 8m and 10m/Below 8m respectively).
Table 3: Parameterization of Tonle Sap water level variable.

<table>
<thead>
<tr>
<th>Flow from Mekong</th>
<th>Overland Flow</th>
<th>TS runoff</th>
<th>Water level at Kompong Loung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 37000</td>
<td>Above 7600</td>
<td>Above 30000</td>
<td>Above 10m</td>
</tr>
<tr>
<td></td>
<td>Above 7600</td>
<td>Below 30000</td>
<td>42.857</td>
</tr>
<tr>
<td>Above 37000</td>
<td>Below 7600</td>
<td>Above 30000</td>
<td>25</td>
</tr>
<tr>
<td>Above 37000</td>
<td>Below 7600</td>
<td>Below 30000</td>
<td>20</td>
</tr>
<tr>
<td>Below 37000</td>
<td>Above 7600</td>
<td>Above 30000</td>
<td>40</td>
</tr>
<tr>
<td>Below 37000</td>
<td>Above 7600</td>
<td>Below 30000</td>
<td>15</td>
</tr>
<tr>
<td>Below 37000</td>
<td>Below 7600</td>
<td>Above 30000</td>
<td>16.667</td>
</tr>
<tr>
<td>Below 37000</td>
<td>Below 7600</td>
<td>Below 30000</td>
<td>12.5</td>
</tr>
</tbody>
</table>

• Flood level takes into account flood beginning and Tonle Sap water level. The probability of having a “High” Flood level with Tonle Sap water level (at Kompong Loung) being “Between 8 and 10m” and Flood beginning from “Mid Jul to mid Aug” is based on actual data (4/9 out of example years). In general early floods are correlated with higher floodplain flood levels. Shaded probabilities showing Low Flood level even though Tonle Sap Water level is Above 10m are dismissed from calculations through declaring them as impossible combinations in Flooding for Fish variable. Baseline of the node changed a little due to incorporation of hydrological scenarios from WUP_FIN from 49/51 to 51.3/48.7 (High/Low respectively). This seems to confirm that minor changes to probabilities caused by WUP_FIN data does not significantly alter the hydrological module of the model.

Table 4: Parameterization of Flood level variable.

<table>
<thead>
<tr>
<th>Tonle Sap water level</th>
<th>Flood beginning</th>
<th>Flood level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Above 10m</td>
<td>Before Mid-July</td>
<td>100</td>
</tr>
<tr>
<td>Above 10m</td>
<td>Mid July to Mid Aug</td>
<td>100</td>
</tr>
<tr>
<td>Above 10m</td>
<td>After Mid Aug</td>
<td>0</td>
</tr>
<tr>
<td>Between 8 and 10m</td>
<td>Before Mid-July</td>
<td>100</td>
</tr>
<tr>
<td>Between 8 and 10m</td>
<td>Mid July to Mid Aug</td>
<td>44.444</td>
</tr>
<tr>
<td>Below 8m</td>
<td>Before Mid-July</td>
<td>0</td>
</tr>
<tr>
<td>Below 8m</td>
<td>Mid July to Mid Aug</td>
<td>0</td>
</tr>
<tr>
<td>Below 8m</td>
<td>After Mid Aug</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: as detailed above, Built structures do not intervene in the calculation of Flood level.

• The fourth stakeholders consultation identified the spilling of water to the floodplains (i.e. when water breaches natural levee around the open lake and rivers) as the threshold for Flood beginning. However it is impossible to identify these levees from the 1964 Certeza survey contour lines, as well as from the Hydrographic Atlas (produced in 1998) that only covers the open lake. It should be possible to identify this threshold precisely from the MRCS/WUP-FIN depth measurements, but for a number of reasons these were unavailable during the study. Alternatively we used generic thresholds already agreed by stakeholders (early flood = "Before mid-July", normal = "Between mid-July and mid-August" and late = "After mid-August"). Corresponding water levels for each date from each year were checked, and
4m water level was chosen as the threshold that fits best with floods regarded as early (2000-2002) and late (1998). Probabilities were calculated by the software from the occurrences recorded between 1985 and 2003 (“Before mid-July” = 36%, “Mid-July to mid-August” = 46% and “After mid-August” = 18%). This was then slightly changed due to incorporation of WUP_FIN output data (“Before mid-July” = 40%, “Mid-July to mid-August” = 40% and “After mid-August” = 20%), which shows minor increase in earlier and late floods. This change is due to length of WUP_FIN data available, but even so the simplified version still represents strength of each state well. Detailed justifications and data can be found in Jantunen (2006).

• In order to parametrize Flood duration, the outputs of the MIKE11 hydrological model were used to define the exact moment of flow reversal in the Tonle Sap River at Prek Kdam towards the Mekong. Duration was calculated by combining the date of floodplain flooding, and probabilities were calculated from the recorded occurrences from years 1985 to 2003 (“More than 11 weeks” = 15.79%, “Around 8 weeks” = 78.95% and “Less than 6 weeks” = 5.26%). Flood duration is also influenced by Flood beginning and Flood level, but the 19 years screened did not cover every combination of states theoretically possible. For instance all cases of flood beginning between “Mid-July and Mid-August” had a duration of “Around 8 weeks” whereas in theory longer and shorter durations are possible; therefore these probabilities had to be estimated based on the data available. Furthermore, incompatible hydrological combinations had to be eliminated from the model (they were given 0% probability; see Table 5).

Table 5: Parameterization of Flood duration variable.

<table>
<thead>
<tr>
<th>Flood beginning</th>
<th>Flood level</th>
<th>More than 11 weeks</th>
<th>Around 8 weeks</th>
<th>Less than 6 weeks</th>
<th>Justifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before mid-July</td>
<td>High</td>
<td>42.857</td>
<td>57.143</td>
<td>0</td>
<td>3/7 of Before mid-July floods were &quot;more than 11 weeks&quot; long and 4/7 lasted &quot;around 8 weeks&quot;</td>
</tr>
<tr>
<td>Before mid-July</td>
<td>Low</td>
<td>33.333</td>
<td>66.667</td>
<td>0</td>
<td>Estimated because no examples in data.</td>
</tr>
<tr>
<td>Mid-July to mid-August</td>
<td>High</td>
<td>33.333</td>
<td>66.667</td>
<td>0</td>
<td>Estimated because no examples in data.</td>
</tr>
<tr>
<td>Mid-July to mid-August</td>
<td>Low</td>
<td>15.79</td>
<td>78.95</td>
<td>5.26</td>
<td>Based on average possibilities calculated from 19 example years</td>
</tr>
<tr>
<td>After mid-August</td>
<td>High</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>Not possible to have more than 6 weeks flood After Mid-July</td>
</tr>
<tr>
<td>After mid-August</td>
<td>Low</td>
<td>0</td>
<td>66.667</td>
<td>33.333</td>
<td>2/3 of After Mid-July floods were around 8 weeks, 1/3 Less than 6 weeks</td>
</tr>
</tbody>
</table>

With these changes the baseline of Flood duration ended up being (“Before mid-July” = 25.7%, “Mid-July to mid-August” = 67% and “After mid-August” = 7.3%. This was then slightly changed due to incorporation of WUP_FIN output data which effected Flood duration node through Flood beginning and Flood level nodes (“Before mid-July” = 26.2%, “Mid-July to mid-August” = 66.1% and “After mid-August” = 7.7%). Detailed justifications and setting of thresholds can be found in Jantunen (2006).

• The variable Flooding for fish was parameterized with the values and justifications shown in the table below. Incompatible hydrological combinations such as late and long flood are marked with an X and are not taken into account by the model in any of the calculations or respective probabilities.
Table 6: Parameterization of Flooding for fish variable.

<table>
<thead>
<tr>
<th>Flood Level</th>
<th>Flood Beginning</th>
<th>Flood Duration</th>
<th>Good - Bad</th>
<th>Justifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Before mid-July</td>
<td>More than 11 weeks</td>
<td>80% - 20%</td>
<td>Big and long flood =&gt; considered very good for fish (but not 100% positive since longest floods do not correspond to highest catches)</td>
</tr>
<tr>
<td>High</td>
<td>Before mid-July</td>
<td>Around 8 weeks</td>
<td>100% - 0%</td>
<td>Big flood and appropriate timing still long enough =&gt; considered very good</td>
</tr>
<tr>
<td>High</td>
<td>Before mid-July</td>
<td>Less than 6 weeks</td>
<td>X X</td>
<td>Historically incompatible</td>
</tr>
<tr>
<td>High</td>
<td>Between mid-July and mid-August</td>
<td>More than 11 weeks</td>
<td>90% - 10%</td>
<td>High and timely flood =&gt; considered very good for fish</td>
</tr>
<tr>
<td>High</td>
<td>Between mid-July and mid-August</td>
<td>Around 8 weeks</td>
<td>100% - 0%</td>
<td>High flood of average duration, coming on time =&gt; considered ideal</td>
</tr>
<tr>
<td>High</td>
<td>Between mid-July and mid-August</td>
<td>Less than 6 weeks</td>
<td>60% - 40%</td>
<td>High and timely flood but too short, not so good</td>
</tr>
<tr>
<td>High</td>
<td>After mid-August</td>
<td>More than 11 weeks</td>
<td>X X</td>
<td>Incompatible</td>
</tr>
<tr>
<td>High</td>
<td>After mid-August</td>
<td>Around 8 weeks</td>
<td>X X</td>
<td>Incompatible</td>
</tr>
<tr>
<td>High</td>
<td>After mid-August</td>
<td>Less than 6 weeks</td>
<td>40% - 60%</td>
<td>High, but late and too short flood =&gt; not so good for fish</td>
</tr>
<tr>
<td>Low</td>
<td>Before mid-July</td>
<td>More than 11 weeks</td>
<td>55% - 45%</td>
<td>Low flood, but timely and long =&gt; medium quality</td>
</tr>
<tr>
<td>Low</td>
<td>Before mid-July</td>
<td>Around 8 weeks</td>
<td>45% - 55%</td>
<td>Low flood, timely and long =&gt; medium quality</td>
</tr>
<tr>
<td>Low</td>
<td>Before mid-July</td>
<td>Less than 6 weeks</td>
<td>X X</td>
<td>Incompatible</td>
</tr>
<tr>
<td>Low</td>
<td>Between mid-July and mid-August</td>
<td>More than 11 weeks</td>
<td>50% - 50%</td>
<td>Low flood, timely and long duration =&gt; medium quality</td>
</tr>
<tr>
<td>Low</td>
<td>Between mid-July and mid-August</td>
<td>Around 8 weeks</td>
<td>20% - 80%</td>
<td>Low flood, timely and normal duration =&gt; rather bad for fish</td>
</tr>
<tr>
<td>Low</td>
<td>Between mid-July and mid-August</td>
<td>Less than 6 weeks</td>
<td>25% - 75%</td>
<td>Low flood, timely but too short =&gt; rather bad for fish</td>
</tr>
<tr>
<td>Low</td>
<td>After mid-August</td>
<td>More than 11 weeks</td>
<td>X X</td>
<td>Incompatible</td>
</tr>
<tr>
<td>Low</td>
<td>After mid-August</td>
<td>Around 8 weeks</td>
<td>20% - 80%</td>
<td>Low and late flood of medium duration =&gt; bad for fish</td>
</tr>
<tr>
<td>Low</td>
<td>After mid-August</td>
<td>Less than 6 weeks</td>
<td>10% - 90%</td>
<td>Short, small and late flood =&gt; very bad for fish</td>
</tr>
</tbody>
</table>

Based on experience and model runs, that Flooding for fish variable and associated table seem to have most influence on the outcome of the catch node of the model.

7.3 Habitat variables

- For variable Floodplain dissolved oxygen data was derived from the MRCS/WUP-FIN water quality model due to temporal and spatial limitations in measured point water quality data. As part of collaborative activities with WorldFish, the WUP-FIN team produced directly compatible output data that could be directly inputted into the BayFish model. Data table for this can be seen below and detailed justifications in Jantunen (2006).

---

1 This combination was tweaked to better fit the curve of Dai catches
Table 7: Parameterization of Floodplain dissolved oxygen variable.

<table>
<thead>
<tr>
<th>Water level</th>
<th>Land use</th>
<th>&lt; 2 mg/l</th>
<th>2 – 4 mg/l</th>
<th>&gt; 4 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 8m flood (1998)</td>
<td>grass</td>
<td>54</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>shrub</td>
<td>72</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>forest</td>
<td>37</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>From 8 to 10m flood (1997)</td>
<td>grass</td>
<td>51</td>
<td>28</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>shrub</td>
<td>65</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>forest</td>
<td>27</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Above 10m flood (2000)</td>
<td>grass</td>
<td>60</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>shrub</td>
<td>69</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>forest</td>
<td>32</td>
<td>53</td>
<td>15</td>
</tr>
</tbody>
</table>

- A literature review and discussion with fish biologists and aquaculturists led to the conclusion that dissolved oxygen for residents is not bearable (0% acceptable) if DO level is below 2mg/l; it is considered acceptable for these tolerant black fish between 2 and 4 mg/l, and above 4 mg/l.

- White long-distance migrant fish are less tolerant than black fish; as a consequence in variable dissolved oxygen for Mekong migrants above 4mg/l only is considered as “Acceptable” (100%) for White fish. Therefore the state “From 2 to 4” and “Below 2” mg/l was elicited as impossible (0% “Acceptable”).

- Grey short-distance migrant fish are less tolerant to environmental conditions than resident fish, but also more tolerant than Mekong migrants. As a consequence in variable dissolved oxygen for TS migrants the state “Above 4mg/l” is considered as “Acceptable” (100%) while state “From 2 to 4” was given 50% and “Below 2” mg/l was elicited as impossible (0% “Acceptable”).

- Parameterization of Flooded vegetation was based on the JICA land use GIS map produced in 1999 and edited by the MRCS/WUP-FIN project. When this modelling study started this map was the latest and had the best accuracy available. The original 40 land use classes were reduced to three: Grass (JICA classes 3-17), Shrub (JICA classes 18-21), and Forest (JICA classes 22-32). Other classes such as water or soil and rock left out. The corresponding map is given in Figure 16.

Figure 16: Map of the Tonle Sap vegetation cover (1999, JICA data reclassified; Jantunen 2006).

Percentages for each of the three classes were calculated from surface area to elevation table, and were manually imported into the model probability table (see below).
Table 8: Parameterization of Flooded vegetation variable.

<table>
<thead>
<tr>
<th>Land use by elevation</th>
<th>Grass</th>
<th>Shrub</th>
<th>Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>43.9</td>
<td>53.7</td>
<td>2.4</td>
</tr>
<tr>
<td>1-10</td>
<td>55.8</td>
<td>42.3</td>
<td>1.9</td>
</tr>
<tr>
<td>1-road</td>
<td>60.8</td>
<td>37.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

- Habitat for residents, Habitat for TS migrants and Habitat for Mekong migrants were elicited by fishery experts by default. In fact the lack of information about the detailed ecological requirements of each the 3 different guilds did not allow making a difference in the response of each guild to environmental conditions; therefore the parameters are the same for all guild. “Impossible” (i.e. unbearable) dissolved oxygen level is 100% bad for fish and acts as a threshold, that defines a given habitat as bad whatever the other environmental conditions. Forest is traditionally seen as the best habitat for fish (100%), but because fish catch has not decreased dramatically even though the forests has been largely cut down shrub is also regarded as a good habitat (90%). Grass does not provide shelter and food in the way that shrub and forest do, therefore it is only 50% “Good”. The resulting table is detailed below:

Table 9: Parameterization of Habitat for fish nodes.

<table>
<thead>
<tr>
<th>Flooded vegetation</th>
<th>Dissolved oxygen</th>
<th>Good</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>Acceptable</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Grass</td>
<td>Impossible</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Shrub</td>
<td>Acceptable</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>Shrub</td>
<td>Impossible</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Forest</td>
<td>Acceptable</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Forest</td>
<td>impossible</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

- Floodplain refuges were parameterized using JICA (1999) data on area of Perennial and Temporal ponds in the floodplain. The total surface area of ponds identified by JICA amounts to 323.7 km², and perennial ponds represents 237 km², or 73.23% of the total (see Jantunen 2006 for details). Hence among floodplain refuges, Perennial refuges = 73.23% and Temporary refuges = 26.77%

- Parametrization of Built structures is based on JICA (1999) road data and Certeza Survey (1964) 1m contour data and the JICA 1999 GIS road layer and 10m contour line data. Probabilities were derived by comparing the total area of the each elevation category (0-8m, 0-10m and 0-12m) to the area limited by the road. Details can be found in Jantunen (2006).

Table 10: Parameterization of the Built Structures node.

<table>
<thead>
<tr>
<th>Built structures</th>
<th>TS water level</th>
<th>Blocking</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 10 m</td>
<td>8.25</td>
<td>91.75</td>
<td></td>
</tr>
<tr>
<td>From 8 to 10</td>
<td>2.51</td>
<td>97.49</td>
<td></td>
</tr>
<tr>
<td>Below 8 m</td>
<td>0</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
7.4 Fish migration variables

Overall, information on fish migrations, on the impact of built structures or of fishing practices on fish migrations is very deficient. The parameters below are therefore largely “guesstimates” awaiting for new quantitative studies of fish migrations in the system studied. Overall this module on fish migration is very simplistic and can be largely be improved; at the moment it mainly highlights in a qualitative way the importance of migrations in the sustainability of the overall fishery production system.

- The [Migration of Mekong migrants](#) is assumed to be hampered by two main obvious factors: by the fences of the large scale fishing sector and by built structures. In absence of detailed quantitative information, the fishing lots are assumed to contribute 80% of the obstacle to migrations, while built structures contribute 20%. This limited number of factors probably overlooks the role of the two other fishing sectors (middle scale and small scale) whose gears also act against migrations, but the role of these two sectors has been deemed too fuzzy to be quantified.

Table 11: Parameterization of Migration of Mekong migrants node.

<table>
<thead>
<tr>
<th>Built Structures</th>
<th>Pressure from large scale fisheries</th>
<th>Free</th>
<th>Blocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocking</td>
<td>Nil</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Blocking</td>
<td>Blockage</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Open</td>
<td>Nil</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Open</td>
<td>Blockage</td>
<td>20</td>
<td>80</td>
</tr>
</tbody>
</table>

- According to fishery experts consulted, the [Migration of residents](#) is hampered by fishing lots but also by the fishing pressure exerted on refuges during the dry season; therefore the 80% previously allocated to fishing lots only (in the case of white fish) were split between fishing lots proper (40%) and refuges (40%), the share of built structures remaining the same (20%).

Table 12: Parameterization of Migration of residents node.

<table>
<thead>
<tr>
<th>Built Structures</th>
<th>Refuges</th>
<th>Pressure from large scale fisheries</th>
<th>Free</th>
<th>Blocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocking</td>
<td>Perennial</td>
<td>Nil</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Blocking</td>
<td>Perennial</td>
<td>Blockage</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Blocking</td>
<td>Temporary</td>
<td>Nil</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Blocking</td>
<td>Temporary</td>
<td>Blockage</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Open</td>
<td>Perennial</td>
<td>Nil</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Open</td>
<td>Perennial</td>
<td>Blockage</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Open</td>
<td>Temporary</td>
<td>Nil</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Open</td>
<td>Temporary</td>
<td>Blockage</td>
<td>20</td>
<td>80</td>
</tr>
</tbody>
</table>

- The migration of Tonle Sap migrants is poorly known. Since these fish have ecological requirements intermediate between white and black fish, it was assumed that the constraint they face is somehow intermediate between those experienced by black and white fish. Hence three parent variables (Pressure
from large scale fisheries, refuges and built structures) and a similar weight given to each parent node (33%). The resulting table of probabilities is detailed below:

Table 12: Parameterization of Migration of Tonle Sap migrants node.

<table>
<thead>
<tr>
<th>Built Structures</th>
<th>Refuges</th>
<th>Pressure from large scale fisheries</th>
<th>Migration of Mekong migrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocking</td>
<td>Perennial</td>
<td>Nil</td>
<td>66.7</td>
</tr>
<tr>
<td>Blocking</td>
<td>Perennial</td>
<td>Blockage</td>
<td>33.3</td>
</tr>
<tr>
<td>Blocking</td>
<td>Temporary</td>
<td>Nil</td>
<td>33.3</td>
</tr>
<tr>
<td>Blocking</td>
<td>Temporary</td>
<td>Blockage</td>
<td>0</td>
</tr>
<tr>
<td>Open</td>
<td>Perennial</td>
<td>Nil</td>
<td>100</td>
</tr>
<tr>
<td>Open</td>
<td>Perennial</td>
<td>Blockage</td>
<td>66.7</td>
</tr>
<tr>
<td>Open</td>
<td>Temporary</td>
<td>Nil</td>
<td>66.7</td>
</tr>
<tr>
<td>Open</td>
<td>Temporary</td>
<td>Blockage</td>
<td>33.3</td>
</tr>
</tbody>
</table>

7.5 Fishery variables

The fishing component of the model is based on background studies by Nettleton and Baran (2004) and additional field surveys by Kum (2004), supplemented by unpublished stakeholders consultations. The fishing pressure actually results from a combination of four components:

Fishing pressure = fishing intensity = number of fishers + time spent fishing + size of fishing gears + gear efficiency.

In practice, the only factor that could be approached by a degree of monitoring is the number of fishers, hence the focus on this variable in the model. This fact illustrates the fact that significant additional research remains necessary to properly understand the various components of the fisheries and its main driving forces. As a consequence, the fisheries module of the BayFish model, based “only” on the very limited quantitative knowledge available, remains the least strong component of this model.

7.5.1 Small-scale fishery

The fishing Pressure from small-scale fishery results from four driving variables: Activity of subsistence fishers; Gear size of subsistence fishers; Number of Khmer subsistence fishers and Number of Vietnamese/Cham subsistence fishers; the parametrization of these variables is detailed below.

- The Activity of subsistence fishers is directly linked to water level in the Tonle Sap Lake. If there is more water, then there is more fish and thus subsistence fishers' shift to more fishing as fish is more valuable than crops per kilogram. In absence of quantified information the proportions were estimated as follows:
Table 13: Parameterization of the Activity of subsistence fishers variable.

<table>
<thead>
<tr>
<th>Water level</th>
<th>More fishing</th>
<th>More farming</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above_10m</td>
<td>80</td>
<td>20</td>
<td>When water level is above 10m, there is a 80% chances that fishers-farmers switch towards more fishing.</td>
</tr>
<tr>
<td>From_8_to_10m</td>
<td>50</td>
<td>50</td>
<td>When water level is between 8 and 10m, there is a 50-50% chances that fishers-farmers go fishing or farming.</td>
</tr>
<tr>
<td>Below_8m</td>
<td>70</td>
<td>30</td>
<td>When water level is below 8m, there is a 70% chances that fishers-farmers switch towards more farming (but fishing still important, as fish catchability is higher).</td>
</tr>
</tbody>
</table>

- According to the World Bank, Cambodia's population growth rate of over 2.5 percent per annum provides almost 200,000 new entrants to the labour force each year, a fraction of these entrants becoming small-scale fishers. This trend is increased by the Fisheries Reform that gives more access to small scale fishers over fishing lots. Despite emigration towards cities mentioned above, we consider that at least in the coming years the Number of Khmer subsistence fishers has 100% chances of "Increasing".

- The Number of Vietnamese/Cham subsistence fishers looks moderately increasing, except in Kompong Chnang province where they migrate to become workers. According to anecdotal evidence, the growth of Vietnamese/Cham communities is less important than that of Khmer people; subsequently it was decided that this variable would qualify as 75% "Increasing" and 25% "Stable".

- According to Keskinen (2003), there are 94.8% of Khmer, 3% of Vietnamese and 2.2% of Cham in the Lake’s basin (see section 5.5.1). The combinations of these variables are detailed in Table 14.

Table 14: Parameterization of the Number of subsistence fishers variable.

<table>
<thead>
<tr>
<th>Number of Khmer subsistence fishers</th>
<th>Number of Vietnamese/Cham subsistence fishers</th>
<th># of subsistence fishers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>100</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>5.2</td>
</tr>
<tr>
<td>Stable</td>
<td>Increasing</td>
<td>94.8</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>5.2</td>
</tr>
</tbody>
</table>

- The Gear size of subsistence fishers is changing over time. During field interviews all villagers admitted that the length of their gillnets had increased two to four times in the past years, up to 200m to 400m per gill net (Kum, 2004). However, the gear size cannot increase forever: the longer the gillnets, the more time required to process the catch. Moreover, longer gillnets require more capital investment, which is not always possible for the subsistence fishers whose investment power is limited. Given this context the chances of fishing gear size increasing were estimated to 25% and those of staying stable to 75%.

- The overall fishing Pressure from small-scale fishery is determined by 3 variables, whose combination is detailed in Table 15 (after Kum, 2004):
### Table 15: Parameterization of Pressure from small-scale fishery variable.

<table>
<thead>
<tr>
<th>Subsistence fisher activities</th>
<th>Size of gear</th>
<th>Number of subsistence fishers</th>
<th>Pressure from small-scale fishery</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>More fishing</td>
<td>Increasing</td>
<td>Increasing</td>
<td>100</td>
<td>If the number of subsistence fishers increases, their activity involves more fishing and the size of gear increases, there is a 100% chance that this will result in an increase of the small scale fishing pressure.</td>
</tr>
<tr>
<td>More fishing</td>
<td>Increasing</td>
<td>Stable</td>
<td>50</td>
<td>If the number of subsistence fishers is stable, but their activity involves more fishing and the size of gear is stable, there is a 50% chance only that this will result in an increased fishing pressure.</td>
</tr>
<tr>
<td>More fishing</td>
<td>Stable</td>
<td>Increasing</td>
<td>80</td>
<td>If the number of subsistence fishers is stable, their activity involves more fishing, but the size of gear is stable, there is a 80% chance that this will result in an increased fishing pressure.</td>
</tr>
<tr>
<td>More fishing</td>
<td>Stable</td>
<td>Stable</td>
<td>30</td>
<td>If the number of subsistence fishers is stable, their activity involves more fishing, and the size of gear is stable, there is a 30% chance only that this will result in an increased fishing pressure.</td>
</tr>
<tr>
<td>More farming</td>
<td>Increasing</td>
<td>Increasing</td>
<td>70</td>
<td>If the number of subsistence fishers increases, the size of their gears increases but their activity involves more farming, there is a 70% chance that this will result in an increased fishing pressure.</td>
</tr>
<tr>
<td>More farming</td>
<td>Increasing</td>
<td>Stable</td>
<td>20</td>
<td>If the number of subsistence fishers is stable, the size of their gears increases but their activity involves more farming, there is a 50% chance only that this will result in an increased fishing pressure.</td>
</tr>
<tr>
<td>More farming</td>
<td>Stable</td>
<td>Increasing</td>
<td>50</td>
<td>If the number of subsistence fishers increases and their activity involves more farming, but the size of gears is stable, there is a 50% chance that this will result in an increased fishing pressure.</td>
</tr>
<tr>
<td>More farming</td>
<td>Stable</td>
<td>Stable</td>
<td>0</td>
<td>If the number of subsistence fishers is stable, their activity involves more farming and the size of their gears is stable, there is a 100% chance that this will result in a stable small scale fishing pressure.</td>
</tr>
</tbody>
</table>

7.5.2 Middle-scale fisheries

- **Number of Khmer middle-scale fishers**
  Nettleton *et al.* (2004) reported that for Khmer fishers who can own land, fishing is becoming less and less profitable, in particular considering the significant capital investment needed in this fishery. In the other hand the recent abolishment of the licence fees on middle-scale fisheries created an incentive to invest in this sector. In absence of additional information, we define the **Number of Khmer commercial fishers** as 50% “Increasing” and 50% “Stable”.

- **Number of Viet./Cham middle-scale fishers**
  The Vietnamese families around the Lake do not usually own any land and depend on fishing for their livelihood, and the fishing seems more attractive to them because of their well-known expertise in the job (e.g. only 15 out of the total 1,072 Vietnamese families in Psar Chnnang commune are running sale business). Therefore, although the growth trend of the Vietnamese population is not clearly known (Kum, 2004), it is expected that the chance that the number of Vietnamese fishers in the floodplain increases is more likely at least by the natural growth. Based on this, we define the **Number of Viet./Cham middle-scale fishers** as 75% “Increasing” and 25% “Stable”.

- **Number of migrant middle-scale fishers**
  There is no recorded data about the migrant families who come seasonally to fish in some areas in the Tonle Sap Great Lake. Interviews of local fishers (Kum 2004) led to the conclusions that despite a significant social problem with migrant fishers who tend to over-harvest fish, there is no significant increase in the number of families of migrant fishers. Because of the lack of data, we define the state of **Number of migrant middle-scale fishers** as 50% “Increasing” and 50% “Stable”.
• Total Number of middle-scale fishers

After discussion and vote among the stakeholders, the share of each community in the fishing pressure has been amounted to 40% to Vietnamese and Cham fishers, 40% to Khmer fishers and 20% to migrant fishers respectively (Kum, 2004).

Figure 17: Share of each ethnic group in middle scale fisheries

Table 16: Parameterization of the variable Number of middle-scale fishers.

<table>
<thead>
<tr>
<th>Number of migrant fishers</th>
<th>Number of Vietnamese/Cham fishers</th>
<th>Number of Khmer fishers</th>
<th>Pressure from middle-scale fishers</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>Increasing</td>
<td>100 0</td>
<td>If the number of migrant, Vietnamese/Cham and Khmer middle-scale fishers increases, the chance that the fishing pressure from middle scale fishers increases is 100%.</td>
</tr>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>Stable</td>
<td>60 40</td>
<td>If the number of migrant and Vietnamese/Cham fishers increases but the number of Khmer fishers is stable, the chance that the pressure from middle scale fishers increases is 60%</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>Increasing</td>
<td>60 40</td>
<td>If the number of migrant and Khmer fishers increases but the number of Vietnamese/Cham fishers is stable, the chance that the pressure from middle scale fishers increases is 60%.</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>Stable</td>
<td>20 80</td>
<td>If the number of migrant fishers increases but the number of Vietnamese/Cham and Khmer fishers is stable, the chance that the pressure from middle scale fishers increases is 20%.</td>
</tr>
<tr>
<td>Stable</td>
<td>Increasing</td>
<td>Increasing</td>
<td>80 20</td>
<td>If the number of migrant fishers is stable but the number of Vietnamese/Cham and Khmer fishers increases, the chance that the pressure from middle scale fishers increases is 80%</td>
</tr>
<tr>
<td>Stable</td>
<td>Increasing</td>
<td>Stable</td>
<td>40 60</td>
<td>If the number of migrant and Khmer fishers is stable but the number of Vietnamese/Cham fishers increases, the chance that the pressure from middle scale fishers increases is 40%</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>Increasing</td>
<td>40 60</td>
<td>If the number of Khmer fishers increases while the number of Vietnamese/Cham and migrant fishers remains stable, the chance that the pressure from middle scale fishers increases is 40%</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>Stable</td>
<td>0 100</td>
<td>If the number of migrant, Vietnamese/Cham as well as Khmer fishers remain stable, the chance that the fishing pressure from middle scale fishers increases is nil.</td>
</tr>
</tbody>
</table>

• Middle-scale gear efficiency

In the past few years new ways of operating middle-scale fishing gears have spread, such as electrification of drag-nets, and overall the mesh size has been reduced. In the other hand the cost of operation (engine, petrol) has also increased, which slows down the tendency to increase the overall size and reduce the mesh size of the gears actively dragged. Based on this anecdotal evidence and in absence of additional information, we define the state of Middle-scale gear efficiency as 75% “Increasing” and 25% “Stable”.

• Pressure from middle-scale fishery

was roughly estimated to be 30% determined by the efficiency of middle-scale gears, and 70% by the number of fishers. The subsequent table of probabilities is:
Table 17: Parameterization of Pressure from middle-scale fishery variable.

<table>
<thead>
<tr>
<th>Number of middle-scale fishers</th>
<th>Fishing efficiency</th>
<th>Pressure from middle-scale fishery</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>100</td>
<td>If the number of fishers and the gear efficiency both increase, the chance that the fishing pressure from middle scale fishery increases is 100%.</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>70</td>
<td>If only the number of fishers increases, the chance that the pressure from middle scale fishery increases is 70%.</td>
</tr>
<tr>
<td>Stable</td>
<td>Increasing</td>
<td>30</td>
<td>If only the gear efficiency increases, the chance that the pressure from middle scale fishery increases is 30%.</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>0</td>
<td>If both the number of commercial fishers and the gear efficiency remain stable, there is a 100% chance that the pressure from the middle-scale fishery remains stable.</td>
</tr>
</tbody>
</table>

7.5.3 Large-scale fisheries

- **Pressure from large-scale fishery**
  
  Basically, the fishing pressure from large scale fishery results from the number of lots and from the extent of fishing fences associated to lots. In order to reflect the actual fishing conditions, we encompassed as part of lots the fishing pressure from community fisheries in former lots decommissioned in 2000. The extent of fences was calculated from a digitization of GIS maps, and operating fishing lots currently total 409 km of fences (see Jantunen 2006 for details). The extent of fishing lots decommissioned amounts to 596 km, and it was considered that in these former lots the fencing is less systematic, and only blocks 50% of the waterways\(^2\), hence an assumed length of fences of 298 km in decommissioned fishing lots. The total length of fences thus amounts to 409+298 = 707 km, which represents 59% of the periphery of the lake. Hence the elicitation of the **Pressure from large scale fishery** node: 59% blockage, 41% nil.

\(^2\) The team attempted to calculate the actual ratio [length of fences / area considered] in the Prek Toal study site (current fishing lot n°2 and former lot n°3 not under community fishery regime). However this calculation was impossible because:
- the resolution of orthophotomaps does not allow formally identifying lines as fences without extensive field verification;
- a lot of gears and fences are located among the vegetation and under trees, and are not visible from the sky;
- extensive nets are set underwater over hundreds of meters, but cannot be seen by remote sensing.
7.5.4 Fishing pressure on each fish guild

The fishing pressure on the TS fish harvest results from small-scale fishery, medium scale fishery and large-scale fishery as officially defined (Gum, 2000). An assessment of the pressure of each type of fishery on each guild of fish requires 1) a quantification of the share of each fishery to the total catch, and 2) an assessment of the proportion of each guild of fish in each type of fishery.

**Share of each fishery to the total catch**

According to Van Zalinge et al. (2000):

- Large scale fishing ranks between 39,000 and 91,000 tons (average 65,000 tons);
- Middle scale fishing operation ranks between 85,000 and 100,000 tons (average 92,500 tons);
- Small scale fishing operation rank between 165,000 and 240,000 tons (average 202,500 tons).

The above data reflects the situation before the 56% reduction in surface of the lots in 2000. To better reflect the present situation, we assume that the reduction in the fishing lots surface results in a 56% decrease in total catch of the large scale fishing operation (although it is said that the decommissioned lots were much less productive than the remaining ones). We also assume that the catch lost by fishing lots, i.e. around 36,400 tonnes, is shared between the two other fisheries according to their respective importance (31% for the middle scale fishery, and 69% for the large scale fisheries). Based on this, the average catch from the Lake fisheries is:

- Large scale fishing operation: 65,000 - 56% = 28,600 tonnes = 7.9%
- Middle scale operation is 92,500 + 11,300 = 103,800 tonnes = 28.8%
- Small scale operation is 202,500 + 25,100 = 227,600 tonnes = 63.2%
- Average total catch: 360,000 tons.

![Figure 18: Estimated proportion of the total catch by type of fishery.](image)

**Share of each guild to each fishery**

Table 18, based on bibliographic references applying to the whole of Cambodia, shows the proportion of resident black and migrant white fish in the catch of small scale, middle scale and large scale fisheries.

<table>
<thead>
<tr>
<th></th>
<th>Black fish (%)</th>
<th>White fish (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale fishing*</td>
<td>25.5</td>
<td>74.5</td>
</tr>
<tr>
<td>Middle scale fishing*</td>
<td>17</td>
<td>83</td>
</tr>
<tr>
<td>Large scale fishing**</td>
<td>39</td>
<td>61</td>
</tr>
</tbody>
</table>

* Source: Ahmed et al. (1998)
**Source: Baran et al. (2003)

This gives the estimated proportion of resident black fish and migrant white fish in the total catch of the Tonle Sap system:

**Table 19: Proportion of resident and migrant fish in the catch of Tonle Sap fisheries.**

<table>
<thead>
<tr>
<th></th>
<th>Black fish (%)</th>
<th>White fish (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale fishing</td>
<td>25.5*63 =16%</td>
<td>74.5*63 =47%</td>
</tr>
<tr>
<td>Middle scale fishing</td>
<td>17*29 =5%</td>
<td>83*29 =24%</td>
</tr>
<tr>
<td>Large scale fishing</td>
<td>39*8 =3%</td>
<td>61*8 =5%</td>
</tr>
<tr>
<td>Total</td>
<td>24%</td>
<td>76%</td>
</tr>
</tbody>
</table>
**Pressure of each fishery on each guild**

**Pressure on residents**
- small-scale fishing contributes 16/24 of the Catch of residents (cf. Table 19); i.e. 66.7%
- middle-scale fishing contributes 5/24 of the Catch of residents; i.e. 20.8%
- large-scale fishing contributes 16/24 of the Catch of residents; i.e. 12.5%
Thus when these fisheries are integrated, the probability table of their combinations is next:

<table>
<thead>
<tr>
<th>Fishing pressure on resident fish</th>
<th>Small scale fishing</th>
<th>Middle scale fishing</th>
<th>Large scale fishing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>Nil</td>
<td>100 0</td>
</tr>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>Blockage</td>
<td>87.5 12.5</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>Nil</td>
<td>79.2 20.8</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>Blockage</td>
<td>66.7 33.3</td>
</tr>
<tr>
<td>Stable</td>
<td>Increasing</td>
<td>Blockage</td>
<td>20.8 79.2</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>Nil</td>
<td>12.5 87.5</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>Blockage</td>
<td>0 100</td>
</tr>
</tbody>
</table>

**Pressure on Mekong migrants**
- small-scale fishing contributes 47/76 of the Catch of residents (cf. Table 21); i.e. 61.8%
- middle-scale fishing contributes 24/76 of the Catch of residents (cf. Table 21); i.e. 31.6%
- large-scale fishing contributes 5/76 of the Catch of residents (cf. Table 21); i.e. 6.6%
Thus when these fisheries are integrated, the probability table of their combinations is next:

<table>
<thead>
<tr>
<th>Fishing pressure on White fish</th>
<th>Small scale fishing</th>
<th>Middle scale fishing</th>
<th>Large scale fishing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>Nil</td>
<td>93.4 6.6</td>
</tr>
<tr>
<td>Increasing</td>
<td>Increasing</td>
<td>Blockage</td>
<td>100 0</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>Nil</td>
<td>61.8 38.2</td>
</tr>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>Blockage</td>
<td>68.4 31.6</td>
</tr>
<tr>
<td>Stable</td>
<td>Increasing</td>
<td>Nil</td>
<td>31.6 68.4</td>
</tr>
<tr>
<td>Stable</td>
<td>Increasing</td>
<td>Blockage</td>
<td>38.2 61.8</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>Nil</td>
<td>0 100</td>
</tr>
<tr>
<td>Stable</td>
<td>Stable</td>
<td>Blockage</td>
<td>6.6 93.4</td>
</tr>
</tbody>
</table>

**Pressure on Tonle Sap migrants**
The absence of catch statistics for grey fish forced us to assimilate again grey fish to white fish (see section 7.1), and to parametrize the table of Pressure on Tonle Sap migrants just like in Table 21.

The overall BayFish – Tonle Sap model is depicted in Figure 19.
8 RESULTS

Model testing was carried out in order to verify the models logical workability. Testing consisted in choosing 100% probability for a given state of each variable and analysing the changes in the probabilities of other variables, especially the most relevant ones. A number of scenarios, based on MRC/WorldBank scenarios (2004) and computed at MRCS/WUP_FIN were tested with the model, concentrating on hydrological changes. In addition to development scenarios a baseline scenario production figures for several years was compared with the Dai fisheries fish catch data in order to obtain estimates of the model accuracy.

8.1 Model testing and verification

The model testing concentrated more on hydrology and habitat sections of the model as these are largely supported by data, with all nodes checked and approved by extensive stakeholders consultations (less consultations contributed to the building and elicitation of the fisheries module). In addition, in the hydrological section of the model there are several nodes with state combinations that are incompatible in the natural system, and therefore careful testing, modification and validation was required to address this issue. These testing results were achieved with MRCS/TSLV_JICA data.

8.1.1 Bugs identification

One problem in the model workability was found during testing with Overland flow probabilities. In the natural system when Overland flow state “Above 7600” has 100% probability it should increase the Water level at Kompong Loung probabilities linearly from “Below 8m” to “Above 10m”. However, as can be seen in Table 21 the probabilities actually decrease from “Below 8m” to “From 8 to 10m” before increasing again.

<table>
<thead>
<tr>
<th>Water level at Kompong Loung</th>
<th>TS Runoff Above 30000 Below 30000</th>
<th>Flow from Mekong Above 37000 Below 37000</th>
<th>Overland flow Above 76000 Below 76000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>53.7</td>
<td>46.3</td>
<td>47.6</td>
</tr>
<tr>
<td>Below 8m</td>
<td>57.9</td>
<td>42.1</td>
<td>49.1</td>
</tr>
<tr>
<td>From 8 to 10m</td>
<td>57.9</td>
<td>42.1</td>
<td>53.6</td>
</tr>
</tbody>
</table>

The problem was located in Water level at Kompong Loung node, where one set of probabilities was just averaged between the three states due to lack of examples in the data. The problem was solved by giving weights to the averaged probabilities based on probabilities derived from the data.

The combinations of states causing the lower water levels were chosen for comparison. From Table 23 it can be seen from the probabilities (selected node state = “Above”) that the most effect on water level in the Lake is inflicted by TS Runoff (row 2) and Flow from Mekong (row 1) respectively. Therefore, Overland flow probabilities for high water levels (and vice verse for low water levels) should be below that of rows 1 and 2, but above the lowest possible probabilities (row 3). So Water level at Kompong Loung state “Above 10m” probability was set at 15% which is between otherwise lowest probabilities in rows 2
and 3 (Table 22). “From 8 to 10m” was set at 55% (lower than both rows 1 and 2, but higher than 3) and “Below 8m” at 30% (higher than rows 1 and 2, but lower than 3). By changing the probabilities in above manner based on existing weights between the probabilities derived from the data the workability problem was solved (Table 24).

Table 23: Changes made to Water level at Kompong Loung probability table. Row 4a (bolded) represents averaged probabilities and 4b (italics) weighted probabilities.

<table>
<thead>
<tr>
<th>Water level at K. Loung</th>
<th>Flow from Mekong</th>
<th>Overland flow</th>
<th>TS Runoff</th>
<th>Above 10m</th>
<th>From 8 to 10m</th>
<th>Below 8m</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Above 37000</td>
<td>Below 7600</td>
<td>Below 30000</td>
<td>Below</td>
<td>20</td>
<td>60</td>
<td>20</td>
<td>Flow from Mekong has second highest influence on water level</td>
</tr>
<tr>
<td><strong>2</strong> Below 37000</td>
<td>Below 7600</td>
<td>Above 30000</td>
<td>16.667</td>
<td>66.667</td>
<td>16.667</td>
<td></td>
<td>TS Runoff has highest influence on water level</td>
</tr>
<tr>
<td><strong>3</strong> Below 37000</td>
<td>Below 7600</td>
<td>Below 30000</td>
<td>12.5</td>
<td>37.5</td>
<td>50</td>
<td>All “below” average</td>
<td></td>
</tr>
<tr>
<td><strong>4a</strong> Below 37000</td>
<td>Above 7600</td>
<td>Below 30000</td>
<td>33.333</td>
<td>33.333</td>
<td>33.333</td>
<td>Original probabilities averaged between all states</td>
<td></td>
</tr>
<tr>
<td><strong>4b</strong> Below 37000</td>
<td>Above 7600</td>
<td>Below 30000</td>
<td>15</td>
<td>55</td>
<td>30</td>
<td>New weighted probabilities</td>
<td></td>
</tr>
</tbody>
</table>

Table 24: Final results for Water level at Kompong Loung node testing of problematic probabilities.

<table>
<thead>
<tr>
<th>Water level K. Loung</th>
<th>TS Runoff</th>
<th>Flow from Mekong</th>
<th>Overland flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Above 30000</td>
<td>Below 30000</td>
<td>Above 7600</td>
</tr>
<tr>
<td>Baseline</td>
<td>53.7</td>
<td>46.3</td>
<td>47.6</td>
</tr>
<tr>
<td>Below 8m</td>
<td>41.6</td>
<td>58.4</td>
<td>38.9</td>
</tr>
<tr>
<td>From 8 to 10m</td>
<td>55.3</td>
<td>44.7</td>
<td>46.9</td>
</tr>
<tr>
<td>Above 10m</td>
<td>62.3</td>
<td>37.7</td>
<td>57.6</td>
</tr>
</tbody>
</table>

8.1.2 Hydrology section analysis

Hydrological analysis of the model workability included testing sensitivity of hydrological variables to changes in selected nodes (Table 24). Sensitivity of Tonle Sap water flow input variables to water level changes in the Lake revealed that Overland flow has the highest impact on the “Above 10m” water level. This is because the variable is closely linked to inflow from the Mekong River as overland flow only takes place when water levels are high enough in the Mekong, especially characteristic of extreme floods such as years 2000 and 2001. The water level in the Lake is extremely low in years not experiencing any overland flow, such as 1998. Therefore “Below 6400” overland flow also causes “Above 10m” water level to decrease to 19.5% compared to the baseline value of 29.6% while increasing “From 8 to 10m” water level from 47.8% to 54%.

On the other hand overland flow has slightly less impact on probabilities of Water level at Kompong Loung state “Below 8m” compared to Tonle Sap Runoff and Mekong Inflow. In conclusion flood cycles with average or high overland flow are likely to have high water levels in the Tonle Sap Lake. Also, approximately 50% of all floods are between 8 and 10m, with roughly 30% extremely high (>10m) and 20% very low (<8m) as shown by the baseline values. Both extremes are considered bad for fish production.
Table 25: Results for testing Water level at Kompong Loung node.

<table>
<thead>
<tr>
<th>Water level at Kompong Loung</th>
<th>Above 10m</th>
<th>From 8 to 10m</th>
<th>Below 8m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>29.6</td>
<td>47.8</td>
<td>22.6</td>
</tr>
<tr>
<td>Mekong Inflow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above 34400</td>
<td>34.0</td>
<td>46.8</td>
<td>19.2</td>
</tr>
<tr>
<td>Below 34400</td>
<td>22.9</td>
<td>49.4</td>
<td>27.6</td>
</tr>
<tr>
<td>Overland flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above 6400</td>
<td>36.3</td>
<td>43.7</td>
<td>20.0</td>
</tr>
<tr>
<td>Below 6400</td>
<td>19.5</td>
<td>54.0</td>
<td>26.5</td>
</tr>
<tr>
<td>Tonle Sap runoff</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above 30000</td>
<td>33.7</td>
<td>47.7</td>
<td>18.6</td>
</tr>
<tr>
<td>Below 30000</td>
<td>24.8</td>
<td>48.0</td>
<td>27.2</td>
</tr>
</tbody>
</table>

Analysis of flood beginning, duration and flood level revealed that high, long and early floods provide the best flooding conditions for fish stocks whereas low, short, and late floods are detrimental to them (see Table 26). This has also been shown in literature, e.g. van Zalinge et al. (2000). It seems that late flood has more negative gross effect than early flood has positive. Similarly short flood is more detrimental than a long flood is beneficial. Perhaps this is a sign that the natural system is more effective and productive with earlier and longer floods; manmade changes to this pattern might severely affects its balance. Therefore serious consideration should be given to dam building upstream which could cause the floods to become shorter and to arrive later. The single most influential variable for flooding conditions in terms of fisheries is Flood level, followed by Flood beginning and Flood duration. However, flood beginning has an effect on flood level and duration, whereas flood level only affects flood duration (section 4.2). Mekong migrant fish seem to be most susceptible to hydrological changes, whereas residents are less susceptible. All probabilities reflect the natural system and its fluctuations as they are understood by experts at the moment.

Table 26: Tests on the effect of hydrological variables on flooding conditions in the floodplain.

<table>
<thead>
<tr>
<th>Node State</th>
<th>Flood for fishes</th>
<th>STOCK TS resident</th>
<th>STOCK TS migrants</th>
<th>STOCK Mek migrants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
<td>Bad</td>
<td>Abundant</td>
<td>Scarce</td>
</tr>
<tr>
<td>Baseline</td>
<td>60.6</td>
<td>39.4</td>
<td>48.5</td>
<td>51.5</td>
</tr>
<tr>
<td>Flood beginning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before mid July</td>
<td>81.7</td>
<td>18.3</td>
<td>56.5</td>
<td>43.5</td>
</tr>
<tr>
<td>Mid July to mid Aug</td>
<td>61.4</td>
<td>38.6</td>
<td>48.8</td>
<td>51.2</td>
</tr>
<tr>
<td>After mid Aug</td>
<td>16.7</td>
<td>83.3</td>
<td>31.7</td>
<td>68.3</td>
</tr>
<tr>
<td>Flood duration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than 11 weeks</td>
<td>76.2</td>
<td>23.8</td>
<td>54.4</td>
<td>45.6</td>
</tr>
<tr>
<td>Around 8 weeks</td>
<td>60.1</td>
<td>39.9</td>
<td>48.3</td>
<td>51.7</td>
</tr>
<tr>
<td>Less than 6 weeks</td>
<td>12</td>
<td>88</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>Flood level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>93.5</td>
<td>6.5</td>
<td>61</td>
<td>39</td>
</tr>
<tr>
<td>Low</td>
<td>25.9</td>
<td>74.1</td>
<td>35.3</td>
<td>64.7</td>
</tr>
</tbody>
</table>

8.1.3 Habitat section analysis

Habitat analysis concentrated on flooded vegetation, floodplain dissolved oxygen levels and water level changes (Table 26). Flooded vegetation “Forest” state is by far the best vegetation type for both dissolved oxygen and habitats. “Grass” is better than “Shrub” for dissolved oxygen, but worse as overall habitat, because “Shrub” provides more food and shelter for fish than “Grass”. Water level directly affects the surface area of vegetation flooded as well as dissolved oxygen levels. With a high flood (>10m) dissolved oxygen levels are lower than normal (8-10m) because more floodplain periphery with more or
less anoxic condition water are included in the calculation. Also, resident fish depend more on water level than migrant fish due to accessibility of their dry season refuges to open water.

Table 27: Tests on habitat variables

<table>
<thead>
<tr>
<th></th>
<th>O2 for Mekong migrants</th>
<th>O2 for residents</th>
<th>Habitat for Mekong migrants</th>
<th>Habitat for residents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acceptable</td>
<td>Impossible</td>
<td>Acceptable</td>
<td>Impossible</td>
</tr>
<tr>
<td>Baseline</td>
<td>16.1</td>
<td>83.9</td>
<td>39.5</td>
<td>60.5</td>
</tr>
<tr>
<td>Flooded vegetation</td>
<td>Grass</td>
<td>19.3</td>
<td>80.7</td>
<td>44.7</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
<td>11.5</td>
<td>88.5</td>
<td>31.5</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>28.3</td>
<td>71.7</td>
<td>68.3</td>
</tr>
<tr>
<td>Floodplain oxygen</td>
<td>Above 4mg/l</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>From 2 to 4mg/l</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Below 2mg/l</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Water level</td>
<td>Above 10m</td>
<td>12</td>
<td>88</td>
<td>37.1</td>
</tr>
<tr>
<td></td>
<td>From 8 to 10m</td>
<td>18.7</td>
<td>81.3</td>
<td>43.5</td>
</tr>
<tr>
<td></td>
<td>Below 8m</td>
<td>18.2</td>
<td>81.8</td>
<td>36.7</td>
</tr>
</tbody>
</table>

8.1.4 Fishery section analysis

Both subsistence fisher activity and small scale gear size have more impact on fishing pressures than nodes affecting middle scale fisheries because small scale fishing contributes most to the annual fish catch. From the number of middle scale fisherman the Khmer fishers have the most impact, while Vietnamese and migrant fishers have equal importance.

Table 28: Results for testing fisheries variables.

<table>
<thead>
<tr>
<th>Pressure from small scale fishery</th>
<th>Pressure from middle scale fishery</th>
<th>PRESSURE on residents</th>
<th>PRESSURE on Mekong migrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Stable</td>
<td>Increasing</td>
<td>Stable</td>
</tr>
<tr>
<td>Baseline</td>
<td>73.4</td>
<td>26.6</td>
<td>64.5</td>
</tr>
<tr>
<td>Small scale fishery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity of SS fishers</td>
<td>More fishing</td>
<td>84.3</td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td>More farming</td>
<td>54.4</td>
<td>45.6</td>
</tr>
<tr>
<td>Gear size of SS fishers</td>
<td>Increasing Stable</td>
<td>88.4</td>
<td>11.6</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>68.4</td>
<td>31.6</td>
</tr>
<tr>
<td>No. of Khmer SS fishers</td>
<td>Increasing Stable</td>
<td>73.4</td>
<td>26.6</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No. of Viet./Cham SS fishers</td>
<td>Increasing Stable</td>
<td>74</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>71.4</td>
<td>28.6</td>
</tr>
<tr>
<td>Middle scale fishery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Khmer MS fishers</td>
<td>Increasing Stable</td>
<td>78.5</td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>50.5</td>
<td>49.5</td>
</tr>
<tr>
<td>No. of migrant MS fishers</td>
<td>Increasing Stable</td>
<td>71.5</td>
<td>28.5</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>57.5</td>
<td>42.5</td>
</tr>
<tr>
<td>No. of Viet./Cham MS fishers</td>
<td>Increasing Stable</td>
<td>71.5</td>
<td>28.5</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>43.5</td>
<td>56.5</td>
</tr>
<tr>
<td>MS gear efficiency</td>
<td>Increasing Stable</td>
<td>72</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>42</td>
<td>58</td>
</tr>
</tbody>
</table>
In terms of actual fish production, migrant fish contribute more than resident fish (see section 7.5). However it was decided not to analyze in detail the catch of each guild nor the total Tonle Sap catch. This is justified by two main reasons:

1) **there are excessive knowledge gaps regarding grey fish and the nature and functioning of the overall fishery sector** (absence of disaggregated catch statistics for Tonle Sap migrants, lack of quantitative factors describing precisely each type of fishery, and overly simplistic descriptors of the each type of fishery);

2) the nature of the fishery module of the model is different from that of the other modules: while the Hydrology, Habitat and Migration variables are based on the current or past situation as documented by data and expert experience, the fishery module uses variables that refer to the future (e.g. number of fishers increasing). This fact is due to the quasi-total absence of information and data about the fishery sector and its history (how many fishermen, what fishing effort, etc). This situation introduces a twist in the model and an excessive reliance, for that module, on assumptions and guesses; it also highlights the urgent need for researchers and managers to start documenting and monitoring the fishery sector for its role in the sustainability of the fish production can be better appraised.

For these reasons, we focused on the relationship between environmental factors (hydrology, habitat, migrations) and the fish stocks. Fish stock variables were also used for scenario analysis and for comparison with Dai fishery fish catch data. The model shows that the main influence on resident fish stocks is due to **Flood for fishes** and **Habitat for residents**, whereas Mekong migrants are mainly influenced by **Migrations of Mekong migrants**. For **Tonle Sap migrants** no single driving variable is more influential than another.

### 8.2 Model validation

This model validation is based on the Baseline scenario fish production. The baseline scenario based on probabilities elicited by the stakeholders was compared with the Dai fisheries annual fish catch data. This dataset is regarded as the best fish catch data available in Cambodia, and reflects the Tonle Sap Lake fish production quite well.

Years 1995 to 2003 were used for the comparison, even though WUP-FIN model has output data for years 1996-2000 only. During the testing it was assumed that same consistency shown in Tables 32-34 in WUP_FIN and WUP_JICA baselines would apply for 1995 and 2001-2003. Model input states for **Mekong flow**, **Overland flow** and **Flood beginning** were used for each year at a time to set up the model (Table 29). Years 1996-1997 and 2000-2001 have the same flooding states, and therefore flood for fish probabilities as well.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date of floodplain flooding</th>
<th>Flow from Mekong</th>
<th>Overland flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Mid July to mid Aug</td>
<td>Above 34300</td>
<td>Above 6400</td>
</tr>
<tr>
<td>1997</td>
<td>Mid July to mid Aug</td>
<td>Above 34300</td>
<td>Above 6400</td>
</tr>
<tr>
<td>1998</td>
<td>After Mid Aug</td>
<td>Below 34300</td>
<td>Below 6400</td>
</tr>
<tr>
<td>1999</td>
<td>Before mid Jul</td>
<td>Below 34300</td>
<td>Below 6400</td>
</tr>
<tr>
<td>2000</td>
<td>Before mid Jul</td>
<td>Above 34300</td>
<td>Above 6400</td>
</tr>
</tbody>
</table>
Comparison of actual data vs. predicted outputs

We ran BayFish for each year between 1995 and 2004, and calculated for each year the probability of a high fish stock, knowing all actual environmental parameters for these years. The model outputs were then compared to the data of the Dai fishery, that is the only fishery for which catches have been scientifically monitored over a long period of time. The modelled curves of Mekong migrant and Tonle Sap resident fish stocks fits well with published catch data for the Dai fishery (Figure 20).

These results have been produced by the BayFish model on the sole basis of variables and parameters proposed *a priori* by stakeholders and extracted from databases; no adjustment nor recalibration has been done at this stage.

Table 30: Results for Baseline scenario analysis for fish harvest and fish stocks.

<table>
<thead>
<tr>
<th>Node State</th>
<th>Flood for fishes</th>
<th>STOCK of resident</th>
<th>STOCK of TS fishers</th>
<th>STOCK of Mekong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Good 60.6 39.4</td>
<td>Abundant 48.5 51.5</td>
<td>Abundant 49.8 50.2</td>
<td>Abundant 43.9 56.1</td>
</tr>
<tr>
<td>1995</td>
<td>-10.2 15.7</td>
<td>Bad -4.7 4.5</td>
<td>Bad -3.8 3.8</td>
<td>Bad -3.2 2.5</td>
</tr>
<tr>
<td>1996</td>
<td>62.9 37.1</td>
<td>Abundant 49.2 50.8</td>
<td>Abundant 50.4 49.6</td>
<td>Abundant 44.3 55.7</td>
</tr>
<tr>
<td>%</td>
<td>3.8 -5.8</td>
<td>Bad 1.4 -1.4</td>
<td>Bad 1.2 -1.2</td>
<td>Bad 0.9 -0.7</td>
</tr>
<tr>
<td>1997</td>
<td>62.9 37.1</td>
<td>Abundant 49.2 50.8</td>
<td>Abundant 50.4 49.6</td>
<td>Abundant 44.3 55.7</td>
</tr>
<tr>
<td>%</td>
<td>3.8 -5.8</td>
<td>Bad 1.4 -1.4</td>
<td>Bad 1.2 -1.2</td>
<td>Bad 0.9 -0.7</td>
</tr>
<tr>
<td>1998</td>
<td>20 80</td>
<td>Abundant 33 67</td>
<td>Abundant 36.5 63.5</td>
<td>Abundant 34.1 65.9</td>
</tr>
<tr>
<td>%</td>
<td>-67.0 103.0</td>
<td>Bad -32.0 30.1</td>
<td>Bad -26.7 26.5</td>
<td>Bad -22.3 17.5</td>
</tr>
<tr>
<td>1999</td>
<td>76.6 23.4</td>
<td>Abundant 55 45</td>
<td>Abundant 55.4 44.6</td>
<td>Abundant 48.1 51.9</td>
</tr>
<tr>
<td>%</td>
<td>26.4 -40.6</td>
<td>Bad 13.4 -12.6</td>
<td>Bad 11.2 -11.2</td>
<td>Bad 9.6 -7.5</td>
</tr>
<tr>
<td>2000</td>
<td>91 9</td>
<td>Abundant 59.9 40.1</td>
<td>Abundant 59.7 40.3</td>
<td>Abundant 51.2 48.8</td>
</tr>
<tr>
<td>%</td>
<td>50.2 -77.2</td>
<td>Bad 23.5 -22.1</td>
<td>Bad 19.9 -19.7</td>
<td>Bad 16.6 -13.0</td>
</tr>
<tr>
<td>2001</td>
<td>91 9</td>
<td>Abundant 59.9 40.1</td>
<td>Abundant 59.7 40.3</td>
<td>Abundant 51.2 48.8</td>
</tr>
<tr>
<td>%</td>
<td>50.2 -77.2</td>
<td>Bad 23.5 -22.1</td>
<td>Bad 19.9 -19.7</td>
<td>Bad 16.6 -13.0</td>
</tr>
<tr>
<td>2002</td>
<td>75.9 24.1</td>
<td>Abundant 54.1 45.9</td>
<td>Abundant 54.6 45.4</td>
<td>Abundant 47.5 52.5</td>
</tr>
<tr>
<td>%</td>
<td>25.2 -38.8</td>
<td>Bad 11.5 -10.9</td>
<td>Bad 9.6 -9.6</td>
<td>Bad 8.2 -6.4</td>
</tr>
<tr>
<td>2003</td>
<td>40.6 59.4</td>
<td>Abundant 40.9 59.1</td>
<td>Abundant 43.4 56.6</td>
<td>Abundant 39.3 60.7</td>
</tr>
<tr>
<td>%</td>
<td>-33.0 50.8</td>
<td>Bad 15.7 14.8</td>
<td>Bad 12.9 12.7</td>
<td>Bad -10.5 8.2</td>
</tr>
</tbody>
</table>
8.3 Scenario analysis

8.3.1 Development scenarios

Development scenarios for Lower Mekong Basin and Tonle Sap Lake have been designed by Mekong River Commission Basin Development Programme, WorldBank (2004) and Cambodian National Mekong Commission (2004). However, very little has been published in actual numeric data on the scenarios required as an input for this model. Therefore, WUP-FIN hydrological model was used to obtain the data for the scenario input states (nodes: Mekong Inflow, Overland flow and Flood beginning). Due to differences between the MRCS/TSLV_JICA and WUP_FIN models the output data is somewhat different. Two hydrological development scenarios were created for testing purposes, both based on MRC scenarios:

1) High development (HD) scenario. The High Development Scenario has been defined by the MRCS according to the table below (Koponen et al. 2007):

<table>
<thead>
<tr>
<th>Scenario Summary</th>
<th>Baseline</th>
<th>High Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Mekong Basin Dams</td>
<td>None</td>
<td>Xiowan and Nuozhadu</td>
</tr>
<tr>
<td>Diversions</td>
<td>None</td>
<td>• Inter-basin diversion from Chiang Rai tributary</td>
</tr>
<tr>
<td>Irrigated Areas</td>
<td>• Total irrigated area of 74,655 km² allocated among sub-areas on the basis of the data contained in the DSF</td>
<td>• Total irrigated area of 104,287 km² allocated among sub-areas on the basis of the projections used in the DSF</td>
</tr>
<tr>
<td>Hydropower</td>
<td>• 4 dams modelled: Nam Ngum, Theun Hinboun, Houay Ho, Yali</td>
<td>• 8 dams modelled: Nam Ngum, Theun Hinboun, Nam Theun 2, Nam Theun 3, Yali, Xe Kaman 1, Se Kong 5, Lower Se San &amp; Lower Sre Pok</td>
</tr>
</tbody>
</table>

2) Main stream dam (MSD) development scenario. The Mainstream Dams scenario includes mainstream dam development to the High Development Scenario. The net storage of the reservoirs is assumed to be 85 billion m³ (Mekong Committee, 1970) based on the most feasible hydropower and irrigation development plan.

Results from the scenario testing can be seen in tables 32-35. The results are also compared to the baseline of TSLV/WUP_JICA results that were used previously in the model to ensure data integrity. It is clear from the tables that the baselines from two different models fit well (bold figures representing years with Above average flows, or beginning of the flood). For the development scenarios average of WUP_FIN baseline was used. This produced clear differences especially with Mainstream dams development scenario. For Mekong inflow above average flow probabilities drop from 60% to 40% (HD) and 20% (MSD), similar trend being seen in Overland flow. MSD scenario for overland flow was not received from WUP_FIN, but by analysing the data it can be seen that the trend follows closely Mekong inflow trends, hence only year 2000 is going to be above average flow (giving 20% above average
probability). For overland flow baseline year 1997 flow of 6400 was counted as above average (average being 6408) in order to follow old baseline based on WUP_JICA model data.

**Table 32: Mekong inflow results from WUP_FIN model**

<table>
<thead>
<tr>
<th>Year</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>37523</td>
<td>35910</td>
<td>20624</td>
<td>29865</td>
<td>47895</td>
<td>34363</td>
</tr>
<tr>
<td>High Development</td>
<td>34775</td>
<td>33083</td>
<td>15704</td>
<td>26012</td>
<td>46568</td>
<td>31228</td>
</tr>
<tr>
<td>Mainstream Dam dev</td>
<td>25256</td>
<td>24206</td>
<td>8461</td>
<td>20301</td>
<td>38494</td>
<td>23344</td>
</tr>
<tr>
<td>Baseline from WUP_JICA</td>
<td>43910</td>
<td>40897</td>
<td>22110</td>
<td>35718</td>
<td>49772</td>
<td>38481</td>
</tr>
</tbody>
</table>

**Table 33: Overland flow results from WUP_FIN model**

<table>
<thead>
<tr>
<th>Year</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>8400</td>
<td>6400</td>
<td>240</td>
<td>4500</td>
<td>12500</td>
<td>6408</td>
</tr>
<tr>
<td>High Development</td>
<td>6500</td>
<td>4800</td>
<td>20</td>
<td>3100</td>
<td>10700</td>
<td>5024</td>
</tr>
<tr>
<td>Mainstream Dam dev</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline from WUP_JICA</td>
<td>9118</td>
<td>11621</td>
<td>1309</td>
<td>7036</td>
<td>16366</td>
<td>9090</td>
</tr>
</tbody>
</table>

Flood beginning remained the same for both of the baselines and HD scenario, but MSD scenario showed a change towards later floods. Also the analysis showed that another stakeholders consultation would be required to be able to determine flood beginning in a more precise way to increase the sensitivity of the model.

**Table 34: Flood beginning results from WUP_FIN model**

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>15.7</td>
<td>2.48</td>
<td>2.58</td>
<td>2.55</td>
<td>4.05</td>
<td>5.03</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>3.69</td>
<td>4.56</td>
<td>3.56</td>
<td>4.82</td>
<td>6.72</td>
</tr>
<tr>
<td></td>
<td>15.8</td>
<td>5.18</td>
<td>6.31</td>
<td>3.95</td>
<td>6.25</td>
<td>7.22</td>
</tr>
<tr>
<td>High Development</td>
<td>15.7</td>
<td>2.51</td>
<td>2.64</td>
<td>2.54</td>
<td>3.85</td>
<td>4.85</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>3.55</td>
<td>4.44</td>
<td>3.27</td>
<td>4.46</td>
<td>6.44</td>
</tr>
<tr>
<td></td>
<td>15.8</td>
<td>4.86</td>
<td>6.05</td>
<td>3.51</td>
<td>5.80</td>
<td>6.79</td>
</tr>
<tr>
<td>Mainstream Dam dev</td>
<td>15-Jul</td>
<td>2.48</td>
<td>2.57</td>
<td>2.43</td>
<td>4.05</td>
<td>4.74</td>
</tr>
<tr>
<td></td>
<td>01-Aug</td>
<td>3.43</td>
<td>4.00</td>
<td>2.94</td>
<td>4.67</td>
<td>6.07</td>
</tr>
<tr>
<td></td>
<td>15-Aug</td>
<td>4.48</td>
<td>5.16</td>
<td>3.23</td>
<td>5.65</td>
<td>6.42</td>
</tr>
<tr>
<td>WUP_JICA baseline</td>
<td>15.7</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>5.0</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>4.2</td>
<td>4.9</td>
<td>3.8</td>
<td>5.8</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>15.8</td>
<td>5.6</td>
<td>6.7</td>
<td>4.3</td>
<td>7.1</td>
<td>8.3</td>
</tr>
</tbody>
</table>

After analyzing results from WUP_FIN output data it was noted that flood duration did not change at all with HD scenario and very little even with MSD scenario, except for one year in the time series (1996). In addition, the data showed that with MSD scenario all but one year actually had an increase in flood duration, whereas one had 2 weeks shorter duration, hence no clear trend was seen. It also appears that development scenarios mainly cause flood beginning to change, but not flood duration. This is partly due to the definition of flood duration in the model in weeks, which blends in the minor changes in duration occurring often in days. The phenomenon is well illustrated by figure 10 below.
Table 35: Flood duration results from WUP_FIN model

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>WUP_FIN Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (d)</td>
<td>67</td>
<td>48</td>
<td>45</td>
<td>80</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>Weeks</td>
<td>9.6</td>
<td>6.9</td>
<td>6.4</td>
<td>11.4</td>
<td>9.6</td>
<td></td>
</tr>
<tr>
<td>Flow reversal</td>
<td>07-Oct</td>
<td>18-Sep</td>
<td>29-Sep</td>
<td>03-Oct</td>
<td>23-Sep</td>
<td></td>
</tr>
<tr>
<td>High Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (d)</td>
<td>68</td>
<td>48</td>
<td>45</td>
<td>81</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Weeks</td>
<td>9.7</td>
<td>6.9</td>
<td>6.4</td>
<td>11.6</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td>Flow reversal</td>
<td>08-Oct</td>
<td>18-Sep</td>
<td>29-Sep</td>
<td>04-Oct</td>
<td>24-Sep</td>
<td></td>
</tr>
<tr>
<td>Main stream Dams Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (d)</td>
<td>52</td>
<td>50</td>
<td>48</td>
<td>83</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>Weeks</td>
<td>7.4</td>
<td>7.1</td>
<td>6.9</td>
<td>11.9</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>Flow reversal</td>
<td>05-Oct</td>
<td>19-Sep</td>
<td>01-Oct</td>
<td>05-Oct</td>
<td>25-Sep</td>
<td></td>
</tr>
<tr>
<td>WUP_JICA baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length (d)</td>
<td>69</td>
<td>51</td>
<td>49</td>
<td>81</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>Weeks</td>
<td>9.9</td>
<td>7.3</td>
<td>7.0</td>
<td>11.6</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>Flow reversal</td>
<td>09-Oct</td>
<td>21-Sep</td>
<td>03-Oct</td>
<td>04-Oct</td>
<td>22-Sep</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10: Simulated Tonle Sap Lake water levels for the WUP_FIN baseline and Mainstream Dams scenario (Koponen et al. 2007).

8.3.2 Results of scenarios

When comparing WUP_FIN (baseline) and High Development scenario it can be seen that there is tendency for lower flood levels at the Lake, as well as some shortening of the floods. However, the difference in stock is minute. On the other hand, MSD scenario shows alarming rate of lowering of flood levels and increasing of shorter floods, also reflected in fish stocks. Resident fish stocks seem to be more sensitive to mainstream dam development with 8.6% reduction in stock probability units in model (4.3 units), while similar reduction is 6% for Mekong migrants. Tonle Sap migrants stock are reduced by 7.1% in the model. Scenario comparison can be seen in table below:
Table 36: Scenario comparison

<table>
<thead>
<tr>
<th></th>
<th>Flood for fishes</th>
<th>Tonle Sap water level</th>
<th>Flood duration</th>
<th>Abundant STOCK for fishes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
<td>Bad</td>
<td>Above 10</td>
<td>8-10</td>
</tr>
<tr>
<td>WUP_JICA</td>
<td>63.2</td>
<td>36.8</td>
<td>25.4</td>
<td>49.8</td>
</tr>
<tr>
<td>WUP_FIN</td>
<td>60.6</td>
<td>39.4</td>
<td>29.6</td>
<td>47.8</td>
</tr>
<tr>
<td>difference %</td>
<td>-2.6</td>
<td>4.2</td>
<td>-2</td>
<td>-2.2</td>
</tr>
<tr>
<td>difference %</td>
<td>-4.1</td>
<td>16.5</td>
<td>-4.0</td>
<td>-8.9</td>
</tr>
<tr>
<td>High dev</td>
<td>58.8</td>
<td>41.2</td>
<td>24.2</td>
<td>50.2</td>
</tr>
<tr>
<td>difference %</td>
<td>1.8</td>
<td>5.4</td>
<td>-2.4</td>
<td>-3</td>
</tr>
<tr>
<td>Dam dev</td>
<td>49.3</td>
<td>50.7</td>
<td>19.3</td>
<td>51.9</td>
</tr>
<tr>
<td>difference %</td>
<td>11.3</td>
<td>10.3</td>
<td>-4.1</td>
<td>-6.2</td>
</tr>
<tr>
<td>%</td>
<td>-18.6</td>
<td>-34.8</td>
<td>8.6</td>
<td>27.4</td>
</tr>
</tbody>
</table>

| Difference | 2.6 | 4.2 | -2 | -2.2 | 0.5 | -0.9 | 0.4 | 10.3 | - | -7.8 |
| Difference %| -4.1 | 16.5 | -4.0 | -8.9 | 1.9 | -1.3 | 5.5 | 27.0 | - | -15.1 |
| Difference | 1.8 | 5.4 | -2.4 | -3 | 0.5 | -0.4 | -0.1 | 0.6 | 0.5 | 0.4 |
| Difference %| -3.0 | -18.2 | 5.0 | 13.3 | -1.9 | 0.6 | 1.3 | -1.2 | -1.0 | -0.9 |
| Difference | 11.3 | 10.3 | -4.1 | -6.2 | 5.5 | 0.7 | -6.2 | 4.2 | 3.6 | 2.6 |
| %           | -18.6 | -34.8 | 8.6 | 27.4 | -21.0 | -1.1 | 80.5 | -8.7 | -7.2 | -5.9 |
9 CONCLUSIONS

The Bayesian approach is a good modelling option for situations where the structure of the system is not well known or data are nonexistent. Including years of expert knowledge, often untapped in scientific studies and model building, can substantially improve and develop a model to represent the modelled system more accurately and reliably. Moreover, a Bayesian model can be used as a teaching and training tool for decision makers, civil servants and other stakeholders to improve their understanding of the linkages and trade-offs of a given system. However, the model output is in probabilities which can only be used indicatively for management decisions and scientific predictions.

BayFish – Tonle Sap model has proven in scenario analysis the accuracy obtainable with the combination of data integration and extensive stakeholders consultations into a Bayesian Belief Network. Even though the model is simplified it can be used as an efficient management and planning tool for the Tonle Sap fisheries and environment.

The next steps of the model development are:
1) training of decision makers in using and modifying the model;
2) fine tuning the model according to feedback from decision makers and stakeholders;
3) studying the importance and linkages of overland flow to fish and larvae migration (replenishment of fish stocks);
4) dissemination of model results as well as the model itself to wider audience.


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### ANNEX: Abbreviations used in the Netica model framework and corresponding model section for each of the variables

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Corresponding variable</th>
<th>Model section</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFMigrations</td>
<td>MIGRATIONS of residents</td>
<td>Fish migrations</td>
</tr>
<tr>
<td>BS</td>
<td>Built Structures</td>
<td>Fish migrations</td>
</tr>
<tr>
<td>GFMigrations</td>
<td>MIGRATION of TS migrants</td>
<td>Fish migrations</td>
</tr>
<tr>
<td>Refuges</td>
<td>Floodplain refuges</td>
<td>Fish migrations</td>
</tr>
<tr>
<td>WFMigration</td>
<td>MIGRATION of Mekong migrants</td>
<td>Fish migrations</td>
</tr>
<tr>
<td>BFCatch</td>
<td>CATCH of residents</td>
<td>Fish production</td>
</tr>
<tr>
<td>BFStock</td>
<td>STOCK of residents</td>
<td>Fish production</td>
</tr>
<tr>
<td>GFCatch</td>
<td>CATCH of TS migrants</td>
<td>Fish production</td>
</tr>
<tr>
<td>GFStock</td>
<td>STOCK of TS migrants</td>
<td>Fish production</td>
</tr>
<tr>
<td>TotalCatch</td>
<td>TOTAL FISH CATCH</td>
<td>Fish production</td>
</tr>
<tr>
<td>WFCatch</td>
<td>CATCH of Mekong migrants</td>
<td>Fish production</td>
</tr>
<tr>
<td>WFstock</td>
<td>STOCK of Mekong migrants</td>
<td>Fish production</td>
</tr>
<tr>
<td>BFPressure</td>
<td>PRESSURE on residents</td>
<td>Fishing</td>
</tr>
<tr>
<td>GFPressure</td>
<td>PRESSURE on TS migrants</td>
<td>Fishing</td>
</tr>
<tr>
<td>LSPressure</td>
<td>Pressure from LS fishery</td>
<td>Fishing</td>
</tr>
<tr>
<td>MSFishers</td>
<td># MS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>MSGear</td>
<td>MS gear efficiency</td>
<td>Fishing</td>
</tr>
<tr>
<td>MSKhmer</td>
<td># Khmer MS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>MSmigrant</td>
<td># migrant MS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>MSPressure</td>
<td>Pressure from MS fishery</td>
<td>Fishing</td>
</tr>
<tr>
<td>MSVietCham</td>
<td># Viet./Cham MS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>SSActivity</td>
<td>Activity of SS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>SSFishers</td>
<td># SS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>SSGear</td>
<td>Gear size of SS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>SSKhmer</td>
<td># Khmer SS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>SSPressure</td>
<td>Pressure from SS fishery</td>
<td>Fishing</td>
</tr>
<tr>
<td>SSVietCham</td>
<td># Viet./Cham SS fishers</td>
<td>Fishing</td>
</tr>
<tr>
<td>WFPResure</td>
<td>PRESSURE on Mekong migrants</td>
<td>Fishing</td>
</tr>
<tr>
<td>BF.DO</td>
<td>O2 for residents</td>
<td>Habitat</td>
</tr>
<tr>
<td>BF.Habitat</td>
<td>HABITAT for residents</td>
<td>Habitat</td>
</tr>
<tr>
<td>DO_Floodplain</td>
<td>Floodplain O2</td>
<td>Habitat</td>
</tr>
<tr>
<td>FVegetation</td>
<td>Flooded vegetation</td>
<td>Habitat</td>
</tr>
<tr>
<td>GF.DO</td>
<td>O2 for TS migrants</td>
<td>Habitat</td>
</tr>
<tr>
<td>GF.Habitat</td>
<td>HABITAT for TS migrants</td>
<td>Habitat</td>
</tr>
<tr>
<td>WF.DO</td>
<td>O2 for Mekong migrants</td>
<td>Habitat</td>
</tr>
<tr>
<td>WF.Habitat</td>
<td>HABITAT for Mekong migrants</td>
<td>Habitat</td>
</tr>
<tr>
<td>FBBeginning</td>
<td>Flood beginning</td>
<td>Hydrology</td>
</tr>
<tr>
<td>FDuration</td>
<td>Flood duration</td>
<td>Hydrology</td>
</tr>
<tr>
<td>FFish</td>
<td>Flood for fishes</td>
<td>Hydrology</td>
</tr>
<tr>
<td>FLevel</td>
<td>Flood level</td>
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<td>Mekong inflow</td>
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<td>Hydrology</td>
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</tr>
<tr>
<td>TSWLevel</td>
<td>TS water level</td>
<td>Hydrology</td>
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Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

INTEGRATION OF DATABASES TO THE BAYFISH – TONLE SAP FISH PRODUCTION MODEL.

Prepared by
Teemu JANTUNEN

April 2007 update
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1.8 HYDROLOGICAL DATA FREQUENCY DISTRIBUTIONS

1.9 BAYESIAN BELIEF NETWORK MODEL OUTPUT
Abbreviations:

ADB  Asian Development Bank
BBN  Bayesian Belief Network
BOD  Biological Oxygen Demand
CNMC  Cambodian National Mekong Committee
DHI  Danish Hydrologic Institute
DO  Dissolved Oxygen
DSF  Decision Support Framework
GIS  Geographical Information Systems
IFReDI  Inland Fisheries Research and Development Institute
IWMI  International Water Management Institute
JICA  Japan International Cooperation Agency
MCM  Million Cubic Meters
MOWRAM  Ministry of Water Resources and Meteorology
MPWT  Ministry of Public Works and Transport
MRCS  Mekong River Commission Secretariat
MSL  Mean Sea Level
PPT  Precipitation
TA  Technical Assistance
TIN  Triangulated Irregular Network
TSD  Technical Support Division
TSLV  Tonle Sap Lake and its Vicinities
WUP  Water Utilisation Project

Executive Summary:

A series of datasets have been gathered, analysed, summarised and integrated into the Bayesian Belief Network (BBN) fisheries model. Bayesian networks are based in probabilistic interactions between variables. They have been mainly used for medical diagnosis but recently more for environmental management as well. The data consists of hydrological characteristics (rainfall, runoff, Mekong flow, overland flow, flood beginning, and flood duration), water quality characteristics (dissolved oxygen) and land use characteristics for the Tonle Sap Lake and floodplain. Data accuracy, reliability and suitability for the model were given special attention in the analysis. All datasets have been handed over to IFReDI.

Acknowledgements:

The author would like to thank Mr. Henrik Garsdal for advice and valuable comments about hydrological data; Mr. Jorma Koponen and Dr. Juha Sarkkula for in-depth information, modelling and advice about water quality data; Mr. Christoph Feldkötter, Mr. Ulf Hedlund and Mr. Ith Sotha for information about Geographical Information Systems (GIS) databases; Mr. Huon Rath for assistance with land use data; Dr. Eric Baran for constructive comments and corrections on the report; and Mr. Chris Myschowoda for help with the report language.
1 Introduction

The Asian Development Bank approved a grant for the capacity building of IFReDI (Inland Fisheries Research and Development Institute), with WorldFish Center as an implementing agency. The aim of the technical assistance is to build IFReDI as a relevant and efficient research and development institute.

The project has four components. One of these components focuses on research and development. This component includes a Bioecology-Modelling sub-component. In the field of modelling, this sub-component aims to identify relationships between river hydrology, floodplain habitats and fish production, to integrate this information into a Bayesian model, and to prepare a base for a decision support system aimed for assisting in the management of the river and its floodplain.

The current study consisted in gathering and compiling numerical databases on land use, hydrology and water quality. These sources of information were then analysed, manipulated and validated for integration into the Bayesian model of the Tonle Sap fish resource being developed by the Bioecology-Modelling sub-component of the project (Baran et al., 2004).

The objective of this consultation is to strengthen the model of the Tonle Sap fish resource by including quantitative information extracted from various recent databases of different formats spread across a number of organisations. The use of quantitative data on land use, hydrology and water quality will strengthen the model developed on the basis of stakeholders consultations and will improve its predictive power and accuracy.

This report is divided into four sections and corresponding annexes. The first section introduces the databases that were utilised and the method of data analysis with results. Validation for the use of the selected datasets is given in this section. The second section briefly describes the methodology, options for data input to the Netica model, and how nodes might be parameterised and thresholds set. A detailed description of each node with input data parameterisation and thresholding follows with justifications. The third section deals with aspects of the model outside the scope of this consultancy. Due to the inter-connectivity of the model framework they are dealt with briefly. The final section concludes the findings. In all sections, text in boxes refers directly to nodes of the Bayesian Belief Network fisheries model whereas the node states are referred in italics.
2 Tasks and methods

2.1 About the literature review

A review of relevant documents on the availability and quality of hydrological data with emphasis on fish production was undertaken at the beginning of the consultancy. Geographical Information Systems databases and contact persons were identified from several reports (Campbell, 2003; Eloheimo et al., 2002a and 2002b; MekongInfo MRC online database, 2004). Previous models and water balance calculations on the Tonle Sap Lake were also studied (Sopharith, 1997; Kite, 2000; Koponen et al., 2002a). Stakeholders consultation reports for the fisheries model were reviewed (Baran, et al., 2003; Hort and Baran, 2004; Hort, et al., 2004). The review also assisted in the discovery of some possible linkages between variables in the model and in their parameterisation. A full reference list is included in chapter 6.

2.2 Data collection

Data collected from a number of databases, their format and short descriptions are listed in Table 1. The data collection effort aimed to use existing edited numerical databases and data summaries as much as possible in order to avoid overlapping and duplicating work already done by other technical assistance projects. Some projects were visited to find out, not only the nature of their studies, but also information about ongoing work and future developments. This information was provided to IFReDI and Department of Fisheries employees in seminars.
Table 1 Summary of all data requested through IFReDI and handed over to the institute as a collection of CDs with a short description of the data and their sources.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Area and period</th>
<th>Description</th>
<th>Format</th>
<th>Obtained from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall data</td>
<td>MRCS</td>
<td>Tonle Sap catchment 1980-2003</td>
<td>Average rainfall data over each of the sub-catchments</td>
<td>Numerical</td>
<td>MRCS/JICA &amp; TSLV Flow Reversal Project</td>
</tr>
<tr>
<td>Land use, road network, ponds and administrative data</td>
<td>JICA</td>
<td>Tonle Sap catchment</td>
<td>1999 JICA Land use map simplified for Tonle Sap floodplain</td>
<td>GIS layer 1:100 000</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Land use data</td>
<td>WUP_FIN</td>
<td>Tonle Sap floodplain</td>
<td>Calculated percentages of land use types depending on elevation</td>
<td>Numerical</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Dissolved oxygen data</td>
<td>WUP_FIN and MRCS</td>
<td>Tonle Sap Lake and floodplain</td>
<td>Measurements by MOWRAM and MRCS/WUP_FIN</td>
<td>Numerical</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>MRCS/WUP_FIN model output data</td>
<td>WUP_FIN</td>
<td>Tonle Sap Lake and floodplain</td>
<td>Average dissolved oxygen levels and anoxic conditions prevalent in the lake and floodplain</td>
<td>Numerical</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Certeza survey contour data</td>
<td>MRCS</td>
<td>Tonle Sap floodplain</td>
<td>Digital contour lines based on 1964 levelling survey</td>
<td>GIS layer 1m contour lines</td>
<td>MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Water balance data</td>
<td>JICA &amp; TSLV Flow Reversal Project</td>
<td>Tonle Sap catchment</td>
<td>Calculated water balance to Tonle Sap catchment</td>
<td>Numerical</td>
<td>MRCS/JICA &amp; TSLV Flow Reversal Project and MRCS/WUP_FIN</td>
</tr>
<tr>
<td>Fishing lots</td>
<td>MRC</td>
<td>Tonle Sap catchment</td>
<td>Location, extent and state of fishing lots</td>
<td>GIS layer</td>
<td>MRCS/WUP_FIN</td>
</tr>
</tbody>
</table>

2.2.1 Mekong River Commission Secretariat Technical Support Division (MRCS/TSD)

A request was made to the MRCS/TSD for water level, discharge, precipitation, land use, topography, administrative border, road network and dissolved oxygen data (full list of requested data in annex 1.1). During the discussions with Geographical Information Systems and database experts it was discovered that the MRCS Hydrographic Atlas (1998) was soon to be released as a Geographical Information Systems layer, but that would not be available before May 2004. All of the data used for the modelling were obtained from sub-projects because the majority of the data has not been added into the MRCS/TSD database to date.

Overall, the MRCS holds the best and most comprehensive Geographical Information Systems, hydrological, environmental and remote sensing datasets about Cambodia, the Mekong and the
Tonle Sap. According to experts there will be no new data collection or measurement programmes by the MRCS for the Tonle Sap Lake and floodplain in the near future. After the MRCS moves into Laos the MRCS database will be available in Cambodia through the Cambodian National Mekong Committee (CNMC). Also, the MRCS is currently developing an online database with functions for data searching and possibly downloading. The plan is to have the database for internal use only at first, but it may be made available for public use at a later date. According to estimates, the online database should be ready sometime in the year 2005.

2.2.2 Mekong River Commission Secretariat Water Utilization Project - Finland (MRCS/WUP-FIN)

The MRCS/WUP-FIN has collected a very good database of hydrological and water quality data for the Tonle Sap Lake to meet their model requirements. In addition, the MRCS/WUP-FIN has undertaken extensive data gathering and field sampling programmes in and around the lake. The model developed by the MRCS/WUP-FIN can be used to produce various outputs for this Bayesian model, particularly on the water quality side. The MRCS/WUP-FIN model expert was asked to run this model in order to produce outputs for dissolved oxygen levels in different floodplain land use classes. Also, there is Geographical Information Systems data available at the MRCS/WUP-FIN on the relationship between elevation and land use on the Tonle Sap floodplain.

The MRCS/WUP-FIN project has gathered a wealth of information and expertise about the lake. The model structure, particularly regarding oxygen levels, was discussed with project experts for a broader understanding of possible linkages between dissolved oxygen and other variables in the Bayesian model and their relative importance.

2.2.3 Mekong River Commission Secretariat Water Utilization Project - Japan International Cooperation Agency (MRCS/WUP-JICA)

A MRCS/WUP-JICA hydrology and modelling expert was interviewed to learn more about water level and rainfall data, the water balance in the Tonle Sap Lake, and bank structures affecting the lake’s flow. A MRCS/WUP-JICA project has worked extensively on flow measurements and hydrological data analysis, and this data was utilised for the purposes of the Bayesian model. In addition, the MRCS/WUP-JICA & TSLV Flow Reversal Project produced extremely useful model output data on discharges from the Mekong to the Tonle Sap and on water levels the Tonle Sap Lake as part of their project. For modelling they used MIKE11 hydrological model originally developed by DHI in Denmark.

Overall, the discussions were very useful in establishing the strength of relationships between hydrological variables and in assessing the usefulness of the data for the purposes of the Bayesian fisheries model. Valuable information regarding data quality was also drawn from the discussions. The MRCS/WUP-JICA data is estimated to be available through the MRCS and the Cambodian National Mekong Committee upon request by July 2004.

2.2.4 Ministry of Public Works and Transport (MPWT)

The Ministry of Public Works and Transport (MPWT) mainly holds databases on road networks, topography, build structures (urban areas, bridges, etc.), land use and water courses. Practically all data is available upon request through the MRCS and the Cambodian National Mekong Committee for national line agencies.

A Geographical Information Systems expert from the Ministry of Public Works and Transport was interviewed about JICA land use maps, water level datum and bank structures. Land use maps for all of Cambodia are reportedly going to be ready at the end of April 2004 (in case they are
required for modelling the whole Tonle Sap catchment or other activities in the IFReDI). Also, according to the Geographical Information Systems expert there has been no work done on the extent and length of bank structures around the Tonle Sap Lake. Thus, no data are available on bank structures for the purposes of the Bayesian model.

The results of a recent levelling work done around the lake have only been used for comparison with the contour lines of the Certeza Survey (1964). There is very little difference in average elevation data between the Certeza Survey and the recent levelling work. Therefore, the use of Certeza Survey elevation data in the floodplain is justified. Kampong Loung is regarded as one of the main water level measurement stations on the Tonle Sap Lake. However, the datum level and accuracy of the water level measurement station have not been checked by a levelling survey. Therefore, other means have to be used to check the accuracy of the data from the Kampong Loung station.

2.2.5 Geography Department

The Geography Department has databases on land ownership and titling, road networks, build structures, remote sensing and topography. Most of the data is available upon request through the MRCS and the Cambodian National Mekong Committee to national line agencies.

The Director of the Geography Department was visited mainly to learn more about new developments on the Tonle Sap Lake, but also about the Geographical Information Systems databases held at the department. The discussion yielded no new information about data, but there were suggestions for aerial photography and laser surveying of the Tonle Sap floodplain.

2.3 Data analysis and validation

The Bayesian Belief Network model is designed to handle hydrological, biological and socio-economic parameters in order to predict fisheries and agricultural production in a given flooding season. Therefore, it was decided to handle most of the data in the form of hydrological years (i.e. from the beginning of May to the end of April). If data is analysed in calendar years rather than hydrological years there can be inaccuracies especially in averaged data. This can be caused by the different hydrological properties of the previous rainy season (i.e. a high or low flood the previous year can cause annual statistics to distort for the following year).

2.3.1 Tonle Sap rainfall

According to all experts and reports, precipitation data is the most problematic of all data necessary for the Bayesian fisheries model of the Tonle Sap catchment. This is due to the fact that station records are often short and full of gaps, and that the station network changes from year to year (Garsdal, 6.4.2004, personal communication). The MRCS/WUP-FIN project also found that the mutual correlations between different stations are quite weak (Eloheimo et al., 2002a). Therefore, the existing records are quite inconsistent and unreliable. Thus, it was decided to use the DSF (Decision Support Framework) model (MRCS/WUP-JICA & TSLV Reverse Flow Project) precipitation input data generated by calculating simple mean area rainfall for all Tonle Sap sub-catchments with each station having equal weight (MRCS/WUP-JICA, 2004). With the relatively large uncertainty in some of the rainfall data as well as the non-uniform distribution of the rainfall station network, the MRCS/WUP-JICA did not attempt to apply any sophisticated weighting of the individual stations (MRCS/WUP-JICA, 2004).

The precipitation data was provided as daily totals from 1980 to 2003 for each Tonle Sap sub-catchment (Boribo, Pursat, Dauntri, Sangker, Mongkol Borey, Sisophon, Sreng, Siem Reap,
Rainfall for the whole Tonle Sap catchment was calculated simply by adding the average rainfall for all the Tonle Sap sub-catchments. Monthly averages, maximum, minimum and standard deviation values were calculated from the Tonle Sap catchment totals (annex 1.2). Because of its crucial importance for rainfed agriculture, the rainfall data was also analysed in rainy season (from June to December) amounts. Rainfall for the open lake is not accounted, as evaporation and precipitation over the lake are almost equal (Sarkkula et al., 2004) and therefore cancel each other out.

In the third stakeholders consultation (Hort, et al., 2004) the years 1996, 2000, 2001 and 2002 where named as especially wet years. However, when looking at the data (Figure 1) these years do not appear especially wet, rendering either the longer term data series or the opinions of stakeholders incorrect. In this case, long term data series unreliability was seen as the cause of the incompatibility of the two sources. Due to major uncertainties in the 1980 to 1995 period it was decided to use only the most recent years, namely 1996 to 2003, as rainfall data for the model.

Figure 1 Average rainfall for the Tonle Sap catchment from 1980 to 2003 (millimetres).

2.3.2 Mekong flow

Prek Kdam (station number 20102), about 50 km North of Phnom Penh on the Tonle Sap River was used to determine the discharge of water flowing into the lake from the Mekong. The dataset used consists of simulated discharge values from the MIKE11 model used by the MRCS/WUP-JICA & TSLV project. Reverse flow towards the Tonle Sap Lake dominates from June to September with maximum flows between July and August (annex 1.3.1). The discharge data corresponds well with Tonle Sap water level and Overland flow as well as Tonle Sap runoff discharge, which is essential to keep the proportions of all Kampong Loung water level parent nodes correct in the Bayesian model. The MIKE11 model was calibrated with the years which had direct measurements from the MRCS/WUP-JICA & TSLV project. For the years without direct measurements, the discharge level at Kratie was used as a reference for the model, because Kratie is the only measurement station with records extending back to 1985. The discharge records used are from 1985 to 2003 (Table 2) even though the water level records for Prek Kdam start much earlier. There are doubts about data accuracy at Prek Kdam the further back the
records originate. This is mainly because the data has not been corrected for backwater effect and overland flow impact.

Table 2 Rainy season date (from June to December): Precipitation (mm), River inflow (flow from the Mekong), Overland flow and Runoff totals in Million Cubic Meters; Tonle Sap water level at Kampong Loung (in meters). Years are named as wet or high flood in third stakeholder consultation are marked in bold and 1998 dry year marked in italics.

<table>
<thead>
<tr>
<th>Flood year</th>
<th>Precipitation</th>
<th>River inflow</th>
<th>Overland flow</th>
<th>Runoff</th>
<th>Water level at K. Loung</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>878.6</td>
<td>43376</td>
<td>6751</td>
<td>25680</td>
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</tr>
<tr>
<td>1986</td>
<td>792.1</td>
<td>43266</td>
<td>5935</td>
<td>15636</td>
<td>8.4</td>
</tr>
<tr>
<td>1987</td>
<td>900.4</td>
<td>35522</td>
<td>4451</td>
<td>18322</td>
<td>7.8</td>
</tr>
<tr>
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<td>753.6</td>
<td>26105</td>
<td>1416</td>
<td>18123</td>
<td>7.2</td>
</tr>
<tr>
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<td>28119</td>
<td>2295</td>
<td>39246</td>
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<tr>
<td>1990</td>
<td>1113.8</td>
<td>37999</td>
<td>7668</td>
<td>33970</td>
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</tr>
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<td>1292.8</td>
<td>35561</td>
<td>10639</td>
<td>48354</td>
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</tr>
<tr>
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<td>26758</td>
<td>3807</td>
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</tr>
<tr>
<td>1993</td>
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<td>33704</td>
<td>3299</td>
<td>27185</td>
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</tr>
<tr>
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<td>36535</td>
<td>13076</td>
<td>45501</td>
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</tr>
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<td>43910</td>
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</tr>
<tr>
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<td>11621</td>
<td>22923</td>
<td>9.1</td>
</tr>
<tr>
<td>1998</td>
<td>1029.8</td>
<td>22110</td>
<td>1309</td>
<td>23635</td>
<td>7.1</td>
</tr>
<tr>
<td>1999</td>
<td>1031.5</td>
<td>35718</td>
<td>7036</td>
<td>31855</td>
<td>9.0</td>
</tr>
<tr>
<td>2000</td>
<td>1057.4</td>
<td>49772</td>
<td>16366</td>
<td>30886</td>
<td>10.3</td>
</tr>
<tr>
<td>2001</td>
<td>1035.9</td>
<td>48488</td>
<td>13627</td>
<td>30803</td>
<td>10.0</td>
</tr>
<tr>
<td>2002</td>
<td>1066.6</td>
<td>49466</td>
<td>14222</td>
<td>28121</td>
<td>10.2</td>
</tr>
<tr>
<td>2003</td>
<td>837.8</td>
<td>33753</td>
<td>4555</td>
<td>21632</td>
<td>8.4</td>
</tr>
<tr>
<td>Average</td>
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<td>37388</td>
<td>7621</td>
<td>29675</td>
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<td>10.4</td>
</tr>
<tr>
<td>Min</td>
<td>754</td>
<td>22110</td>
<td>1309</td>
<td>15636</td>
<td>7.1</td>
</tr>
<tr>
<td>St Dev</td>
<td>168</td>
<td>7988</td>
<td>4574</td>
<td>9039</td>
<td>1.0</td>
</tr>
</tbody>
</table>

2.3.3 Overland flow

For Mekong overland flow to the Tonle Sap, simulated output data from the MRCS/WUP-JICA & TSLV project model was used (MIKE11). The MRC/WUP-JICA project measured the flow under the main bridges on National road number 6 where overland flow took place in the year's 2001 to 2003. There are no other existing overland flow data based on actual measurements, but a few estimates from secondary data have been done on the role of overland flow (Sarkkula et al., 2004). Therefore, simulated model output data for 1985 to 2003 (Table 2) is the best available. The simulated data was used to extend the records and to ensure that discharge data is compatible with Prek Kdam and Tonle Sap runoff data and simulated Kampong Loung water level data. There is some overland flow over the year (in channels), but the main flow takes place between July and September (annex 1.3.2). Interestingly, there is usually some overland flow from the Tonle Sap Lake towards the Mekong between October and November. The role of this overland flow in fish migration has not been studied and therefore has not been included in the model at this stage.

2.3.4 Tonle Sap Runoff

At first it was believed that Tonle Sap rainfall includes all precipitation in the Tonle Sap catchment. Therefore, noting separate water flow contributions from Tonle Sap tributaries was deemed unnecessary. However, the correlation between water levels and monthly precipitation is quite
weak with $R^2$ only 10 to 25% (Eloheimo et al., 2002). Therefore, a new node was established between Tonle Sap rainfall and Tonle Sap water level in order to maintain proportions between different variables contributing to Tonle Sap water level and to distinguish between rainfall and runoff. This also enables the best possible probabilities to be calculated for Tonle Sap water level from the MIKE11 model output (MRCS/WUP-JICA & TSLV project). Tonle Sap runoff describes the discharge of water into the lake from the Tonle Sap tributaries. This provides a better combination of variables than using Tonle Sap rainfall directly, and also enables more detailed use of Tonle Sap rainfall for the use of Agricultural production, where it is much more important than in fisheries production. The correlation between the simulated runoff in the MIKE11 model and the Tonle Sap rainfall is high ($R^2 = 0.914$) and can be seen in Table 2 and Figure 2.

![Comparison of Tonle Sap rainfall and runoff during rainy months (June to December).](image)

**Figure 2** Comparison of Tonle Sap rainfall and runoff during rainy months (June to December).

### 2.3.5 Tonle Sap water level data

It is very difficult to represent the whole lake with only one water level value. The water level varies spatially around the lake depending on the topography, distance from build structures, local flooding conditions and duration of water flow from the Mekong and Tonle Sap tributaries. For example, between Snoc Trou and Prek Dam the extreme differences in water levels are -2.5 meters when the flood is rising to +1.5 meters when the flood is receding. (Eloheimo et al., 2002). However, the model can only accept one set of values, and so Kampong Loung (station number 20106), situated on the shore of the southern part of the lake, was seen as a good reference point out of the few possibilities.

At the second stakeholders consultation, the station along the Tonle Sap River in Kampong Chhnang (station number 20103) was named as the reference water level for the lake (Hort and Baran, 2004). According to the original measured datasets, however, there are 34 gaps with 2526 missing days in 37 years of data from Kampong Chhnang but only 8 gaps with 850 missing days in 20 years of data from Kampong Loung (Eloheimo et al., 2002a). For details, see annex 1.4.1.

In addition, parts of the Kampong Chhnang daily water level dataset are uncertain and some of the daily readings inconsistent (Figure 3). Also, for Flood beginning node requirements, a comparison in daily water level differences was done. The statistics between Kampong Chhnang and MIKE11 output for Kampong Loung clearly show that the model output data from Kampong Loung is much more consistent (Table 3). Daily differences in a given flooding season (May to
December) of ±1 meter and over are unrealistic and cannot be considered accurate or reliable. Due to this discrepancy, only the years with a standard deviation of less than 0.1 were included in further analysis (for Flood beginning and Flood duration node purposes). Also, weekly averages of the daily values were calculated to see if greater consistency could be achieved (once again from May to December). These calculations proved to be correct and more gradual changes in the daily water level difference could be seen from the data (annex 1.5.2). For more information see chapters 2.3.6 and 3.2.4.

From literature and data analysis it is clear that Kampong Loung provides the most representative lake level measurements (Koponen et al., 2003a; Hellsten et al., 2003). Therefore, Kampong Loung was chosen in order to most accurately and reliably represents the lake’s water level.

![Figure 3](image)

**Figure 3** Kampong Chhnang daily water level difference from the 21st of June to the 7th of July, 1987.

**Table 3** Comparison of Daily water level differences from the May to December period for the years 1985 to 2002 at K. Chhnang and K. Loung (for K. Loung MIKE11 output water levels were used).

<table>
<thead>
<tr>
<th>Year</th>
<th>Kompong Chhnang (measured)</th>
<th>Kompong Luong (MIKE11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>1985</td>
<td>1.500</td>
<td>-0.710</td>
</tr>
<tr>
<td>1986</td>
<td>1.200</td>
<td>-1.300</td>
</tr>
<tr>
<td>1987</td>
<td>2.340</td>
<td>-0.990</td>
</tr>
<tr>
<td>1988</td>
<td>0.520</td>
<td>-0.840</td>
</tr>
<tr>
<td>1989</td>
<td>0.940</td>
<td>-0.750</td>
</tr>
<tr>
<td>1990</td>
<td>0.800</td>
<td>-0.670</td>
</tr>
<tr>
<td>1991</td>
<td>1.020</td>
<td>-0.500</td>
</tr>
<tr>
<td>1992</td>
<td>0.770</td>
<td>-1.350</td>
</tr>
<tr>
<td>1993</td>
<td>0.810</td>
<td>-0.160</td>
</tr>
<tr>
<td>1994</td>
<td>0.670</td>
<td>-0.470</td>
</tr>
<tr>
<td>1995</td>
<td>0.240</td>
<td>-0.140</td>
</tr>
<tr>
<td>1996</td>
<td>0.360</td>
<td>-0.340</td>
</tr>
<tr>
<td>1997</td>
<td>0.350</td>
<td>-0.140</td>
</tr>
<tr>
<td>1998</td>
<td>0.990</td>
<td>-1.040</td>
</tr>
<tr>
<td>1999</td>
<td>0.330</td>
<td>-0.150</td>
</tr>
<tr>
<td>2000</td>
<td>0.400</td>
<td>-0.160</td>
</tr>
<tr>
<td>2001</td>
<td>0.250</td>
<td>-0.160</td>
</tr>
<tr>
<td>2002</td>
<td>0.680</td>
<td>-0.160</td>
</tr>
</tbody>
</table>
Equations between different water level measurement stations could be used to fill in the gaps in the data for Kampong Loung. For example, equations between Prek Kdam and Kampong Loung (see below) have been established by Sopharith (1997) and Kite (2000). Sopharith’s equation overestimates the level at Kampong Loung (Kite, 2000). The problem with the equations is that they do not take into account overland flow directly from the Mekong to the Tonle Sap Lake from bridge openings on National Road 6 and the backwater effect in the Tonle Sap River. Therefore, the relationship equations are not accurate on all water levels.

1. Equations on the relationship between Kampong Loung and Prek Kdam (\(H_{KL} = \) Water level at Kampong Loung, \(H_{PK} = \) water level at Prek Kdam):

\[
H_{KL} = (0.905533 \times H_{PK}) + 1.235901 \quad (R^2 = 0.84)
\]
International Water Management Institute model (Kite, 2000)

2. Equations on the relationship between Kampong Loung and Kampong Chhnang (\(H_{KL} = \) Water level at Kampong Loung, \(H_{KC} = \) water level at Kampong Chhnang):

\[
H_{KL} = (1.0068 \times H_{KC}) + 0.50 \quad (R^2 = 0.838)
\]

\[
H_{KL} = (0.950519 \times H_{KC}) + 0.806588 \quad (R^2 = 0.94)
\]
For the period from 1924 to 1960 - International Water Management Institute model (Kite, 2000).

\[
H_{KL} = (0.926343 \times H_{KC}) + 0.522631 \quad (R^2 = 0.92)
\]
For the period from 1960 to 1998 - International Water Management Institute model (Kite, 2000).

The decision was made to use simulated Kampong Loung water level data from the MRCS/WUP-JICA & TSLV project flow model. This was seen as a way to deal with the unreliable equations and unexplainable gaps and shifts in the data. For example, there is an average 2.5 meter shift when the 1924 to 1965 and 1996 to 2003 Kampong Loung water level datasets are compared (Garsdal, 6.4.2004, personal communication). Because reference data and datum information is missing from the earlier period it is impossible to estimate whether the shift was caused by changes in gauge level or by the hydrological regime of the Mekong River. However, Nam (2000) found that the peak flood levels during the wet season are lower in the period from 1979 to 1998 than from 1924 to 1963. Nam suggested that upstream dam building since the 1960s was responsible for the difference. This conclusion partly explains the differences in Kampong Loung data between 1924 and 1965 and between 1996 and 2002.

There are also other unexplained shifts in the original measured daily water level data (e.g. Figure 4). The MRCS has prepared a dataset (available in Hymos) with the datum level corrected to the mean sea level (MSL) at Ha Tien (Vietnam). For the later period (from 1997 to 2003) the correction for Kampong Loung is approximately +0.6 meters compared to measured water levels from 1996 to 2003. The MRCS/WUP-JICA & TSLV project model uses this corrected data as input data for their model.
The model data corresponds well to the use of the same dataset for discharge data from Mekong via Prek Kdam, overland flow and Tonle Sap tributaries runoff. The monthly maximum water levels for the period from 1985 to 2003 with related statistics are in annex 1.4.2. The differences in the monthly average water level between the original measured, the original data corrected with Ha Tien Mean Sea Level datum, and the simulated model output datasets can be seen in annex 1.4.3.

The water balance calculated by the MRCS/WUP-JICA & TSLV project (MRCS/WUP-JICA, 2004) is about 40% from Tonle Sap runoff, 50% from River inflow (flow coming from the Mekong River) and 10% from Overland flow. Detailed water balance calculations for the 1985 to 2003 period can be seen in Table 4. The water balance varies every year depending on the input from the Mekong (River inflow and Overland flow) on the one hand and Tonle Sap rainfall (Tonle Sap runoff) on the other. Generally, runoff from the tributaries has a much more significant contribution to the overall volume during dry years.
Table 4 Water balance for the Tonle Sap Lake from 1985 to 2003. Based on MRCS/WUP-JICA & TSLV Flow Reversal Project output data. Years identified by stakeholders as high flooding are marked in blue and low flooding years are marked in red.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mekong Overland Tonle Sap runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>57 9 34</td>
</tr>
<tr>
<td>1986</td>
<td>67 9 24</td>
</tr>
<tr>
<td>1987</td>
<td>61 8 31</td>
</tr>
<tr>
<td>1988</td>
<td>57 3 40</td>
</tr>
<tr>
<td>1989</td>
<td>40 3 56</td>
</tr>
<tr>
<td>1990</td>
<td>48 10 43</td>
</tr>
<tr>
<td>1991</td>
<td>38 11 51</td>
</tr>
<tr>
<td>1992</td>
<td>43 6 51</td>
</tr>
<tr>
<td>1993</td>
<td>53 5 42</td>
</tr>
<tr>
<td>1994</td>
<td>38 14 48</td>
</tr>
<tr>
<td>1995</td>
<td>45 9 46</td>
</tr>
<tr>
<td>1996</td>
<td>53 11 36</td>
</tr>
<tr>
<td>1997</td>
<td>54 15 30</td>
</tr>
<tr>
<td>1998</td>
<td>47 3 50</td>
</tr>
<tr>
<td>1999</td>
<td>48 9 43</td>
</tr>
<tr>
<td>2000</td>
<td>51 17 32</td>
</tr>
<tr>
<td>2001</td>
<td>52 15 33</td>
</tr>
<tr>
<td>2002</td>
<td>54 15 31</td>
</tr>
<tr>
<td>2003</td>
<td>56 8 36</td>
</tr>
<tr>
<td>Mean</td>
<td>51 9 40</td>
</tr>
</tbody>
</table>

2.3.6 Flood beginning and duration

The analysis of the flooding season from May to December was used to determine flood beginning and duration as this is the timeframe when flooding begins. The difference in daily water level was calculated and the results were visually analysed to find the exact date when the given threshold was breached (annex 1.5.1). The validation of the thresholding used to obtain this data is explained in chapter 3.2.4 with the corresponding results.

The third stakeholders consultation (Hort et al., 2004) identified timing of flow reversal as one component that is important for flood beginning. Therefore, Flood beginning dates derived from data on daily and weekly water level differences were also compared with the dates of flow reversal at Prek Kdam. The other component identified was spillover (local flooding of floodplains), but this could not be defined in the available time and data as it is a function of the local topography and varies extensively over the whole area of the lake. The thresholds and parameters for Flood beginning are dealt with in detail in chapter 3.2.4. Due to copyright restrictions, data on daily Mekong discharge at Prek Kdam could not be presented in numerical format in this report.

Flood duration is determined by time span between Flood beginning and a set threshold for the end of the flooding. The same datasets were used to determine Flood duration as Flood beginning because they are so closely related. However, Flood duration can be defined in a number of ways depending on when and where one looks at in the floodplain. As discussed in the above section about water level, the differences in water level on the lake and floodplain can vary significantly. This of course affects the time span when a given area is flooded.
2.3.7 Flooded vegetation

The surface area for different vegetation types in the floodplain was used to determine Flooded vegetation node probabilities. Surface areas were calculated depending on the thresholds of the Tonle Sap water level node. The Certeza Survey (1964) 1 meter contour lines for the floodplain correspond to water level at Kampong Loung directly and therefore these contour lines were used to define the surface area flooded at determined water levels.

Major simplifications were required in order to combine the 39 classes of the JICA (1999) classification into the three identified as the main vegetation types during the second stakeholders consultation (Hort and Baran, 2004). The MRCS/WUP-FIN provided numerical data in which the original data had already been analysed and its accuracy tested (Keskinen and Huon, 2002). The original JICA land use classification is in annex 1.6.1. The percentages of Grass (JICA classifications 3-17), Shrub (JICA classifications 18-21) and Forest (JICA classifications 22-32) at 1 meter elevation intervals can be seen in Figure 5. The JICA land use classes 1-2 (Urban), 33-37 (Water features) and 38-39 (Soil and rock) were left out of this new classification used for the Bayesian fisheries model (annex 1.6.2).

The JICA (1999) land use map for the Tonle Sap floodplain is the latest available, and it has proven relatively accurate by recent field work (Hellsten et al., 2003). The findings of recent Ministry of Public Works and Transport levelling work at the floodplain justify the use of elevation contour lines from the Certeza Survey (1964) to obtain vegetation cover areas from the JICA land use map. According to the Ministry of Public Works and Transport there are only small differences between the latest survey and the original Certeza survey (Huon, 5.4.2004, personal communication; Sarkkula, et al., 2003). The spatial distribution of the three major land use classes used for the Bayesian Belief Network can be seen in Figure 6, and detailed maps of each of the land use classes can be seen separately in annex 1.6.3.

With regard to water quality, the flooded forest has the best dissolved oxygen levels of the three classes (MRCS/WUP-FIN). This fact is due to the location of the forest in the immediate vicinity of the lake as a narrow strip. Therefore, oxygen rich water from the open lake continuously flushes the flooded forest, which brings nutrients from the Mekong for biological primary production. On the other hand, shrub vegetation has low dissolved oxygen levels because water flow is restricted which reduces the flushing effect. Additionally, shrub vegetation produces the most organic material causing more decay, which in turn increases the Biological Oxygen Demand. However, the relationships between Biological Oxygen Demand and land use types have not been quantified and are still being studied. Only approximate best available values can be used to explain the relationships.

![Figure 5 Percentages of Tonle Sap floodplain land use classes depending on elevation (in meters).](image-url)
2.3.8 Dissolved Oxygen data

Only dissolved oxygen was chosen as an indicator of the quality of lake water because of its proven importance in fish production and because other chemical parameters could not be related to fish production (water quality for agricultural production is not considered in this Bayesian fisheries model). The relationship between sediment concentrations and fish production has been studied by the MRCS/WUP-FIN (Koponen et al., 2003b), but definable links between the variables have not been established.

According to the MRCS/WUP-FIN, the lake water is well oxygenated because of wind and wave induced mixing. Also, during flooding, inundated areas are to a large extent anoxic (Koponen, 23.4.2004, personal communication; Koponen, et al., 2003b). Naturally low oxygen concentrations are observed in the floodplain, where the decomposition of organic matter is responsible for high oxygen consumption (Koponen, et al., 2003b). Overall, the organic material has largely decayed after the first 4 to 6 weeks a given area is flooded. However, strong flow caused by a rise in the water level of the lake can force the anoxic “bad” water further into the floodplain in the form of waves. Therefore, the dissolved oxygen levels decrease as the flood begins and then increase again around September or October (Figure 7), when the high water level effectively dilutes the anoxic waters and increases oxygen mixing on the water surface (at higher water levels more vegetation is completely covered by water, thereby exposing more open water surfaces for wind). When the flood recedes around November the anoxic waters from
higher elevations flush through the floodplain causing severe anoxic conditions. This possibly causes the fish to begin their annual migration away from the Tonle Sap Lake (Sarkkula, 7.4.2004, personal communication).

Figure 7 Dissolved oxygen levels for the 2000 and 2001 hydrological years (in milligrams per liter).

Analysis of the water quality data according to station, year and flood cycle was undertaken. The analysis showed that out of all the stations Phnom Krom 4 (PNK4) and 6, (PNK6) and Kampong Loung 3 (KGL3) had less than 10 samples each (annex 1.7). In addition, all these samples had been taken between August and January. Thus, they do not represent the dissolved oxygen levels at other times of the year. Subsequently, these stations were deleted from the dataset.

After removing these three unsuitable stations the standard deviation for maximum and minimum values improved from 3.32mg/l and 1.71mg/l to 2.7mg/l and 0.95mg/l respectively. The other stations have between 45 and 136 samples each, which represent the sites adequately.

When analysing the data on the annual flood cycle (Table 5), it can be seen that there are only four samples for the 1998 to 1999 period (May and June). This is clearly not representative of the annual flood cycle, as can be seen from the much lower average and maximum dissolved oxygen levels. Therefore, this particular flood cycle was removed from the dataset. The flood cycles from 1995 to 2001 have 16 to 24 samples each, and the distribution of these groups of samples cover almost all parts of the flood cycle. Only the early flood samples for 1999 (May to August) are missing. There are 299 samples, on the other hand, for the 2001 to 2002 period due to the sampling programme by the MRCS/WUP-FIN project that commenced in July 2001. A particularly large number of samples are taken from various locations each month during a rising flood. Even though the sampling programme was scaled down in late 2002 the hydrological year from 2002 to 2003 still has a relatively large number of samples (114). The average dissolved oxygen level does not seem to vary radically between flood cycles even though the sample sizes are very different. On the other hand, the two extensively sampled flood cycles show a larger variance in the results (0 –to 15 milligrams per litre) compared to the earlier years with 16 to 24 samples per year (3 to 8 milligrams per litre). Nevertheless, such a small number of measurements taken at a limited number of locations are far from ideal or representative given that the Tonle Sap system is highly dynamic.
Even after removing all the years with insufficient data the data was not deemed representative enough to upscale to cover the situation within the entire floodplain. However, the MRCS/WUP-FIN water quality model deals with the upscaling issue efficiently by linking hydrological, chemical and biological processes. Therefore, the output data for the MRCS/WUP-FIN water quality model was used to investigate dissolved oxygen relationships according to water level and floodplain land use.

Table 5 Dissolved oxygen statistics according to hydrological year, 1995 to 2003 (milligrams per litre).

<table>
<thead>
<tr>
<th>Water quality statistics</th>
<th>Average</th>
<th>Max</th>
<th>Min</th>
<th>No of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>6.0</td>
<td>16.5</td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>95-96</td>
<td>5.7</td>
<td>7.7</td>
<td>1.7</td>
<td>20</td>
</tr>
<tr>
<td>96-97</td>
<td>5.4</td>
<td>7.2</td>
<td>2.7</td>
<td>24</td>
</tr>
<tr>
<td>97-98</td>
<td>5.3</td>
<td>8.5</td>
<td>2.5</td>
<td>24</td>
</tr>
<tr>
<td>98-99</td>
<td>4.9</td>
<td>6.2</td>
<td>3.9</td>
<td>4</td>
</tr>
<tr>
<td>99-00</td>
<td>5.8</td>
<td>7.8</td>
<td>4.1</td>
<td>16</td>
</tr>
<tr>
<td>00-01</td>
<td>6.2</td>
<td>8.1</td>
<td>4.2</td>
<td>20</td>
</tr>
<tr>
<td>01-02</td>
<td>6.1</td>
<td>13.8</td>
<td>0</td>
<td>278</td>
</tr>
<tr>
<td>02-03</td>
<td>6.3</td>
<td>16.5</td>
<td>0.1</td>
<td>114</td>
</tr>
</tbody>
</table>

MRCS/WUP-FIN model takes into account a number of variables when computing the water columns dissolved oxygen levels. Decaying mainly takes place at the bottom, and this is taken into account, whereas the total biological oxygen demand of the water column is not taken into account. Wind induced mixing of oxygen is modelled and also the effect of vegetation (above water level) is considered.

In the model run for the output data for the Bayesian fisheries model a model grid cell was considered flooded when water level in the grid reaches 0.3m. For each of the different land use classes MRCS/WUP-FIN calculated the average surface area with a given Dissolved Oxygen level (3 different ones - < 2, 2-4 and > 4 mg/l) out of the total surface area of that land use class at a given time unit. The final percentage was the average over all time units. I.e. floodplain is divided into three land use types with the aim to find out how large percentage of each of these land use types in one hydrological year (average) has Dissolved Oxygen of less than 2, between 2-4 and more than 4 (data request format can be seen in table 6). The land use classes used for the modelling exercise were Grass (JICA land use classes 3-17), Shrub (JICA land use classes 18-21) and Forest (JICA land use classes 22-32). The use of the model capable of presenting the whole lake at the same time rather than point measurements improves this part of the Bayesian model significantly.

Table 6 Format of requested DO data from MRCS/WUP-FIN.

<table>
<thead>
<tr>
<th>DO Mg/l</th>
<th>Grass (%)</th>
<th>Shrub (%)</th>
<th>Forest (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than 4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Summary data of modelled years used by the MRCS/WUP-FIN water quality model to produce Dissolved Oxygen output data for the Bayesian model can be seen in table 7. Year 1997 represented a normal flood (in the model “From 8 to 10” meter flood), whereas 1998 represented a low (in the model “Below 8” meter flood) and 2000 a high flood (in the model “Above 10” meter flood).
Table 7 Summary of flooded year 1997, 19998 and 2000 used for MRCS/WUP-FIN model runs.

<table>
<thead>
<tr>
<th>Year</th>
<th>1997</th>
<th>1998</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood type</td>
<td>Normal</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Average total flooded area</td>
<td>5726</td>
<td>3712</td>
<td>7491</td>
</tr>
<tr>
<td>Average grass land area</td>
<td>1945</td>
<td>1185</td>
<td>2893</td>
</tr>
<tr>
<td>Average shrub land area</td>
<td>3621</td>
<td>2382</td>
<td>4429</td>
</tr>
<tr>
<td>Average forest land area</td>
<td>160</td>
<td>145</td>
<td>169</td>
</tr>
</tbody>
</table>

The results from the MRCS/WUP-FIN modelling exercise are presented in a summary (used for the model input) in table 8, and completely in annex table 25. The output data included three depths, surface, middle and bottom, as well as an average over all of them. Because the fish can migrate from one layer to another, it was decided to use the average to describe the situation in the whole lake (table 8).
Table 8 Format of requested DO data from MRCS/WUP-FIN.

<table>
<thead>
<tr>
<th>Year</th>
<th>Vegetation</th>
<th>Percentage of Dissolved Oxygen levels</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 2 (mg/l)</td>
<td>2-4 (mg/l)</td>
</tr>
<tr>
<td>2000</td>
<td>Grass</td>
<td>60</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
<td>69</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>32</td>
<td>53</td>
</tr>
<tr>
<td>1997</td>
<td>Grass</td>
<td>51</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>27</td>
<td>37</td>
</tr>
<tr>
<td>1998</td>
<td>Grass</td>
<td>54</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
<td>72</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>37</td>
<td>29</td>
</tr>
</tbody>
</table>

2.3.9 Built structures

Built structures consist in a diversity of constructions or items set up by man, which contribute to changing the hydrology of a natural system. Built structures can consist of constructions that (i) oppose water outflow (e.g., dams, weirs, irrigation schemes, dykes, levees); (ii) prevent water inflow (e.g. embankments, polders, flood control works); or (iii) alter water inflow or outflow (e.g., roads, railways, drainage canals, diversion structures, agricultural works\(^1\), banks and flows modifications\(^2\))

The Built structures effect on Flood level was not defined in detail in the second stakeholders consultation (Hort and Baran, 2004). Through the data collection effort it was learnt that the only available sources for possibly determining the aerial extent and hence importance of Built structures are the Hydrographic Atlas (by MRCS, 1998), road network (by JICA, 1999) and Certeza Survey contour lines of the floodplain (1964). The Hydrographic Atlas is only in numerical form and there are no Hydrographic Atlas Geographical Information Systems layers available at this time. In addition, the Atlas only covers the dry season lake and the Tonle Sap River. The National Roads 5 and 6 are the upper limit of the floodplain and are very rarely overflow by floodwaters (overflow requires more than 11 meters water level height at Kampong Loung). There are a number of roads from the National Roads towards the lake, but there is no data regarding their elevation. Often they get flooded at the same time as the surrounding floodplain, so the flood movement is virtually unrestricted. The Certeza Survey (1964) contour lines are at 1 meter elevation intervals making it impossible to identify any levees or built structures from the contour maps.

There are no data directly available on levees, barriers or other structures situated in the Tonle Sap floodplain because they have never been measured or

\(^1\) such as rice field dikes

\(^2\) such as the Chaktomuk peninsula development works and, in the case of the Tonle Sap Great Lake, fishing gears that are set on a massive scale, altering hydrological flows and obstructing fish movements
surveyed (Huon, 5.4.2004, personal communication; Ith, 7.4.2004, personal communication). In addition, the floodplain is very flat and does not seem to affect the relationship between water level and flood surface area (Figure 8). However, the built structures have a significant effect on overland flow from the Mekong to the Tonle Sap (Garsdal, 6.4.2004, personal communication). The overland flow commences when the Mekong discharge at Kampong Cham exceed 30,000 m³/s. The effect of overland flow on the transport of larvae and migration of fish is not known.

![Figure 8 Certeza Survey based Triangulated Irregular Network (TIN) water levels plotted against lake surface areas with an added trendline (S_lake) y = 1880.4x + 1859.8 with R² = 0.9856 (Jantunen, 2001).](image)

For the ADB Built Structures project definition in the model was crucial. However, available data only consisted of JICA (1999) road network. The data does not contain information of the height of these roads compared to the elevation of the floodplain. Smaller roads could not be taken into the analysis as this information was missing. In addition, roads perpendicular to the contour lines of the floodplain are flooded from both sides at the same time; hence the roads are not opposing flow. Also these roads have many bridges and culverts. Therefore it was decided to use the differences between the surface areas of each elevation category and surface area limited by the national roads 5 and 6 to determine the probabilities of the Built Structures node. Elevations used were 8 m contour, 10 m contour and 12 m contour. 12 m contour represents the total catchment area. Certeza Survey (1964) contours were used to create the polygons for each elevation category and JICA 1999 road layer was used to generate the polygon covering the area between the national roads 5 and 6. Each elevation polygon was clipped using the road polygon as a clipping layer to obtain the areas of elevation categories limited by the roads (Figure 9). The analysis assumes the national roads 5 and 6 being definite barriers to water flow and particularly to fish movements, which is based on stakeholders consultation that revealed all culverts and bridges are used by locals for fishing, hence practically catching all fish trying to pass through.
2.3.10 Floodplain refuges

JICA (1999) lake and river layer contains data about the temporal and perennial ponds. Temporal ponds dry up at some point, hence not providing refuge for the fishes, whereas perennial ones have water all year round. This data was used to determine the probabilities of the Floodplain refuges node. Total area of the ponds was obtained and probabilities of each type of pond from the total area was calculated. Areas and probabilities can be seen in table 9. In Cambodia only insignificant area is irrigated to provide three crops per year, hence having water in the canals and partly on the fields all year round. Floodplain refuges node defines that any pond or refuge that is drained or dries up during the year is not a refuge. Therefore canals that dry up are not refuges either. Therefore irrigation canals were not accounted as a floodplain refuge and idea of having them represented as a separate node was dropped.

Table 9: Areas and percentages of perennial and temporal ponds.

<table>
<thead>
<tr>
<th>Ponds</th>
<th>Perennial</th>
<th>Temporal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>237.04</td>
<td>86.65</td>
<td>323.68</td>
</tr>
</tbody>
</table>
2.3.11 Pressure from large scale fishery

Probabilities for the Pressure from LS fishery node are derived from the MRC fishing lot data. The border fences of the Lots that are facing either a river or the lake were digitized from each Lot and the existing and dismantled Lots were identified. Probabilities for the states were then calculated by comparing the length of the digitized Lot boundaries to the periphery of the lake. In case where the Lot fences also border a river the length of the river up to the Lot boundary was also added to the periphery of the lake. The existing lots are assumed to be 100% effective and dismantled lots are assumed to be 50% effective. Lots and digitized boundaries can be seen in figure 10.

![Digitized boundaries of the existing and dismantled lots](image)

<table>
<thead>
<tr>
<th>Lot</th>
<th>Non-existing</th>
<th>Existing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siem Reap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battambang</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pursat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10:** Digitized boundaries of the existing and dismantled lots

<table>
<thead>
<tr>
<th></th>
<th>Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing lots</td>
<td>409</td>
</tr>
<tr>
<td>Dismantled lots (total length divided by 2)</td>
<td>298</td>
</tr>
<tr>
<td>Periphery of the lake</td>
<td>1189</td>
</tr>
<tr>
<td>Percentage</td>
<td>59</td>
</tr>
</tbody>
</table>

| % of total  | 73.23 | 26.77 |
Table 10: Lengths of the lot boundaries facing the lake and the percentage of lot boundaries from periphery of the lake.

3 Data input, parameters and thresholds

3.1 Netica model parameter and threshold options

The Tonle Sap fish model developed during the stakeholders consultations (Hort *et al.*, 2004) is easy to use and both parameters and thresholds are easily changed after the data has been analysed, edited and formatted for the model requirements. Example of a Netica Bayesian model can be seen in Figure 9. Parent nodes (PN1 and PN2) are connected via links to child node (CN). The probabilities of the states for each node have been derived from their respective probability table. The number of states can be as many as required, but the more states are present the more complicated the child node probability tables will become. Three states per node could be seen as the upper limit, but it could be higher or lower depending on the structure of the network. Therefore, it depends on how many parent nodes are linked into a child node (the combined size of the probability table of a child node).

A threshold for a state (or parameter) can be defined either as “discrete” or “continuous”. When the variable is “discrete” or discontinuous, the state of the node is simply selected (e.g. Yes or No, Good or Bad), whereas when the variable is “continuous” a precise numerical values are used. The probability table defines the likelihood of each state if findings are not entered in terms of data. There is no need to fill in the probability tables if a case file with data is incorporated. Data will only fill in all combinations of parent node states if the data also contains all of these combinations. Therefore, the number of states should be as few as possible and probability tables simple. In this Bayesian fisheries model, the nodes Flood beginning, Flood duration and Flooded vegetation are discrete and all others are continuous. For more information about the options and about using Netica, see the Netica User Manual (Norsys), which is also available online at www.norsys.com.

Setting up the exact thresholds and states is absolutely essential in the Bayesian model. The parent node states will directly affect the child nodes. Incompatible or impossible combinations (in nature) can be left out of the probability calculations by marking them with “x” in the corresponding probability table.
3.2 Input of data to model

After the initial model was reviewed, a number of precise questions were raised at the stakeholders consultation on the 9th of April, 2004. The purpose of these questions was to find thresholds for the nodes and to gather information about and justifications for the relationships between the nodes. The results from the stakeholders consultation were incorporated into the model wherever possible. However, some of the thresholds defined by the stakeholders could not be used due to differences in the data ranges and datasets.

Data was entered into the Bayesian model by importing data as a text file with values in textual and numerical form (the command in Netica: Relation/Incorp Case File). This ensures optimal data accuracy because the model will directly calculate the probabilities from the data. Also, changing the parameterisation and thresholds then becomes much easier. For an example of an input file see Table 10. A series of input files was created in order to assess the suitability of slightly different datasets for modelling purpose. The comparisons can be seen in annex 1.9. The differences within nodes are small, but a better picture of the differences can be obtained after the next stakeholders consultation because parameters and thresholds for the nodes are still largely to be set by the stakeholders.

The same input file must be used for all data on connected nodes. Otherwise, Netica will not automatically calculate the probabilities for the probability table. For example, Tonle Sap rainfall, Tonle Sap runoff, Rived inflow, Overland flow and Tonle Sap water level have to be in the same input file (as well as...
Floodplain dissolved oxygen). The Flooded vegetation node probability table is filled in manually.

Table 10 Example of the input file format. Code (// ~->[CASE-1]->~) is required by the software in order to identify the file as an input file for probabilities.

<table>
<thead>
<tr>
<th>IDnum</th>
<th>PK_Flow</th>
<th>TS_Rainfall</th>
<th>Water_level</th>
<th>Flood_duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>35561</td>
<td>*</td>
<td>9.9</td>
<td>Shorter</td>
</tr>
<tr>
<td>1992</td>
<td>26758</td>
<td>*</td>
<td>8.3</td>
<td>Shorter</td>
</tr>
<tr>
<td>1993</td>
<td>33704</td>
<td>*</td>
<td>8.2</td>
<td>Shorter</td>
</tr>
<tr>
<td>1994</td>
<td>36535</td>
<td>*</td>
<td>10.4</td>
<td>Shorter</td>
</tr>
<tr>
<td>1995</td>
<td>39309</td>
<td>1597</td>
<td>9.6</td>
<td>Shorter</td>
</tr>
<tr>
<td>1996</td>
<td>43910</td>
<td>1389</td>
<td>9.5</td>
<td>Longer</td>
</tr>
<tr>
<td>1997</td>
<td>40897</td>
<td>1047</td>
<td>9.1</td>
<td>Shorter</td>
</tr>
<tr>
<td>1998</td>
<td>22110</td>
<td>1304</td>
<td>7.1</td>
<td>Shorter</td>
</tr>
<tr>
<td>1999</td>
<td>35718</td>
<td>1400</td>
<td>9.0</td>
<td>Longer</td>
</tr>
<tr>
<td>2000</td>
<td>47732</td>
<td>1345</td>
<td>10.3</td>
<td>Longer</td>
</tr>
<tr>
<td>2001</td>
<td>48488</td>
<td>1342</td>
<td>10.0</td>
<td>Longer</td>
</tr>
<tr>
<td>2002</td>
<td>49466</td>
<td>1311</td>
<td>10.2</td>
<td>Longer</td>
</tr>
<tr>
<td>2003</td>
<td>33753</td>
<td>979</td>
<td>8.4</td>
<td>Longer</td>
</tr>
</tbody>
</table>

3.1.1 Tonle Sap Rainfall

As can be seen from the data the driest months are December to February with average total rainfall only 56 to 113 millimetres per month (annex 1.2). March and April are relatively dry, but also can have quite high levels of precipitation due to convective rainstorms (also called mango rains). However, these rains have a very limited impact on the water level of the Tonle Sap. Standard deviation is the highest for the period of August to November showing that the main variability in total precipitation per hydrological year comes from the rainiest months (August to October). Because of the importance of rainy season precipitation to flood level as well as to the total variation in hydrological year precipitation levels it was decided to use data from rainy months only (June to December).

The third stakeholders consultation recognised 1996, 2000, 2001 and 2002 as years with high rainfall and flooding (Hort, et al., 2004). This is largely true (Figure 1), but precipitation in year 2002 was almost the same as in 1998, which is also the lowest flooding year in the records. Therefore, it was decided to use two states for the Tonle Sap rainfall node in the Bayesian model, Above 1000 mm and Below 1000 mm (average rainfall over records). In addition, an input file for the whole rainfall data was prepared even though the reliability of pre-1996 rainfall data is questionable. These thresholds were agreed upon in the fourth stakeholders consultation (Baran, 2004).
3.1.2 Tonle Sap Runoff, Mekong flow and Overland flow

The relationship between Tonle Sap runoff, River inflow and Overland flow discharges (Figure 10) was analysed and tested statistically. As can be seen from the figure Mekong flow and overland flow correlate with each other quite closely. The statistical Pearson correlation $R^2 = 0.826$ between the variables is reasonably high. There are exceptions, though. For example, overland flow is much higher than average and Mekong flow lower than average in 1994 (Table 2). Similarly, 1995 Mekong flow is above average when overland flow is below average. Runoff does not correlate with overland flow ($R^2 = 0.365$), and neither do runoff and Mekong flow ($R^2 = 0.018$). The relationship between water level at Kampong Loung and the combined discharge of Mekong flow, overland flow and runoff (Figure 11) correlate very strongly ($R^2 = 0.987$).

![Figure 12](image-url)

**Figure 12** Comparison between total rainy season discharge shares of Mekong flow, Overland flow and Runoff (Tonle Sap).
At first a threshold for discharges and runoff with a 1/5 return period (see annex 1.8) was used to determine the extreme parameters of the node (High and Low) because these parameters correspond with the high flood years (1996, 2000, 2001 and 2002) identified in the third stakeholders consultation (Hort, et al., 2004). Also, the 1998 dry hydrological year supports the Low parameter (see Table 2). However, because the Medium parameter is required (otherwise, it is not present at all in the Tonle Sap water level node) the probability table expands close to an unmanageable size and also introduces an impossibility factor: it is physically impossible (in the Tonle Sap system) for the River inflow discharge to be High and Overland flow discharge to be Low, because these two nodes are interlinked (i.e. high discharge at Prek Kdam is caused by high water levels on the Mekong, which also causes high overland flow). When these combinations are included in the probability table they distort the ultimate probabilities of the child node (Tonle Sap water level) therefore reducing the accuracy and reliability of the model.

In order to test the model framework and overcome these problems it was decided to simplify the parameters. A method used was to select only two parameters for each node, Above mean (average) and Below mean. As discussed above it is possible to have River inflow as Above mean and Overland flow as Below mean. In addition, this reduces the size of the probability table in Tonle Sap water level and therefore strengthens the probabilities. These thresholds were agreed upon in the fourth stakeholders consultation (Baran, 2004).
3.1.3 Tonle Sap water level

In the second stakeholders consultation, the thresholds for Water level at K. Chhnang were set as Above 11m, Between 10 to 11m and Below 10m (Hort and Baran, 2004). However, it was decided to use Kampong Loung as a reference water level for the lake, and therefore these thresholds are no longer valid. The average difference between Kampong Chhnang and Kampong Loung is +25 centimeters (Garsdal, personal communication). However, changing Above 11m to Above 10.75m is futile, because in the records used the water level has never reached 10.75 meters at Kampong Loung. Therefore, it was decided to change the thresholds into Above 9m and Below 9m (average maximum water level at Kampong Loung on record). The frequency distribution of the water level at Kampong Loung can be seen in annex 1.8. The parameters and thresholds were finally defined more precisely in the fourth stakeholders consultation (Baran, 2004). The states agreed upon are Above 10m, From 8 to 10m and Below 8m. These correspond well with stakeholders's expert views about the functioning of the Tonle Sap system and the response in fish and agricultural production.

3.1.4 Flood beginning and duration

The third stakeholders consultation set the threshold for Flood beginning to a 10 centimetre daily increase in the water level at Kampong Chhnang (Hort, et al., 2004). In the interpretation of the daily water level difference values, it was also checked that the water level continued rising after this threshold was reached (annex 1.5.1). On many occasions the water level actually dropped significantly after the threshold was reached. In these cases, the threshold was set after a steady rise in the following months could be seen. For the end of the flooding, it was decided to use the first negative value (receding flood), because the threshold set in the third stakeholders consultation (receding less than 2 to 5 centimetres per day) in most cases took place around February (Hort, et al., 2004). This extended the duration of the flood too long (approximately 6 months) compared to the duration set in the second stakeholders consultation (Hort and Baran, 2004) of Long (over 13 weeks), Medium (5 to 13 weeks) and Short (less than 5 weeks).

At Prek Kdam the flow towards the Tonle Sap Lake can reverse several times in a short period of time due to the delicate balance between Mekong flow, overland flow and water level at the lake. In order to define only one moment in time at which the flow reverses at Prek Kdam a threshold of 1000m³/s was used. The threshold eliminated most of the numerous minor reversals back and forth in the May to June period. The end of the reversal is very sharp and therefore the first negative value could be used.

By analysing the results (Table 11) of a comparison between the three different methods of determining Flood beginning and Flood duration nodes, it was decided to use flow reversal at Prek Kdam as the data for the Bayesian model. The original data for flow reversal (MIKE11 output) seems to be the most
reliable, the time series the longest, and the results (for Flood duration) closest when taking into account what stakeholders decided in the second consultation (Hort and Baran, 2004). However, input files for the Bayesian model with daily values and averaged weekly values has also been prepared for comparison purposes. For Flood beginning and Flood duration the parameters were changed into Below and Above average. The average value depends on the dataset used (Table 11).
### Table 11

Flood beginning and duration derived from weekly averages of daily water level difference data, directly from daily difference data and flow reversal dates from Prek Kdam discharge data.

<table>
<thead>
<tr>
<th>Data Year</th>
<th>Kampong Chhnang</th>
<th>Prek Kdam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekly averages</td>
<td>Daily differences</td>
</tr>
<tr>
<td></td>
<td>Beginning</td>
<td>End</td>
</tr>
<tr>
<td>1985</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td></td>
<td></td>
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<tr>
<td>1990</td>
<td></td>
<td></td>
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<tr>
<td>1991</td>
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<td></td>
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<td>1992</td>
<td></td>
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<td>1993</td>
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<td>1994</td>
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<td></td>
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<td>1995</td>
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<td>1996</td>
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<td></td>
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</tr>
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<td>2003</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Beginning</th>
<th>End</th>
<th>Duration</th>
<th>Beginning</th>
<th>End</th>
<th>Duration</th>
<th>Beginning</th>
<th>End</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>1-Aug</td>
<td>24-Oct</td>
<td>19</td>
<td>24-Jun</td>
<td>18-Oct</td>
<td>22</td>
<td>6-Jul</td>
<td>9-Oct</td>
<td>18</td>
</tr>
<tr>
<td>Min</td>
<td>16-May</td>
<td>26-Sep</td>
<td>12</td>
<td>15-May</td>
<td>27-Sep</td>
<td>15</td>
<td>23-May</td>
<td>15-Sep</td>
<td>11</td>
</tr>
<tr>
<td>St Dev</td>
<td>25.4</td>
<td>8.4</td>
<td>2.7</td>
<td>14.1</td>
<td>7.1</td>
<td>2.1</td>
<td>12.9</td>
<td>7.1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

In the fourth stakeholders consultation, flood beginning and flood duration parameters and states were defined more clearly (Baran, 2004). The thresholds suggested in the third stakeholders consultation did not fit with the data used. Therefore, it was decided to use water spilling onto the floodplain as a threshold for flood beginning. However, the natural levee around the lake (Koponen et al., 2003b) is not visible in the Certeza Survey (1964) contour lines, and this part of the floodplain was not included in the Hydrographic Atlas (1998) bathymetric survey of the lake. On the other hand, the MRCS/WUP-FIN undertook some depth measurements between the open lake and the floodplains. Unfortunately, this data was not available in time for this report, but it should be included in the future. Thus, another method had to be used to extract thresholds for the flood beginning node. In the fourth stakeholders consultation it was agreed that an early flood is Before 15 July, a medium flood Around 1 August, and a late flood After 15 August. The water level at Kampong Loung for these dates and for each hydrological year was checked (Table 12). A threshold of four meters for flood beginning was chosen. When water level at Kampong Loung is 4 meters, the level at Snoc Trou (Northwest end of the lake) approximately 3 meters, and...
at Kampong Chhnang approximately 5 meters (Eloheimo et al., 2002a). Thus, years regarded as late flood (1998) and early flood (2000 to 2002) coincide with the states derived from data.

Table 12 Flood beginning and Flood duration states used for Bayesian model input based on stakeholders consultation and water level data from Kampong Loung and discharge at Prek Kdam. 4 meter threshold used to mark the beginning of flooding. Flood duration calculated from timespan between Flood beginning and flow reversal in the Tonle Sap River at Prek Kdam towards the Mekong.

<table>
<thead>
<tr>
<th>Year</th>
<th>15 July</th>
<th>1 August</th>
<th>15 August</th>
<th>Bayesian Belief</th>
<th>Network state</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>4.7</td>
<td>5.3</td>
<td>6.3</td>
<td>Before_mid_July</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>3.9</td>
<td>4.9</td>
<td>5.9</td>
<td>Mid_July_to_mid_Aug</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>2.9</td>
<td>3.9</td>
<td><strong>4.2</strong></td>
<td>After_mid_Aug</td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>2.8</td>
<td>3.7</td>
<td><strong>4.7</strong></td>
<td>After_mid_Aug</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>3.2</td>
<td><strong>4.4</strong></td>
<td>5.7</td>
<td>Mid_July_to_mid_Aug</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>5.1</td>
<td>6.0</td>
<td>6.9</td>
<td>Before_mid_July</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>3.7</td>
<td>5.2</td>
<td>6.3</td>
<td>Mid_July_to_mid_Aug</td>
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<tr>
<td>1992</td>
<td>2.8</td>
<td><strong>4.0</strong></td>
<td>5.3</td>
<td>Mid_July_to_mid_Aug</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>3.4</td>
<td><strong>4.9</strong></td>
<td>5.7</td>
<td>Mid_July_to_mid_Aug</td>
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<td>1994</td>
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<td>6.7</td>
<td>8.0</td>
<td>Before_mid_July</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>3.3</td>
<td><strong>4.7</strong></td>
<td>6.0</td>
<td>Mid_July_to_mid_Aug</td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>2.9</td>
<td><strong>4.2</strong></td>
<td>5.6</td>
<td>Mid_July_to_mid_Aug</td>
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<th>Weeks</th>
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<th>Network state</th>
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<tr>
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<tr>
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<td>2000</td>
<td>22-Sep</td>
<td>69</td>
<td>10</td>
<td>Around_8_weeks</td>
<td></td>
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</table>
The fourth stakeholders consultation decided that flooding ends when flow reverses in the Tonle Sap River at Prek Kdam (Baran, 2004). This data was used with the three different flood beginning dates to calculate flood duration (Table 12). The states had to be changed slightly in order to accommodate both the data and stakeholders views. None of the floods were longer than 13 weeks or less than 5 weeks as noted in the third stakeholders consultation (Hort and Baran, 2004). Therefore, states Less 6 weeks, Around 8 weeks and More 11 weeks were used for Flood duration node.

The values are somewhat vague and should be defined more precisely in the future. However, there was much uncertainty and disagreement about how to define both Flood beginning and Flood duration, because these terms mean very different things to people depending on occupation, spatial and temporal distribution, etc.

3.1.5 Floodplain vegetation

Percentages of the land use classes (Forest, Shrub and Grass) were first calculated from the data for 1 meter to 9 meter elevation and 1 meter to National Road. The 9 meter contour line of the Certeza Survey (1964) quite accurately corresponds with the 9 meter water level at Kampong Loung. In the fourth stakeholders consultation states for Tonle Sap water level were changed and therefore new percentages were calculated for Flooded vegetation. These can be seen in Table 13. The percentages were manually filled in to the probability table.

<table>
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<th>Land use</th>
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<th>Shrub</th>
<th>Forest</th>
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<td>42.3</td>
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<td>1-road</td>
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<td>37.4</td>
<td>1.8</td>
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</table>

3.1.6 Floodplain dissolved oxygen

Hellsten et al. (2003) conducted a study on habitats in the floodplain. According to them flooded forest, flooded shrubs, grassland and aquatic vegetation grow largely on organic deposits of up to 6 meters elevation (Certeza Survey contour lines, 1964). This would suggest that there is more decay in these areas than in others. However, the parameters and thresholds have to be set from the combination of Tonle Sap water level and Flooded vegetation. As mentioned earlier, the higher the flood the more dilution of anoxic water and mixing of
oxygen into the water take place. Flooded vegetation on the other hand has direct relation to the quantity of anoxic water produced by decaying vegetation. The MRCS/WUP-FIN water quality model produced output data on the relationship between dissolved oxygen and floodplain vegetation type.

The results give percentages of the average time over the flooding season for dissolved oxygen levels in three categories; Above 4mg/l, From 2 to 4mg/l and Below 2mg/l. These categories were determined from literature and by interviewing aquaculture experts. They relate to conditions which are tolerable or intolerable for general black and white fish categories. The model was run with 1997, 1998 and 2000, of which 1998 was a low flood, 1997 average flood and 2000 high flood. Therefore probabilities could be connected with Tonle Sap water level node directly as the sample years relate with the states of the water level node. Results and input data for the Bayesian model can be seen in table 14 below.

Table 14 MRCS/WUP-FIN output percentages for dissolved oxygen levels in the floodplain detailed per year (different flood height), land use and dissolved oxygen concentration.

<table>
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<th>2 - 4</th>
<th>&gt; 4</th>
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<td>shrub</td>
<td>72</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>forest</td>
<td>37</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>From 8 to 10m flood (1997)</td>
<td>grass</td>
<td>51</td>
<td>28</td>
<td>21</td>
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<td></td>
<td>forest</td>
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<td>37</td>
<td>37</td>
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<td>Above 10m flood (2000)</td>
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<tr>
<td></td>
<td>forest</td>
<td>32</td>
<td>53</td>
<td>15</td>
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</table>

The MRCS/WUP-FIN model produced percentages for near bottom, middle and surface depths of the water column as well as an average. Because the fish tend to move and migrate away from anoxic areas, and therefore no single depth is more important than the others, it was decided to use the average of the water column for Floodplain dissolved oxygen node probabilities. An example of the depth distribution can be seen in figures 12-14 below.
**Figure 12** Comparison between 1997 *Grass* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

**Figure 13** Comparison between 1997 *Shrub* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

**Figure 14** Comparison between 1997 *Forest* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.
From the figures it can be seen that forest has the best dissolved oxygen ranges, with only near bottom depth having over 50% Below 2mg/l levels. Shrub has the worst levels, clearly affected by the large amount of decaying material produced by shrubs. For grass land use type surface and middle depths are pretty good in terms of dissolved oxygen levels, probably due to wind induced mixing, but near bottom depth levels are not good for fish.
4 Notes about linkages

4.1 Flooding for agriculture

Floating rice cultivation largely takes place between floodplain elevations of 6 to 8 meters (corresponding to the same water level on the lake) whereas wet season rice cultivation takes place around 5 meters elevation and is located on lake bed and deltaic deposits (Hellsten et al., 2003). According to Hellsten et al. (2003) there has been a slight increase in rice production around the lake in recent years. Importantly, wet season rice totals up to 90% of the production and floating as well as recession rice cultivation have a minor role. Therefore, a level of flooding that affects wet season rice production at water levels around 5 meters should be considered critical here, because of the minor importance of floating rice below 5 meter elevation. Moreover, the duration and timing of floods affect agricultural activities as transplanting takes place from July to August and harvesting from November to December (Hellsten et al., 2003). For example, an early flood can cause crop damage but is good for fish productivity (Hort, 2004).

4.2 Tonle Sap Agricultural production

Rain fed lowland rice is almost completely dependent on rainfall and runoff water (Hellsten et al., 2003). Therefore, stakeholders (agriculturalists) should be asked to define more precise rainfall thresholds for agriculture. Because there is a new node ([Tonle Sap runoff]) between [Tonle Sap rainfall] and [Tonle Sap water level], using more parameters would not render the [Tonle Sap water level] probability table too complicated.

4.3 Number of farmer fishers

In the third stakeholders consultation the link between high floods and farmer fishers was discussed (Hort, et al., 2004). High floods can destroy crops and thereby drive people towards more fishing. This can have a significant effect on the fisheries. Both agriculture and fisheries experts should be interviewed to define this link more precisely.
5 Conclusions

5.1 Data

Overall, the accuracy and availability of data was identified as an important issue. Hydrological data from the Tonle Sap Lake and floodplain has a number of shortcomings. Pre-1975 data is unreliable and impossible to verify, and because of this and possible changes in the Mekong hydrological regime (e.g. effects of upstream dam building) it is not very representative of the present situation. For almost all of the stations, there is a gap in measurements between 1975 and the mid-1990s. Only datasets measured and produced after 1996 can be seen as reliable and representative of the present situation. Therefore, most effort was directed to analysis and utilisation of post-1996 data. In addition, the best existing fisheries data are from the Dai fisheries for the period of 1995 to 2000. When combining the fisheries data with the hydrological, land use and water quality data it is possible to check how well the model runs on a smaller scale (without detailed fisheries activities and the agricultural sector). Due to the complex relationships between flow directions, volumes and water levels between the Tonle Sap Lake and the Mekong, the use of the MIKE11 flow reversal model output data was appropriate. This provides the latest data available on the hydrological interactions between the Mekong and the Tonle Sap and the best way to estimate probabilities of nodes representing different water inflows to the lake.

The utilisation of land use data was straightforward because only one dataset exists and it is regarded as both reliable and accurate. On the other hand, water quality measurements from the lake and floodplain were analysed and it was clear that point measurements cannot represent the different floodplain vegetation classes over the whole lake. Therefore, it was seen that using output data from the MRCS/WUP-FIN water quality model to evaluate proportions of dissolved oxygen in different land use areas would be beneficial. Unfortunately, the model output data was not ready in time for the report, but the data will be incorporated as soon as it becomes available.

5.2 Results

The reliability of the nodes on hydrology, water quality and land use were strengthened by entering probabilities based on data into the model. The reliability of the interactions between these nodes was also strengthened in this way. After the results from this data analysis study have been presented, the data in the model will aid stakeholders to decide upon parameters and thresholds in a more quantitative way. All hydrological nodes as well as Flooding vegetation have data to define probabilities. The thresholds were set by the stakeholders
thereby incorporating expert knowledge. Compromises had to be made to accommodate data limitations and stakeholders expertise into a dataset with proper thresholds. In addition, the structure of the model had to be kept as simple as possible due to data limitations and to ensure the model is manageable. Overall, the probabilities interact in the way expected and correspond to the physical nature of the lake (e.g. choosing Below 7600 state for Overland flow node reduces probabilities of More than 10m in Tonle Sap water level node. Another example is how Above 1000 state for Tonle Sap rainfall node increases the probability of Above 7600 state for Tonle Sap runoff node and More than 10m state for Tonle Sap water level node. A more thorough study of the accuracy should be performed once the stakeholders expertise and fisheries data has been incorporated into the model system as parameters and thresholds.
6 References


Ith, S. (7.4.2004). *Personal communication*. Director, Geography Department, Phnom Penh, Cambodia.


Sarkkula, J. (7.4.2004). *Personal communication*. Team Leader, MRCS/WUP-FIN, Phnom Penh, Cambodia.


1 Annex

1.1 Data collection

List of data requested from the MRCS for the Bayesian Belief Network fisheries modelling activities:

1. Water level data (daily) corrected to same datum level and used as the DSF model input data. The recordings requested are for the entire period of record from the following stations:

   H 14901 Mekong River at Kratie
   H 20106 Tonle Sap Lake at Kampong Loung
   H 20101 Tonle Sap River at Phnom Penh Port
   H 20102 Tonle Sap River at Prek Kdam

2. Water level data (daily) recordings requested are for the entire period of record from the following station hold at the MRCS/WUP-FIN database:

   H 20103 Tonle Sap River at Kampong Chhnang
   H 20106 Tonle Sap Lake at Kampong Loung

3. MIKE11 model output data 1984-2003 produced in the MRCS/WUP-JICA & TSLV Flow Reversal study for the following: Water level at 20106 (Kampong Loung), discharge at 14901 (Kratie) and 20102 (Prek Kdam) and overland flow.

4. Average rainfall data for sub-catchments of the Tonle Sap catchment edited and checked in the MRCS/WUP-JICA & TSLV project. We would like daily precipitation data for the period of 1980 to 2003.

5. JICA (1999) land cover data and calculations from the Tonle Sap floodplain edited by MRCS/WUP-FIN for floodplain vegetation/habitat and water level analysis purposes. In addition, JICA (1999) Geographical Information Systems layers on topography (1:100 000), road networks, administrative borders and population centres are requested from MRCS/WUP-FIN.

6. MRCS/WUP-FIN water quality model output data on dissolved oxygen levels in the Tonle Sap Lake and Floodplain.


8. MRCS/WUP-FIN database on dissolved oxygen measurements in and around the Tonle Sap Lake from 1995 to 2003.

9. Tonle Sap Lake water balance calculations by the MRCS/WUP-FIN and MRCS/JICA & TSLV.
### 1.2 Tonle Sap rainfall

Table 15 Hydrological year precipitation monthly averages, annual averages and data statistics (mm).

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<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
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1.3 Discharge data

1.3.1 Mekong flow

Table 16 Mekong flow (Million Cubic Meters) monthly average discharge at Prek Kdam from 1985 to 2003. Negative values indicate flow towards the Mekong and positive values flow towards the Tonle Sap Lake.

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## 1.3.2 Overland flow

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### 1.4 Water level at Kampong Loung

#### 1.4.1 Water level data gaps in Kampong Loung and Kampong Chhnang

Based on Eloheimo *et al.* (2002a).

**Kampong Loung Gaps:**
- Sep. - Dec., 1960: 122 days
- Jan. – May, 1996: 151 days
- Dec. 3, 4, 31, 1996: 3 days
Aug. 30, 1997 - June, 1998  305
Dec., 1998 31
Feb. 28, Mar. 5, 1999  2
May 3 - 4, 1999  2
Dec, 2000 31
Altogether  850 days

Kampong Chhnang Gaps:
Aug. - Dec., 1956  153 Days
Nov. 2, 1957 1
Sep. 1 - Oct. 9, 1961  39
Mar. 15 - 21, 1963  63
Sep. 2 - 5, 1963  63
Oct. 20 - Nov. 8, 1963 20
Dec. 26 - 31, 1963 6
Jan. 1 - 22, 1964 22
Sep. 28 - Oct. 14, 1964 17
Aug. 16 - Dec. 31, 1967 138
Aug. - Dec., 1970 153
Aug., 1971 31
Nov. 16, 1971 - Jan. 11, 1972  57
Feb. 1 - Apr. 1, 1972  61
May 29 - Jun. 15, 1972 18
Oct., 1972 31
Jan. – Jun. 19, 1982 170
Feb. - May 6, 1984 95
Apr. 26 - 30, 1985 5
Oct. – Nov. 1985 61
Mar. - Sep., 1986 214
Dec. 1986 – 1987 396
Feb. - May 6, 1988 95
May 11 – Jun. 11, 1996 32
Nov. 12 – Dec. 12, 1996 31
Jun. 23 - 30, 1998 8
Aug. 1998 31
Oct. - Dec., 1998 92
Jan. 16, 21, 26, 1999  3
Feb. 28, 1999 1
Apr. 20, 21, 26, 1999 3
Dec. 31, 1999
Altogether  2526 Days
1..4.2 Water level at Kampong Loung

Table 18 Monthly maximum water levels (meters) for Kampong Loung from 1985 to 2003.

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1.4.3 Comparison of different Kampong Loung datasets

**Table 19** Comparison of Kampong Loung average monthly water level (meters) between simulated MIKE11 model output, Ha Tien datum corrected and original measured data.

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**Figure 14** Comparison of average monthly water levels between MIKE11 model output, Ha Tien datum corrected and original measured data for the year 2001.
1.5 Flood beginning and duration

1.5.1 Kampong Chhnang daily water level difference

Table 20 Daily Kampong Chhnang water level difference (meters). Beginning and end of flood is marked in bold, possible inaccuracies in the data are highlighted.

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1.5.2 Kampong Chhnang weekly average water level difference

Table 21 Average weekly water level difference in Kampong Chhnang calculated from daily water level difference data (meters). The beginning and end of flooding is marked in bold.

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### 1.6 Land use

#### 1.6.1 JICA land use classes

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<td>2</td>
<td>Urban, Built-up areas</td>
<td>Infrastructure (Airfield, factory, etc.)</td>
</tr>
<tr>
<td>3</td>
<td>Agricultural lands</td>
<td>Paddy field</td>
</tr>
<tr>
<td>4</td>
<td>Agricultural lands</td>
<td>Receding and Floating rice fields</td>
</tr>
<tr>
<td>5</td>
<td>Agricultural lands</td>
<td>Field crop</td>
</tr>
<tr>
<td>6</td>
<td>Agricultural lands</td>
<td>Swidden agriculture (Slash and burn)</td>
</tr>
<tr>
<td>7</td>
<td>Agricultural lands</td>
<td>Orchard</td>
</tr>
<tr>
<td>8</td>
<td>Agricultural lands</td>
<td>Plantation (Rubber plantation)</td>
</tr>
<tr>
<td>9</td>
<td>Agricultural lands</td>
<td>Village garden crop</td>
</tr>
<tr>
<td>10</td>
<td>Agricultural lands</td>
<td>Garden crop</td>
</tr>
<tr>
<td>11</td>
<td>Agricultural lands</td>
<td>Paddy field with villages</td>
</tr>
<tr>
<td>12</td>
<td>Grasslands</td>
<td>Grassland (Undifferentiated)</td>
</tr>
<tr>
<td>13</td>
<td>Grasslands</td>
<td>Abandoned field covered by grass</td>
</tr>
<tr>
<td>14</td>
<td>Grasslands</td>
<td>Flooded grassland</td>
</tr>
<tr>
<td>15</td>
<td>Grasslands</td>
<td>Grass Savannah</td>
</tr>
<tr>
<td>16</td>
<td>Grasslands</td>
<td>Grass with termite mounds</td>
</tr>
<tr>
<td>17</td>
<td>Grasslands</td>
<td>Marsh and swamp</td>
</tr>
<tr>
<td>18</td>
<td>Shrublands</td>
<td>Shrubland (Undifferentiated)</td>
</tr>
<tr>
<td>19</td>
<td>Shrublands</td>
<td>Abandoned field covered by shrub</td>
</tr>
<tr>
<td>20</td>
<td>Shrublands</td>
<td>Flooded shrub</td>
</tr>
<tr>
<td>21</td>
<td>Shrublands</td>
<td>Woodland and scattered trees (C &lt; 10%)</td>
</tr>
<tr>
<td>22</td>
<td>Forest covers</td>
<td>Evergreen broad leafed forest</td>
</tr>
<tr>
<td>23</td>
<td>Forest covers</td>
<td>Coniferous forest</td>
</tr>
<tr>
<td>24</td>
<td>Forest covers</td>
<td>Deciduous forest</td>
</tr>
<tr>
<td>25</td>
<td>Forest covers</td>
<td>Dry Deciduous (Open) forest</td>
</tr>
<tr>
<td>26</td>
<td>Forest covers</td>
<td>Mixed forest from evergreen and deciduous species</td>
</tr>
<tr>
<td>27</td>
<td>Forest covers</td>
<td>Riparian forest</td>
</tr>
<tr>
<td>28</td>
<td>Forest covers</td>
<td>Bamboo and Secondary forests</td>
</tr>
<tr>
<td>29</td>
<td>Forest covers</td>
<td>Flooded forest</td>
</tr>
<tr>
<td>30</td>
<td>Forest covers</td>
<td>Mangrove forest</td>
</tr>
<tr>
<td>31</td>
<td>Forest covers</td>
<td>Degraded mangrove forest</td>
</tr>
<tr>
<td>32</td>
<td>Forest covers</td>
<td>Forest plantation</td>
</tr>
<tr>
<td>33</td>
<td>Water features</td>
<td>Lakes (&gt;8 ha)</td>
</tr>
<tr>
<td>34</td>
<td>Water features</td>
<td>Lakes (&lt;8 ha)</td>
</tr>
<tr>
<td>35</td>
<td>Water features</td>
<td>Reservoir</td>
</tr>
<tr>
<td>36</td>
<td>Water features</td>
<td>Shrimp/Fish farming and Salt pan</td>
</tr>
<tr>
<td>37</td>
<td>Water features</td>
<td>Others (Sea, bay, etc.)</td>
</tr>
<tr>
<td>38</td>
<td>Soils and Rocks</td>
<td>Barren land</td>
</tr>
<tr>
<td>39</td>
<td>Soils and Rocks</td>
<td>Sand bank</td>
</tr>
</tbody>
</table>
1.6.2 Calculated land use class surface areas according to elevation

Table 23 Surface area (square kilometers) of Bayesian Belief Network land use classes depending on elevation.

<table>
<thead>
<tr>
<th>Water level (m)</th>
<th>Urban</th>
<th>Grass</th>
<th>Shrub</th>
<th>Forest</th>
<th>Water &amp; Soil</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>0.23</td>
<td>241.18</td>
<td>753.81</td>
<td>125.59</td>
<td>1312.68</td>
<td>2433.49</td>
</tr>
<tr>
<td>2-3</td>
<td>0</td>
<td>247.82</td>
<td>625.21</td>
<td>42.33</td>
<td>24.86</td>
<td>940.22</td>
</tr>
<tr>
<td>3-4</td>
<td>0</td>
<td>347.55</td>
<td>810.22</td>
<td>6.62</td>
<td>29.75</td>
<td>1194.14</td>
</tr>
<tr>
<td>4-5</td>
<td>0</td>
<td>405.04</td>
<td>880.88</td>
<td>9.04</td>
<td>18.57</td>
<td>1313.53</td>
</tr>
<tr>
<td>5-6</td>
<td>0</td>
<td>472.48</td>
<td>778.24</td>
<td>9.27</td>
<td>14.99</td>
<td>1274.98</td>
</tr>
<tr>
<td>6-7</td>
<td>0</td>
<td>777.8</td>
<td>387.74</td>
<td>2.83</td>
<td>11.97</td>
<td>1180.34</td>
</tr>
<tr>
<td>7-8</td>
<td>0</td>
<td>1081</td>
<td>131.78</td>
<td>1.52</td>
<td>12.29</td>
<td>1226.59</td>
</tr>
<tr>
<td>8-9</td>
<td>0.23</td>
<td>1251.05</td>
<td>29.92</td>
<td>0.36</td>
<td>8.86</td>
<td>1290.42</td>
</tr>
<tr>
<td>9-10</td>
<td>4.36</td>
<td>981.1</td>
<td>9.09</td>
<td>1.03</td>
<td>5.53</td>
<td>1001.11</td>
</tr>
<tr>
<td>10-road</td>
<td>14.76</td>
<td>1477.3</td>
<td>74.92</td>
<td>17.51</td>
<td>14.75</td>
<td>1599.24</td>
</tr>
<tr>
<td>Total</td>
<td>19.58</td>
<td>7285.74</td>
<td>4482.83</td>
<td>220.53</td>
<td>2830.38</td>
<td>14839.06</td>
</tr>
</tbody>
</table>
1.6.3 Land use class distribution

**Figure 15** Spatial distribution of Bayesian Belief Network model floodplain vegetation, *Forest* parameter for the landuse node.

**Figure 16** Spatial distribution of BBN model floodplain vegetation, *Shrub* parameter for the landuse node.
1.7 Dissolved oxygen

Table 24 Dissolved oxygen (milligrams per liter) statistics by station. Comparison between standard deviation when all stations are selected and when unfit stations (marked bold) have been removed.

<table>
<thead>
<tr>
<th>Station</th>
<th>Average</th>
<th>Max</th>
<th>Min</th>
<th>No. of samples</th>
<th>Years</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNK1</td>
<td>4.34</td>
<td>11.60</td>
<td>0.00</td>
<td>45</td>
<td>2001-2001</td>
<td>2001 from Jul.</td>
</tr>
<tr>
<td>PNK2</td>
<td>6.63</td>
<td>16.50</td>
<td>0.30</td>
<td>68</td>
<td>2001-2001</td>
<td>2001 from Jul.</td>
</tr>
<tr>
<td>PNK4</td>
<td>5.97</td>
<td>8.60</td>
<td>1.40</td>
<td>9</td>
<td>2001-2002</td>
<td>Dec-Jan</td>
</tr>
<tr>
<td>PNK6</td>
<td>5.40</td>
<td>5.60</td>
<td>5.20</td>
<td>2</td>
<td>2002</td>
<td>Jan</td>
</tr>
<tr>
<td>KGL1</td>
<td>5.90</td>
<td>13.10</td>
<td>0.20</td>
<td>136</td>
<td>1995-2001</td>
<td>Almost annual</td>
</tr>
<tr>
<td>KGL2</td>
<td>7.04</td>
<td>13.80</td>
<td>0.10</td>
<td>109</td>
<td>2001-2001</td>
<td>June</td>
</tr>
<tr>
<td>KGL3</td>
<td>4.07</td>
<td>8.90</td>
<td>0.30</td>
<td>10</td>
<td>2001</td>
<td>Aug-Dec</td>
</tr>
<tr>
<td>KCH1</td>
<td>5.40</td>
<td>8.50</td>
<td>2.50</td>
<td>90</td>
<td>1995-2002</td>
<td>Almost annual</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>All stations</th>
<th>Total</th>
<th>521</th>
</tr>
</thead>
<tbody>
<tr>
<td>St Dev</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Selected stations</th>
<th>Total</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>St Dev</td>
<td></td>
<td>0.95</td>
</tr>
</tbody>
</table>
Table 25 Dissolved oxygen percentages from MRCS/WUP-FIN data.

<table>
<thead>
<tr>
<th>Year 2000</th>
<th>Percentage of Dissolved Oxygen levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer</td>
<td>Vegetation</td>
</tr>
<tr>
<td>Vertical averages</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Surface</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Middle depth</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Near bottom</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 1997</th>
<th>Percentage of Dissolved Oxygen levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer</td>
<td>Vegetation</td>
</tr>
<tr>
<td>Vertical averages</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Surface</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Middle depth</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Near bottom</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 1998</th>
<th>Percentage of Dissolved Oxygen levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer</td>
<td>Vegetation</td>
</tr>
<tr>
<td>Vertical averages</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Surface</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Middle depth</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
<tr>
<td>Near bottom</td>
<td>Grass</td>
</tr>
<tr>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
</tr>
</tbody>
</table>
1.8 Hydrological data frequency distributions

**Figure 18** Frequency distribution of Mekong flow (MCM) towards the Tonle Sap Lake from 1985 to 2003.

**Figure 19** Frequency distribution of overland flow (MCM) towards the Tonle Sap Lake from 1985 to 2003.
Figure 20 Frequency distribution of rainy season Tonle Sap tributaries runoff (MCM) from 1985 to 2003.

Figure 21 Frequency distribution of Kampong Loung maximum water level (m) from 1985 to 2003.
1.9 Bayesian Belief Network model output

Table 26 Bayesian Belief Network model output probabilities comparison depending on different datasets used. Only probabilities which changed have been noted in the table.

<table>
<thead>
<tr>
<th>Node</th>
<th>Parameter</th>
<th>Suggested</th>
<th>Long ppt</th>
<th>Daily difference</th>
<th>Weekly difference</th>
<th>Ha Tien</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Good</td>
<td>54.5</td>
<td>57.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bad</td>
<td>45.5</td>
<td>42.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonle Sap Runoff</td>
<td>Above mean</td>
<td>54.1</td>
<td>55.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Below mean</td>
<td>45.9</td>
<td>44.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overland flow</td>
<td>Above mean</td>
<td>42.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Below mean</td>
<td>57.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mekong flow</td>
<td>Above mean</td>
<td>47.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Below mean</td>
<td>52.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonle Sap water level</td>
<td>More 9m</td>
<td>55</td>
<td>55.2</td>
<td></td>
<td></td>
<td>54.7</td>
</tr>
<tr>
<td></td>
<td>Less 9m</td>
<td>45</td>
<td>44.8</td>
<td></td>
<td></td>
<td>45.3</td>
</tr>
<tr>
<td>Flood beginning</td>
<td>Before</td>
<td>47.6</td>
<td></td>
<td>60</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>52.4</td>
<td></td>
<td>40</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Flood duration</td>
<td>Longer</td>
<td>42.9</td>
<td></td>
<td>40</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shorter</td>
<td>57.1</td>
<td></td>
<td>60</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

_Fisheries Component_

**INFLUENCE OF BUILT STRUCTURES ON TONLE SAP FISH RESOURCES**

Prepared by

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LENG Sy Vann\(^2\), PRUM Setha\(^3\), PUM Sok Hourt\(^3\) and Yumiko KURA\(^1\)

\(^1\) WorldFish Center
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\(^3\) Fisheries Administration

December 2006
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INTRODUCTION

1. Fish and fisheries in many tropical river systems are strongly affected by the natural flood regimes and factors that affect these flood regimes (e.g. Welcomme and Halls 2004; Sparks 1995; Junk et al. 1989). These river systems are also subject to a variety of developmental pressures, including modified flow regimes, habitat loss, land use change and intensive exploitation of aquatic resources (Arthington et al. 2004). It is also suggested that in many cases the planning of many such developments has focused on commercial uses of natural resources, such as agriculture, and taken much less account of other uses, such as subsistence fishing (e.g. Islam and Braden 2006; Oosterbaan 1988). In order to mitigate the negative impacts of developmental activities that involve the construction, modification or removal of structures that affect the flood regime it is important therefore to better understand the effects that they have. This study has looked at three types of structures: a large scale irrigation scheme, floodplain road construction and large scale fishing gear in order to provide some insights into these structures that could inform future decision-making.

2. Built structures have the potential to impact, both positively and negatively, all fish species through the variety of effects, both direct and indirect, that they can produce. These effects, including, but not limited to, changes in hydrology, habitats and patterns of exploitation, can impact fish locally, and even result in transboundary impacts. Evidence of the impacts of built structures have mostly centered around the effects of irrigation and hydroelectric schemes and channelling of rivers (e.g. Nguyen-Khoa et al. 2005; Warren 2000; Halls et al. 1999; Bailey and Cobb, 1984; Bernacsek, 1984). These studies suggest that these types of built structures can result in a variety of impacts, often with negative impacts on the fisheries as a result of a reduction in or change to aquatic habitat (including connectivity) or changes to and on fish migration and reproduction. However, some positive effects of irrigation and hydroelectric schemes have also been described, primarily arising from associated higher dry season water levels.

3. Roads can also affect fisheries because they can also alter hydrology and sedimentation regimes, consequently affecting the nature of the aquatic habitats and the fish associated with them (Roni et al. 2005; Gibson et al. 2005; Duke et al. 2003; LaMarche and Lettenmaier 2001; Sidle et al. 1985). Finally, large-scale fishing gears can affect the movement, migration and presence of fish (by design) but may also have less direct effects on fish by affecting water movement, retention and quality (e.g. Kurien et al. 2006).

4. In examining the effect of built structures on fish it is important to understand the nature of the fish species that are being affected. Fish in river-floodplain systems can be categorized as belonging to one of three groups based on their spawning and migratory behavior (see also the fish bioecology-hydrology report). These are white fish (e.g. Cyclocheilichthys sp., Henichorhynchus sp. and Paralaubuca sp.), which migrate upstream to spawn in the main channels and whose fry drift downstream on the currents and then onto the floodplains, black fish (e.g. Channa striata and Anabas testudineus) which are largely resident on the floodplain and which spawn on the floodplain, and finally the grey fish, a group intermediate between black-fishes and white-fishes (Welcomme 2001; Lévêque and Paugy 1999). Species of this group undertake short migrations between the floodplains and adjacent rivers and tributaries and may also make similar short migrations between permanent and seasonal floodplain water bodies (Welcomme 2001).
5. White fish, because of their more complex spawning and recruitment requirements are considered to be the group that could most easily be affected by hydrological modifications as they are widely distributed, vulnerable to changes to the main channel and, along with the other types, to floodplain modifications, and, in addition, require connectivity between habitats (e.g. Poulsen et al. 2002).

I METHODS AND TOOLS

I.1 APPROACH AT THE BASIN AND SUB-BASIN SCALES

6. At the Mekong Basin and Tonle Sap sub-basin levels, this project did not make plans for specific fieldwork, so conclusions are based on previous work and a literature review.

I.2 APPROACH AT THE LOCAL SCALE

7. At the local level, the fisheries component has been designed to provide information that will complement the information generated from the other components and thereby contribute to the overall assessment. Based on discussions between components, the specific objectives of the fisheries surveys were identified as:
   1. Identify how built structures have modified:
      a) habitats (created/increased/reduced)
      b) fishing opportunities, including changes in access to habitats
      c) fish catches and fish populations
   2. Generate new information on fish ecology in the Tonle Sap

8. The survey has been designed to generate general information on these aspects rather than providing detailed quantitative information. Where such quantitative information is required it was suggested that supplemental questions should be integrated into the household surveys being undertaken through the livelihoods and socioeconomic components.

9. Three sites were selected for the study: an irrigation scheme at Stung Chinit, a large scale fishing gear at Prek Toal and rural roads in Pursat. Stung Chinit was selected as there are two major environmental concerns associated with such schemes: the impact of barriers on migratory fish and the impact of the use of pesticides and fertilisers in the project area. Unfortunately, because the scheme only started operating earlier this year it is too soon to be able to look at the effect of agricultural inputs and the study concentrated on the first concern. This should provide useful information that can be used by planners considering irrigation schemes.

10. Pursat is the site of many proposed developments, including irrigation developments, roads and canals. Given the relatively flat nature of the area, constructions that divert or retain water could have quite significant local hydrological effects. Studying the effect of the rural road structure at this site could provide useful insights into the effect of such potential barriers on fisheries and how these effects can be enhanced (if positive) or mitigated (if negative), which could be useful during the implementation of the planned developments.
11. The extensive fishing gears (a 35km long bamboo barrage) at Fishing Lot #2 near Prek Toal serve to concentrate the fish leaving the floodplain making them easier to catch. Given the extent of the gears it is possible that they could significantly affect local hydrological regimes, fish species and local livelihoods (e.g. Kurien et al. 2006). While these gears are also present at other fishing lots, the productivity of the area around Prek Toal makes this a most suitable site at which to study the effects of the structure.

12. The type of structure and its operation meant that the approach taken by the fisheries component survey team differed at each site. For Stung Chinit, a site containing a recently completed built structure, the survey concentrated on identifying the changes and effects due to the structure by comparing the fisheries situation before and after completion. For Prek Toal, where the structure has been in use for a long time, the survey team also surveyed a nearby area that was managed without a similar structure to identify differences in fishing practices and outcomes that could be attributed to the structure. Finally, in Pursat a mixed approach was taken by comparing the situation before and after with villagers who might be directly affected by the structure, and also comparing villagers nearby who were not affected by the structure.

13. A major issue that had to be carefully considered in developing the survey methodology and content was the clear trade-off between the quantity and detail of the information collected on the one hand and the needs of the participating fishers on the other. In particular the methodology was developed with the aim of keeping the respondents engaged in order to enable discussions to develop and answers to be explained. It was important that the fishers were not allowed to get bored and were not kept too long as if the respondents get bored or restless the quality of information is likely to suffer (e.g. Silver and Campbell 2005).

14. Given this approach, a methodology was developed that could generate information related to the objectives by utilizing the detailed time and place knowledge of local expert fishers. The types of information to be collected are directly related to the objectives and based on subject areas identified by the domestic fisheries specialist.

15. In accounting for the fact that the fish fauna in Cambodian inland waters comprise a mixture of black, white and grey fish, a bio-ecological review was undertaken that involved merging the FishBase and MRC Mekong Fish databases, a method similar to that employed by Baran et al. (2005) for Lao PDR, and using information from a number of other sources (see Annex A). The aim of this was to identify homogenous groups (“guilds”) of fish species that have similar ecological conditions and that are thus likely to be similarly influenced by built structures. With regard to fish catches, populations and ecology, the methodology incorporates the materials developed by the domestic fisheries specialist from the review of bio-ecological information on Tonle Sap Lake fish species.

I.3 METHODOLOGY AT THE LOCAL SCALE

16. It is well recognized that fishers and others dependent upon natural resources have a wealth of time and place knowledge that can be valuable for management decision-making within fisheries (e.g. Jentoft 2000; Bergmann et al. 2004; Dubois 2005; Garaway et al. 2006; Wilson et al. 2006). The survey methodology therefore sought to access local ecological knowledge relating to each of the specific survey objectives.
17. In gathering local ecological knowledge, experiences have suggested that the use of closed, questionnaire type surveys are less appropriate and that less structured, and more visual, participatory appraisal type methodologies have been suggested (e.g. Pido et al. 1996). However, these methodologies require a certain level of skill and familiarity with their use if they are to be successful.

18. As a result of pre-testing of methodologies, a survey methodology was developed that was comfortable for the data collectors to use and that included elements of both formal questionnaires as well as visual methodologies, such as mapping and the use of fish picture cards for species identification (see Annex B). The actual survey at each site was preceded by a pre-survey that was intended to see if there were any additional factors that would need to be accounted for in the full survey and to identify the respondent groups who would provide the information. The results from the pre-surveys are provided in Annex C. During the pre-survey, criteria were developed that could be used at each site to identify suitable fishers and help ensure that the information that they were able to provide covered an adequate time period and geographical area. The criteria for selection of expert fishers were as follows:

- between 40 and 60 years old;
- having 10-15 years fishing experience;
- currently actively fishing;
- well-known for fishing skills in the village, and
- fishers selected from different locations in the same village to potentially provide information on all fishing locations.

19. The local fisheries officer and village and commune headmen were asked to identify knowledgeable fishers in the survey locations who met the above criteria, and to contact them to see if they would be willing to take part in the surveys in groups of three. This provided a total of between sixty and eighty experienced and knowledgeable fishers for each study site.

20. In order to separate the effect of the built structure from other factors that have been, and are, affecting hydrological conditions and fisheries, respondent groups were asked first about aspects of the fishery, e.g. patterns in fishing effort, changes in fish size and fish prices, and what they thought were the reasons for any observed change. They were then asked what effect they thought that the built structure had had and for their perceptions of the positive and negative impacts of the built structure and how any negative impacts might be mitigated (see Annex B).
II RESULTS

II.1 MEKONG SCALE

II.1.1 Water management basinwide

21. Water coming from the Mekong (either through the Tonle Sap River or overland during floods) represents 60% of the Tonle Sap water (Koponen et al. 2007 and Figure 1). This means that the development of built structures upstream of the Tonle Sap sub-system would have a significant impact on the lake's hydrology.

![Figure 1: Contribution of the Mekong to the Tonle Sap water level (Koponen et al. 2007)](image)

22. In fact Laos contributes 19 percent of Tonle Sap water, and while China and Thailand contribute 9 and 10 percent respectively. This calculation is possible knowing the contribution of each country to the Mekong annual flows (see Table I), the contribution of Mekong flows to Tonle Sap flows (see above) and the share of Mekong annual average flow at the level of Phnom Penh (i.e. 93.3 percent of the total Mekong flow).

Table I: Contribution of riparian countries to Mekong and Tonle Sap flows

<table>
<thead>
<tr>
<th>Country</th>
<th>Contribution to Mekong flows (%)</th>
<th>Contribution to Tonle Sap flows (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laos</td>
<td>35</td>
<td>19</td>
</tr>
<tr>
<td>Cambodia</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Thailand</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>China</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>Vietnam</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>Myanmar</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

II.1.1.1 Mekong flows and built structure development

23. The degree of inundation in the Mekong depends on the strength of the annual monsoon, as 85-90% of the discharge is generated during the wet season. However, the average wet season discharge in the last twenty years (1979-98) appears to be at least 10% lower than in 1924-1956, while the inter-annual variations have become more extreme (Nam Sokleang 2000). The downward trend seems to be independent of fluctuations in rainfall and therefore has been linked to dam building activities that started in the late fifties in the basin (Van Zalinge et al. 2003). White (2000) also identified dams as the projects that pose the highest degree of systematic risk to the region, under criteria that include displacement of vulnerable people, impact irreversibility, environmental impacts on the mainstream river flow and quality, and economic impact.
24. In the Mekong Basin according to the MRC (2003), thirteen hydropower dams of a capacity higher than 10 megawatts existed in 2003: two in China on the mainstream, 5 in Laos, 4 in Thailand and 2 in Vietnam, the latter nine being on tributaries, for a total production of 4,400 megawatts (15% of the basin’s hydropower potential estimated at 30,000 megawatts). Many more are under construction or being planned, including at least six in China and “a number” in Laos. There is also “a positive attitude towards hydropower development” in Vietnam (MRC 2001), as attested to by the recent plans of Electricity of Vietnam to build 173 new hydroelectric power stations with a total capacity of 2,296 MW to supplement the existing 500 small and medium sized hydroelectric power stations. Until recently no new major dams were planned in Thailand and Cambodia, but this is changing quickly. In Cambodia, the government “places high priority on attracting increased private sector investment and participation in electricity production and distribution” and the Prime Minister of Cambodia has recently requested the Chinese ambassador in Cambodia “to attract her country’s companies to invest in hydroelectric power generation”.

Table II: Sites with existing hydropower capacity or proposed for development in Cambodia

<table>
<thead>
<tr>
<th>River/Site</th>
<th>Multi-site</th>
<th>Single site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sre Pok</td>
<td>3 sites in Cambodia: 787 MW.</td>
<td>Mekong Sambor 2: 3300 MW / 14870 GW</td>
</tr>
<tr>
<td></td>
<td>7 sites in Viet Nam: 841 MW</td>
<td>O Chum II: 1 MW / 4.4 GW</td>
</tr>
<tr>
<td>Se San</td>
<td>2 sites in Cambodia: 582 MW / 3042 GW;</td>
<td>Kamchay: 180 MW / 550 GW</td>
</tr>
<tr>
<td></td>
<td>5 sites in Viet Nam: 1516 MW</td>
<td>Prek Chbar: 5 MW / 32 GW</td>
</tr>
<tr>
<td>Se Kong</td>
<td>2 sites in Lao PDR: 390 MW / 1269 GW</td>
<td>Stung Atay: 110 MW / 588 GW</td>
</tr>
<tr>
<td>O Phlai</td>
<td>4 sites; 21 MW / 147 GW</td>
<td>Stung Cheay Areng: 260 MW / 1350 GW</td>
</tr>
<tr>
<td>Stung Pursat I</td>
<td>4 sites: 96 MW / 485 GW</td>
<td>Stung Chikreng: 2 MW / 8 GW</td>
</tr>
<tr>
<td>Prek Liang</td>
<td>3 sites: 121 MW / 581 GW</td>
<td>Stung Chinit: 5 MW / 23 GW</td>
</tr>
<tr>
<td>Prek Por</td>
<td>3 sites: 34 MW / 204 GW</td>
<td>Stung Sreng: 7 MW / 69 GW</td>
</tr>
<tr>
<td>Prek Ter</td>
<td>3 sites: 50 MW / 269 GW</td>
<td>Stung Staung: 4 MW / 23 GW</td>
</tr>
<tr>
<td>Stung Battambang</td>
<td>3 sites: 73 MW / 384 GW</td>
<td>Stung Sva Slapp: 4 MW / 20 GW</td>
</tr>
<tr>
<td>Prek Chlong</td>
<td>2 sites: 31 MW / 203 GW</td>
<td>Stung Tanat: 4 MW / 27 GW</td>
</tr>
<tr>
<td>Prek Kam</td>
<td>2 sites: 8 MW / 53 GW</td>
<td>Stung Tatay: 80 MW / 250 GW</td>
</tr>
<tr>
<td>Prek Kreing</td>
<td>2 sites: 14 MW / 85 GW</td>
<td>Stung Treng: 980 MW / 4870 GW</td>
</tr>
<tr>
<td>Prek Rwei</td>
<td>2 sites: 12 MW / 128 GW</td>
<td></td>
</tr>
<tr>
<td>Stung Mongkulborey</td>
<td>2 sites: 14 MW / 97 GW</td>
<td></td>
</tr>
</tbody>
</table>

Capacity installation (MW) / Energy production (GW)

Sources: Hydroelectricity Department, Ministry of Industry, mines and energy; MRC Hydropower development strategy 2001; Cambodge Nouveau n° 215 and 241

25. This assessment only refers to hydropower dams of medium or large size, which do not consume water but only alter the flow regime and fragment aquatic habitats. However, these dams are supplemented by thousands of small irrigation reservoirs and weirs that aim at extracting water from the river and thus reduce flow, among other impacts. These small schemes are not individually identified, although they are quite visible on remote-sensing maps, particularly in North-East Thailand (see for instance MRC 2003). In addition to existing ones, multiple smaller schemes are being considered (including 15 dams for

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1 This includes, according the Vientiane Times (28 March 2006) plans for a 240 MW dam at Khone Falls, more specifically at Don Sahong. Such dam would have a very significant negative impact on dry season migrations, since Don Sahong is the only channel that fish can use to migrate from Cambodia to Laos during the dry season.

2 Vietnam Economic Times, 04 August 2005. This covers the whole of Vietnam, not just the share of the Mekong Basin lying within Vietnam.

3 Rectangular Strategy, side 3, Development of the energy sector and electricity network. This approached is balanced by a commitment to “enabling a supportive fisheries and ecological system” (side 2 of the rectangular strategy).

4 Phnom Penh Post, 1-14 December 2006
irrigation purposes, mainly in Thailand and Vietnam). The Vietnam National Mekong Committee (2003) states that currently there are 580 irrigation projects of various size within the Sesan and Srepok basins (major Mekong tributaries) in Vietnam only, servicing at least 46,180 hectares of rice paddies and coffee plantations in the central highlands. The irrigation water demand of crops in the Sesan and Srepok basins in Vietnam is estimated to grow by 36%, from 2.8 in 2001 to 3.8 billion m³/year by the year 2010. The projected water demand in dry season represents 63% of the total runoff, an unrealistic quantity to extract without extensive water development infrastructure. Consequently, further development - and rehabilitation- of irrigation schemes are planned. About 658 irrigation works are expected to be constructed in the Gia Lai, Dak Lak and Kon Tum provinces.

II.1.1.2 Water allocation mechanisms and fisheries economics

26. To date, scientifically underpinned comprehensive water allocation mechanisms have not been set for the Lower Mekong Basin (Petersen 2003). Among the preliminary works, the model proposed by Ringler (2000, 2001) to determine the optimal allocation of water resources in the Mekong Basin should be mentioned. Unfortunately, lack of data and data unreliability hampered the predictive power of the model (Johnston et al. 2003). Ringler finds that artificial diversions of water from the Mekong could readily cause negative impacts on fisheries and saltwater intrusion into the Mekong Delta during the dry season.

27. Table III shows that total profits from optimal water allocation and use were estimated at USD 1.8 billion in 1990, irrigated agriculture ranking first with USD 917 million and fish catches second with USD 546 million. Vietnam obtains the greatest benefits from basin water uses, contributed chiefly by irrigated agriculture and fish production. Profits from hydropower are largest in Laos, and fish catch and wetlands are the major water-related income sources in Cambodia. One must note that this scenario is based on data available in 1999, when total Mekong fisheries catches amounted to 1 million tons, not 2.6 or 3.2 million tons as per recent estimates.

<table>
<thead>
<tr>
<th>Country/region</th>
<th>Irrigation</th>
<th>Municipal &amp; Industrial</th>
<th>Hydropower</th>
<th>Fisheries</th>
<th>Wetlands</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yunnan, PRC</td>
<td>20</td>
<td>11</td>
<td>0.05</td>
<td>5</td>
<td>6</td>
<td>31</td>
</tr>
<tr>
<td>Lao PDR</td>
<td>38</td>
<td>6</td>
<td>33</td>
<td>19</td>
<td>5</td>
<td>101</td>
</tr>
<tr>
<td>Thailand</td>
<td>320</td>
<td>65</td>
<td>10</td>
<td>151</td>
<td>4</td>
<td>551</td>
</tr>
<tr>
<td>- N Thailand</td>
<td>52</td>
<td>5</td>
<td>10</td>
<td>4</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>- NE Thailand</td>
<td>268</td>
<td>60</td>
<td>10</td>
<td>141</td>
<td>4</td>
<td>483</td>
</tr>
<tr>
<td>Cambodia</td>
<td>26</td>
<td>7</td>
<td>7</td>
<td>188</td>
<td>80</td>
<td>301</td>
</tr>
<tr>
<td>Vietnam</td>
<td>513</td>
<td>81</td>
<td>188</td>
<td>44</td>
<td>825</td>
<td></td>
</tr>
<tr>
<td>- VN, Central Highland</td>
<td>29</td>
<td>6</td>
<td></td>
<td>35</td>
<td>790</td>
<td></td>
</tr>
<tr>
<td>- VN, Mekong Delta</td>
<td>484</td>
<td>75</td>
<td>188</td>
<td>44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Basin</td>
<td>917</td>
<td>170</td>
<td>43</td>
<td>546</td>
<td>134</td>
<td>1,809</td>
</tr>
</tbody>
</table>

28. To our knowledge no socioeconomic analysis has been done at the scale of the whole Mekong Basin. At the moment the Mekong River Commission is developing a simple resource allocation and optimization model (RAOM) similar to Ringler’s model, but drawing on recent hydrological information to examine how water resources in the Lower Mekong Basin (LMB) can be allocated among various water-consuming activities and functions. The values used to run the model are simply unit estimates, and integration of environmental flow requirements is in principle possible, depending upon the progress that is made with current valuation initiatives by partners (Johnston et al. 2003).
29. The MRC and Halcrow Ltd. have also set up a Decision Support Framework (DSF) that consists of a suite of data analysis software and models intended to assess the magnitude and impact of changes in the water-resource system (Halcrow 2004a). These tools are supposed to allow macro-level sustainability analyses and potentially impacted population analyses. However, the nature and contents of these tools are not detailed in the sixteen volumes of documentation about the DSF, and the “meaningful socio-economic assessment of future development scenarios will require a more detailed set of data” than the current MRC Social Atlas, and “significant efforts remain to assemble data sets to support socio-economic assessments” (Halcrow 2004b and c).

30. Overall, the NSF (1998) and Smith et al. (in press) found that the diversity of fisheries-related livelihood strategies is poorly represented in practice by socioeconomic analyses and policies.

II.1.1.3 Water management, fisheries and livelihoods

31. In the Mekong Basin, the bulk of the catch originates from part-time and subsistence fishers rather than from those classified as full-time fishers (Dixon et al. 2003). According to that study, in the three Lower Mekong countries studied, the majority of full-time fishers categorise themselves as very poor, and also highly dependent on others for finance. However, they are considered relatively less vulnerable than agriculturally-based poor who are more subject to seasonal scarcity periods. The majority of part-time fishers also categorise themselves as poor or very poor. The third group of subsistence fishers includes landless labourers, women, children and small farmers. They range from very poor to rich and in most cases are not fully dependent upon fisheries for income-generation or subsistence. As such, they are less likely to be deeply impacted by a degradation of the wild resource. The fact that inland fisheries are often regarded as an activity for the poor but can also be an activity for the more wealthy was noted by Béné and Neiland (2003), which led Coates et al. (2004) to call for a better understanding of how fisheries and their management contribute to, or are affected by, wealth differentiation.

32. The threats to fisheries take place in a context of limited knowledge, if not ignorance, about the extent and importance of natural resources in terms of overall household livelihood strategies. The usual census approach, which consists of thinking in terms of primary and secondary occupations, conceals the importance of diversified activities and particularly of inland capture fisheries to the livelihoods of the Mekong rural poor (Dixon et al. 2003; Keskinen 2003)

33. Consultations with local communities (Dixon et al. 2003) allowed the identification of two main threats to fisheries common to the three Mekong countries: unsustainably high fishing pressure, and degradation or loss of wetlands and floodplain habitat. The latter was specified as resulting from i) increased agricultural activities (inducing deforestation and agro-chemical pollution), and ii) modification of river-flows by flood control, drainage and irrigation structures or hydropower schemes. Thus, built structures are indeed central to development options and fisheries issues in the basin.

34. Participatory rural appraisal results showed that all of the above challenges and threats to inland fisheries have already reduced the livelihood base of poor people and made them
more vulnerable to hazards from drought and flooding, natural declines in the fish population, inadequate market access and high population growth. However, the study also concluded that in terms of pressing issues, access to fisheries and threats to aquatic resources come after personal and communal poverty issues such as lack of rural infrastructure (roads, clean water sources, sanitation facilities, schools), lack of land for farming rice and crop pests. Normal flooding is not a problem, only exceptional floods are.

II.1.2 Impact of large scale built structures on the basin fisheries

35. Preliminary calculations suggesting a 20% increase in demand for fish in the LMB over the next 10 years (Sverdrup-Jensen 2002), combined with a major threat that fisheries habitats will be reduced due to barriers to migration, conversion of floodplains into agricultural and urban areas, and changes in natural flow regimes due to dams and irrigation, make the future of Mekong fisheries uncertain. We detail below some of the major changes whose impacts have been at least partly documented.

36. The impacts of dams on Mekong aquatic resources have been highly debated (e.g. Roberts 1995, Siebert 2001, TERRA 2003, FEER 2004). Hill and Hill (1994) first attempted a thorough assessment of the consequences of dams on Mekong fish and fisheries. They highlighted the exceptional ecological importance of the Khone Falls area, the devastating consequences that a dam across the Tonle Sap River would have, the need to consider true "run-of-the-river" dams rather than blocking dams, and overall the absence of appropriate information. In fact their review itself is hampered by a systematic lack of data.

II.1.2.1 Gaps and flaws in assessments

37. Ten years later, specific information on the impacts of dams on fisheries is still lacking and/or of poor quality. In his review of the Economic Impact Assessment of the Nam Theun 2 dam in Laos, Wegner (1997) takes note of the high value of indigenous fish species and expresses concern that these have not been considered adequately in the impact assessment. Similarly the World Bank (in Amornsakchai et al. 2000) acknowledges the fact that for the Pak Mun Dam in Thailand the lack of detailed baseline studies on fisheries has made it difficult to estimate fishery losses in the cost-benefit analysis of the dam. Bernacsek (1997b) notes that aquatic impact assessments were carried out before impoundment in only seven cases out of 40 dams or reservoirs surveyed in the basin.

38. In a scenario analysis prepared for the MRC, Halcrow (2004d) estimated that the impact of five additional large dams in the Lower Mekong Basin would reduce the maximum longitudinal fish migration network by only 1.6%. However, among other flaws and biases, the distances computed include twice the length of large streams, with the argument that "fishes migrate most commonly along either river bank"! (op. cit., Appendix A). Of course, this bias minimizes the calculated impact of upstream dams on the whole river network open to migrations.
II.1.2.2 Recent breakthroughs

39. In 2004, Podger et al. assessed the impact of different water management scenarios on flows and on a number of indices, including a fish habitat availability index (HAI). The study concluded that the expected losses to the HAI range between 1% and 13% for the area downstream from Kratie in northern Cambodia. However, going beyond benign relative values, Barlow (pers. comm.) highlighted the fact that this is a fraction of a huge resource amounting to 2.6 million tons; it can be shown by a pro-rata calculation that this limited relative reduction would correspond, in Cambodia and Vietnam alone, to a loss of 15,000-199,000 tons with a monetary value of USD 10-135 million a year. The livelihood value of this fraction is not known.

40. Baran (2007) has recently detailed the consequences of flow modifications on the Mekong fish production. Several points are highlighted:

41. Development scenarios generally consider that dams will store water in the wet season and release it in the dry season. If dry season flows are indeed increased by infrastructure, then dry season migration thresholds or cues might never be reached, which will inhibit the migration of species sensitive to these low flows. As most migrations occurring in the dry season have a reproductive purpose, the biological impact of increased dry season flows might be on reproduction success. Another consequence would be that most artisanal gears designed to catch species migrating at low water levels could not be operated any longer or would be less efficient at higher water levels, hence a loss of catch and productivity even in the presence of fish.

42. A contrario, it is also hypothesized that significant water abstraction for irrigation might decrease flows in the dry season. Such reduction would have dramatic consequences in Southern Laos if the discharge in the Mekong main stream goes below 2000 m³.s⁻¹, since no catches are recorded for such low discharge levels.

43. Dams, depending upon their operation rules, can also delay the flood onset by buffering the flood pulse. This delay might have a significant negative impact on the fish abundance as the flood onset is playing a strong trigger role in the migration of a majority of commercially important species. Several reports have documented a positive relationship between an early flood and a productive fishing year (cf. Baran et al. 2001). According to Welcomme and Halls (2003), in a system where the upstream movement of adults compensates for the downstream drift of larvae, a natural or artificial variation of the flow regime is likely to result in a very different distribution of fry and thus in a fluctuating production in downstream regions; this kind of perturbation has been documented in South America for instance.

44. The basinwide impact of rainy season flow modifications due to large scale built structures such as dams would be minor compared to dry season flow changes. Decreased flood peaks in the rainy season might slightly improve the catchability of fish, and delayed flood peaks might not have a major impact since they happen at a time when fish do not noticeably migrate or breed.

45. The impact of Chinese dams is also feared in the Mekong Delta, though according to Nguyen Minh Quang (2003), the hydrologic impacts of the Manwan Dam observed in Northern Laos are not perceptible in the Mekong Delta. However, the impact of reduced
flows and sediment input on the productivity of Vietnamese coastal fisheries is surprisingly never mentioned, although it was already highlighted by Chevey (1933) seventy years ago. The impacts of dams on coastal fisheries have proven very significant in a number of countries, and assessing them in the case of new damming plans is a recurrent recommendation (Vidy et al. 2000; Blaber 2002, Dugan et al. 2002; Arthington et al. 2004).

II.1.3 Specific impacts of hydrological changes induced by built structures

II.1.3.1 Hydrological migration triggers

46. The Mekong is the river featuring the highest hydrological variability in the world (Welcomme 1985) and its fish fauna display exceptional migratory behaviour. Since these migrations happen on a large scale and are well coordinated, the factors that trigger migrations in the basin have recently been reviewed (Baran 2007). The underlying question concerns the consequences of modifications to the hydrology and hydrodynamics of the river by infrastructure on the fish resource.

47. Migration cues have been documented for 30 out of the 165 Mekong fish species known to migrate; the cues are unknown for the remaining 82% of these migratory species. The literature review identified five major migration triggers in the Mekong: i) discharge, water level and current; ii) rainfall at the end of the dry season; iii) changes in water color and turbidity; iv) apparition of insects; and v) lunar phase (although its role remains unclear and is probably combined with hydrological factors).

48. Ninety percent of Mekong fish species for which migration cues are documented respond to a variation in water level or in discharge. Some fish families are extremely sensitive to hydrological migrations triggers, in particular Pangasiids (catfishes), of which 58% of 19 species are sensitive. In general, catfishes, which include several families, are the group most sensitive to migration triggers. Catfishes have a high value in commercial fisheries and also play a major role in the regional aquaculture sector. Since catfish fingerlings are caught in the wild to be raised in cages, the modification of triggers and of the reproductive success of catfishes might result in diminished supply for the whole aquaculture sector in Cambodia and southern Vietnam.

49. Khone Falls is the only stretch of the basin where long-term catch statistics can be coupled with long-term hydrological records. Analyses of the Khone Falls fisheries (Baran et al. 2005; Baran 2007) show that ninety-six per cent of the total fish biomass harvested year-round in Khone Falls is harvested between 2000 and 8000 m³.s⁻¹, i.e. low discharge levels corresponding to the dry season. The most “productive” discharge levels are 2000 and 3000 m³.s⁻¹; they total more than 60% of the annual yield. This dependence of catches on low, dry season discharge levels is due i) to the fish migration waves that occur during the dry season; ii) to the dominance in catches of a few fish taxa that migrate at this season, and iii) to the better catchability of fish at these discharge levels.

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5 In Cambodia, the aquaculture production of species whose cycle is mastered represents less than 5.5% of the total freshwater fish production. Ninety-four percent of the fish production thus originates from capture fisheries and from wild fingerlings – including catfishes – grown in cages.
50. The conclusion is that the impact, by dams or other built structures, of dry season flow alterations would be dramatic for fishers and food security. This importance makes it a priority area of research to better inform development options. The water allocation rules being developed and used by the MRC and the Mekong riparian countries should in particular integrate the information regarding fisheries and their dependence on low discharge levels.

II.1.3.2 Additional impacts to be considered

51. The evolution of the size of fish caught is a parameter that should be integrated into comprehensive assessments of the impact of built structures. Year after year, total catches seem to contain a higher proportion of less valuable small fish and a lower proportion of medium and big sized fish of high economic value. This evolution is mainly driven by fishing pressure, which tends to select and kill larger individuals or species (Welcomme 1995). However, hydrological changes or jaggedness tends to favour opportunistic fish species, whose reproductive strategy (early age at first maturity, lots of eggs) allows them to cope with environmental variability. These species happen to be small and short-lived (e.g. Henicorhynchus spp. or Trey riel), and they proliferate at the expense of larger species. The economic impact of this replacement of quality fish by low value fish is invisible in global statistics based on biomass and has never been assessed.

52. In Africa, detailed studies in the Niger Central Delta have shown that a reduction of 75% of the area of floodplains resulted in a 50% loss of the fish harvest, the two dams of the system contributing 10% of these losses (Laë 1992). However, these studies also highlighted that declining natural fish production was blurred by an increased concentration of fishes (hence a higher catchability) and increased fishing efficiency.

II.1.4 Mitigation measures and positive influence of dams on fisheries

53. The negative effects of dams on inland fisheries have been extensively described (WCD 2000) and alternatives or mitigation measures such as fish ladders have been proposed. Warren and Mattson (2000) expressed reservations about the efficiency of such mitigation measures in the Mekong context; Roberts (2001) confirmed the inefficiency of the Pak Mun Dam fish ladder and Baran et al. (2001b) showed that the intensity of migrations (e.g. 30 tons of fish caught per hour in the Tonle Sap River during the migration peak) makes fishways unrealistic in most main channels (Jensen 2001).

54. The creation of reservoir fisheries following the creation of a dam is often cited as a compensation for the loss of capture fish. However, out of 160 families living in freshwater, only 17 are fully lacustrine or able to live in lakes at one stage of their lifecycle (Fernando & Holcik 1982), most species having to return to free-flowing rivers to breed. Baran (2007) showed that in the Mekong Basin, nine species only are known to breed in reservoirs such as the ones that could be created behind dams.

55. On the positive side of dam building, additional water reservoirs increase fish production locally (Lagler 1976, Bernacsek 1997b). The latter author gives an equation predicting the catch of a new reservoir:
Catch in tons.year\(^{-1}\) = 1.877(Reservoir area in km\(^2\)) – 12(mean depth in m) + 0.03835(Affluent inflow volume in mcm.y\(^{-1}\))

It should be noted, however, that i) this equation does not integrate the loss in wild fish production down the reservoir (as demonstrated in southern Laos by Lorenzen \textit{et al.}, 2000), and ii) the biological productivity generated by this environmental modification is often concomitant with significant social changes in fisheries, particularly in terms of access rights, wealth distribution and equity (WCD 2000, Hirji and Panella 2003).

56. Among the beneficial impacts of damming are the increased dry season flows that would oppose the annual saline intrusion hampering rice culture in the delta (Feng Yan \textit{et al.} 2004). However, the saline intrusion is also highly beneficial to fish production (abundant coastal fishes entering the delta) and shrimp aquaculture (one kilogram of shrimp being worth about 50 kg of rice), and the trade-offs between these different commodities and their underlying socioeconomic implications remain to be assessed.

II.2 TONLE SAP SCALE

II.2.1 Impact of hydrological changes driven by built structures

57. Observations on the \textit{Dai} fishery for migrating fish in the Tonle Sap River during 1995–2002 indicate that year-to-year variations in maximum Mekong River flood levels strongly affect the yield of this fishery (Van Zalinge \textit{et al.} 2003, Hortle \textit{et al.} 2004), which is dominated by about 40% of short-lived opportunistic species (Baran \textit{et al.} 2001c, van Zalinge \textit{et al.} 2004). According to Starr (2004), very low water levels in 2003 caused the fish catch to decrease by as much as 50%, also causing fish prices to double around the Tonle Sap Lake. Among the 10 dominant taxa in Cambodia listed by van Zalinge \textit{et al.} (2000), four are sensitive to hydrological migration cues: \textit{Cyclocheilichthys enoplos}, \textit{Pangasius spp.}, \textit{Barbonymus gonionotus} and \textit{Paralaubuca typus}. They represent 18% of the total catch and 14% of the commercial value respectively.

58. Some dramatic impact of dams on fisheries in Cambodia have been illustrated by the Yali Dam located in Vietnam on a river flowing down to Cambodia. McKenney (2001) estimated that the erratic flow release of this dam resulted in over USD 2.5 million in lost income in 1999 for 3,434 households. On average, livelihood income per household decreased from about USD 109 per month to USD 46 per month (-57%). Non-quantified impacts of this dam include deaths and illnesses, livestock losses due to suspected water quality problems, and rarefaction of some natural resources. The Fisheries Office of Ratanakiri province (Fisheries Office 2000) as well as Baird \textit{et al.} (2002) confirmed these impacts while emphasizing the losses in fish catches and water quality and the total disruption of local livelihoods.

II.2.2 Impact of water quality and habitat losses

59. Among the threats to fisheries can be listed are chemicals that are widely used in agriculture schemes around the Tonle Sap Lake. Sixty-seven percent of the farmers surveyed used pesticides in 2000 (EJF 2002), with volumes as high as 72 l/ha/year for
vegetables, and 1.3 million litres of pesticides were used in the Tonle Sap catchment area (Yang Saing Koma et al. 2001). Many of them are highly hazardous chemicals (including DDT and methyl-parathion) imported from neighbouring countries and used indiscriminately, for instance to harvest fish or to preserve dry fish (FACT 2001, Touch Seang Tana and Todd 2003). Although one study of organochlorine residue levels based on 48 freshwater fishes concluded that Cambodian fishes are among the less contaminated of the region (In Monirith et al. 1999), the possible consequences of chemical pollution for the population’s health as well as on the environment, have never been quantified on a large scale in Cambodia. These possible consequences were detailed in EJF (2000). Considering the on-going large-scale development of irrigation around the lake, this issue needs to be urgently tackled.

60. One of the issues that recently surfaced is the trapping of sediments and the reduced flow speed that results from dams, particularly those across the mainstream (Sarkkula et al. 2003, Kummu et al. 2005). Analyses detailed in Plinston and He Daming (2000) showed that about half the sediment reaching the Mekong Delta derives from the Upper Mekong in China. A scenario analysis showed, particularly through mapping of sediment concentrations and sedimentation rates, that flow reduction and sediment trapping by the Chinese dams on the Mekong would have a dramatic impact on the net sedimentation and productivity of the Tonle Sap Lake (Sarkkula et al. 2003, Van Zalinge et al. 2003, Sarkkula et al. 2004, Kummu et al. 2005).

II.2.3 Role of fishing structures

61. Several commentators on the fisheries in the Tonle Sap believe that the amount of fish in the lake is dramatically decreasing (e.g. Mak Sithirith 2000; FACT 2001). However, there is also strong evidence that fish stocks have not declined overall but on the contrary that the overall catches at the moment are higher than at any time in the past (Baran et al. 2001a, Van Zalinge et al. 2001). In fact, the population has increased much faster than the harvest. As a result, the catch per unit of effort or per fisher is falling, and medium and large-size species are becoming rare.

62. Fishing lots provide an example of changes in fishing patterns and conflicting interests: large-scale fishing includes fishing lots that are auctioned for exclusive exploitation of fish resources (Van Zalinge et al. 1998). In 1996, these fishing lots covered 80% of the Tonle Sap’s shoreline (Gum 2000). Following social pressure, 56% of the total area of the private fishing lots was converted in 2000 into open access areas to allow the poor to benefit from the fisheries (Royal Government of Cambodia cited in Keskinen 2003). However, fishing lots are also regarded by biologists as a good way to combine exploitation, environmental protection (Chheng Vibolrith 1999), and even biodiversity conservation (Coates et al. 2003). Hence, there is a dilemma between a management system “socially unjust” (as the fruits of the resource are captured by a few operators) that contributes somehow to conservation, and an open access system “socially more fair” but likely to result in unrestricted exploitation levels jeopardizing the resource.
II.3 LOCAL SCALE

II.3.1 Description of the study sites

II.3.1.1 Pursat

63. The fisheries resources available to villagers in Pursat were dependent upon the local topography. While the entire area is relatively flat, the land slopes in two dimensions. The first is the slope of the floodplain from the main road (National Road number 5) down towards the Tonle Sap Lake. The second dimension is that the ground also slopes from beyond Krang Veng village on the one side and around Moat Prey village on the other down towards Chong Khlong and Doung Chua villages. On the other side of Moat Prey, the ground slopes down from around Moat Prey past Kampong Lor village. Both of the lower points were the site of canals that run between the canal parallel to National Road number 5 and the Tonle Sap. According to the fishers interviewed, higher areas are characterised by lower abundance of fish so that the area around Moat Prey, because of the relative height of the land, has relatively low fish abundance.

64. Generally fishers are permitted to fish anywhere around the villages and they are using a variety of fishing places including the nearby rice fields and canals. In addition, fishers from all the villages also fished further down the floodplain in flooded areas and small lakes as well as in the Tonle Sap Lake itself. In terms of restrictions, in Doung Chua there has also been a change in that fishers for the village no longer fish in Ka Cheng pond because this pond has now come under private ownership. Related to the built structure, there has been a regulation put in place by the village road committee that fishers should not obstruct the culverts and gates with their fishing gears.

65. In terms of location (see Figure 2) the villages in the area can be classified depending upon their location relative to the built structure that is enclosing a part of the floodplain. Thus, villages are either outside (Doung Chua and Krang Veng), inside (Moat Prey) or situated on the edge of the structure (Kampong Lor, Ou Ta Prok and Chong Khlong). In order to investigate the effects of the small floodplain road at this site it was decided that the views of fishers at each of these locations relative to the road would be sought, and this difference in location relative to the structure was used in the analysis of the context and effects of the structure.
II.3.1.2 Stung Chinit

66. The site is a large-scale irrigation scheme located in Santuk district of Kampong Thom Province on the Stung Chinit Tonle Sap tributary. There is a second tributary nearby: Stung Tang Krasang. The Stung Chinit irrigation scheme represents a fairly large and complex system consisting of a dam, reservoir, spillway, fish pass, a network of canals, rice fields and a number of associated roads (see Figure 3). As a result, the effects that the scheme will have on hydrology, fish and fisheries are likely to be fairly complex and spatially diverse. The scheme has been subject to quite detailed prior assessments that examined a range of aspects, including farm management, water utilisation, fisheries and navigation (e.g. OTCA 1970; MOWRAM/ADB 2003; MOWRAM/ADB 2002) and which have shown the scheme to be economically and technically feasible and developmentally desirable. The scheme has only recently started operating and for this reason the full nature of the impacts cannot yet be determined. The focus here is on the short-term impacts that have occurred during the start up of the scheme, which might serve to highlight some of the possible longer-term effects.

Figure 2 Location of the villages and road system at the Pursat site
Often irrigation schemes and river development plans do not take into account the effects of the development of built structures on fisheries (Grover, 1980). Destruction or alteration of the aquatic environment, the effect of flood control measures on migrations and spawning movements and triggers, and pollution of aquatic environments with sediments and agro-industrial chemicals are all commonly associated with irrigation systems. In order to capture some of this diversity, the fisheries component surveys examined the effects at villages along a transect from above the dam and main canal at the edge of the scheme to below the scheme (Figure 3). This was done as the scheme has created a large reservoir above the dam that could provide a new fishing location, a series of canals, and rice fields at the middle of the scheme, and has modified the flow of the river downstream as well as affected the connectivity to the section above the dam. Thus, villages have been classified as above the scheme (La’ak and Prey Dom), at the center of the scheme (Snao), at the lower edge of the scheme (Sa’ang), where some 30 out of 72 households will be benefiting from the access to irrigation water, and downstream from the scheme (Thnaot Chum). In addition, these locations could also be grouped as upstream or downstream based on their locations relative to the dam and main canal. Above the scheme it was also considered useful to assess the changes for villages on either side of the scheme as the availability and access to fishery resources may be particularly affected for these upstream villages.
II.3.1.3 Prek Toal

68. The site at Prek Toal consists of forest and floodplain areas that are seasonally submerged and which are managed for fishing located on either side of the Stung Sangkae, which empties into the Tonle Sap Lake. These are highly productive areas of flooded forest and floodplain that contain areas highly important to migratory birds and that have importance for fish conservation such as the Prek Toal Core Area (e.g. Davidson 2006; Goes 2005). On one side of the river along which the survey villages are located is Fishing Lot #2. This is an area that has historically been leased out on a multi-annual lease to the ‘lot operator’. The conditions of the lease and area leased are described in the ‘burden book’ that sets out the lease conditions. During the year there is a ‘closed season’ from 31 May to 30 October, during which people from the surrounding area may fish in the lot using family-scale gears and methods, followed by an ‘open season’ from 1 November to 30 May during which access for fishing is given to the lot owner. During the open season, the lot operator may choose to sublease areas of the lot (e.g. Prek Long Ung, Prek Da, Prek Ang Krang, Prek Dem Cheu, Prek Spout, Boeung Norea and other streams and lakes, except the floodplain areas reserved for small-scale fishers). These sub-leases have been paid for in dollars but more recently the lease prices have been specified in kilograms of gold.

![Figure 4 Location of villages, fishing lots and community fishery at the Prek Toal site](image)
69. As one of the management measures of the fishing lot, the floodplain is enclosed from 15 November - 30 December (depending upon the flood level) until 31 May by the lot operator using a 35km long fence that is approximately 3.5m high and that runs along the edge of the floodplain, acting to channel fish into harvesting compartments. This fence has traditionally been made of bamboo but more recently fine mesh netting with a mesh size of less than 1 cm has been used. This fence is the built structure under consideration.

70. On the other side of Stung Sangkhae the floodplain was managed in a similar way prior to 2001 (as Fishing Lot #3) but was considered a naturally less productive part of the floodplain. After 2001, as part of the fisheries reform process, the structure was removed and the floodplain area was given over for community management for household benefit. Exploitation within the community fishery is intended to be limited to relatively small-scale or household fishing gears.

71. The two areas of floodplain are exploited by fishers from the floating villages located along Stung Sangkhae as well as fishers who migrate from Battambang and other provinces to the area to exploit the fisheries. Of the local fisher villages, closest to the edge of the lake is Prek Toal village and, moving inland along Stung Sangkhae, Anlung Ta Or, Kampong Prahok and Thvang. These villages were all selected as part of the survey and interviews held with fishers in each one as well as with fishing lot workers employed to work in Fishing Lot #2, the lot operator and sub-lessees.

72. Details for each of the villages that were selected at the three sites are provided in Table 5.

**Table 4 Description of the villages selected for sampling by the fisheries component at each of the sites**

<table>
<thead>
<tr>
<th>Pursat</th>
<th>Krang Veng</th>
<th>Doung Chua</th>
<th>Chong Khlong</th>
<th>Ou Ta Prok</th>
<th>Kampong Lor</th>
<th>Moat Prey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commune</td>
<td>Snar Ansar</td>
<td>Ou Sandan</td>
<td>Ou Sandan</td>
<td>Ou Sandan</td>
<td>Kampong Po</td>
<td>Ou Sandan</td>
</tr>
<tr>
<td>Location</td>
<td>Outside</td>
<td>Outside</td>
<td>Edge</td>
<td>Edge</td>
<td>Edge</td>
<td>Inside</td>
</tr>
</tbody>
</table>

**Stung Chinit**

<table>
<thead>
<tr>
<th>Village</th>
<th>La’ak</th>
<th>Prey Dom</th>
<th>Snao</th>
<th>Sa’ang</th>
<th>Thnaot Chum #1</th>
<th>Thnaot Chum #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commune</td>
<td>Kampong Thma</td>
<td>Chaeng Daeng</td>
<td>Kampong Thma</td>
<td>Kampong Thma</td>
<td>Thnaot Chum</td>
<td>Thnaot Chum</td>
</tr>
<tr>
<td>Location</td>
<td>Upstream</td>
<td>Upstream</td>
<td>Middle</td>
<td>Edge</td>
<td>Down stream</td>
<td>Down stream</td>
</tr>
</tbody>
</table>

**Prek Toal**

<table>
<thead>
<tr>
<th>Village</th>
<th>Prek Toal</th>
<th>Anlung Ta Or</th>
<th>Kampong Prahok</th>
<th>Thvang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commune</td>
<td>Kaoh Chiveang</td>
<td>Kaoh Chiveang</td>
<td>Kaoh Chiveang</td>
<td>Kaoh Chiveang</td>
</tr>
<tr>
<td>Location</td>
<td>Lake</td>
<td>Inland</td>
<td>Further inland</td>
<td>Furthest inland</td>
</tr>
</tbody>
</table>
II.3.2 Results of project studies

II.3.2.1 Pursat

73. As a starting point, the respondents were asked about the effect of the built structure on local hydrology. In response to this it was the universal belief among respondents was that the only effect that the built structure might have had on the water locally was a possible decrease in the rate at which water was able to move up and down the floodplain. There was no reported effect on water quality.

74. There was unanimous agreement that fish abundance had declined over time. The perception of the degree to which abundance had declined differed for the three size categories but it was again unanimous that the larger fish had declined most (see Figure 5).

![Figure 5 Mean perceived decrease in fish abundance for three size classes of fish that had decreased over time at the Pursat site](error bars indicate the standard deviation around the mean).

75. When asked what caused the changes in abundance, a variety of reasons were given for the decline in abundance that they have observed. While all the reasons given were due to human/environment interactions, the built structure was not cited as a cause by any of the respondent groups. It was stated by 42% of respondents, including 100% of those with rice fields within the boundary of the road system, that the structure had no effect because of the culverts and gates associated with it (together with the regulations related to them) as well as the presence of canals that enable fish to move up and down the floodplain. There was some variation in reasons for change by location (inside, outside and edge), although these difference do not appear to be significant ($X^2$, $P > 0.05$, df = 18). Considering the top two ranked reasons reported for the decline (Figure 6), it can be seen that the perception was that fishing effort, either as a result of increasing efficiency or increased numbers fishing, has been the main reason for the perceived decline.
Figure 6 Top ranked reasons for the decline in fish abundance perceived by fishers at the Pursat site.

76. In relation to fishing effort, participants were asked whether the built structure was having any effect on fishing effort. There were again no significant differences in the opinions by location ($\chi^2$, $P > 0.05$, df = 4) with the road believed to have had very little effect on overall effort levels. However, patterns of effort were believed to have been affected as the canals in the area and areas around the culverts and gates were believed to have provided additional places to fish. In addition it was unanimously believed that the nature of these additional locations (i.e. deeper water and a channelling effect on fish) promoted the use of the more efficient gear types. Examples of the kinds of new and more efficient gears that were reported to be more widely used predominantly included electro-fishing and the use of fine mesh nets. At the same time the use of more traditional gears such as angruth and chhneang was widely perceived to have declined (see Figure 7). There were no significant differences in the changes in gear types used by location ($\chi^2$, $P > 0.05$, df = 8).

Figure 7 Perceived changes in fishing gear use reported by fishers at the Pursat site.
The decline in fish abundance has meant that there have been changes in the patterns of fishing effort with over 80% of respondents indicating that fishers are now travelling further from their homes in many cases and new fishing locations that had not previously been used by those villagers are being exploited. The majority of these locations are further down the floodplain towards the Tonle Sap Lake, for example Boeung Chhes, Boeung Sambok Ork, Boeung Naktavul, Trapang Khach and Boeung Kambeth Snearth and other areas including the flooded forest.

The decrease in abundance of fish in all categories has been accompanied by increases in price (Table 3). Interestingly, small fish had increased the most in price and also showed the greatest variation in increase. This could reflect the greater diversity in the view of the extent to which this group had declined in abundance (Figure 5) and also that the group will consist of a mixture of lower value and higher value fish species. It is also noticeable that despite large fish being perceived to have decreased the most, this was not reflected in the extent of the price increase over the period.

<table>
<thead>
<tr>
<th>Table 5 Changes in fish price for three size classes of fish at the Pursat site between 2000 and 2006. Standard deviation in brackets.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean price before (2000) (Riel/kg)</td>
</tr>
<tr>
<td>-------------------------------------</td>
</tr>
<tr>
<td>566.7 (238.7)</td>
</tr>
<tr>
<td>Mean price now (2006) (Riel/kg)</td>
</tr>
<tr>
<td>Mean difference</td>
</tr>
</tbody>
</table>

A number of reasons were given for why the prices had increased and these were not significantly different between locations ($X^2$, $P > 0.05$, df = 12). The main reasons for the increase were high local demand (100% of respondents), decreased fish abundance and reduced fish catches (92%) and increased demand for fish for export, principally to Vietnam and Thailand (92%). The results of the socioeconomic surveys in two of the villages at the site also indicated that household catches had decreased but that the overall contribution of fishing to household income had not, likely due to the price increases.

The built structure was universally felt to have contributed to fish price increases by both increasing the access to the villages by middlemen (it was variously reported that visits had increased by 30-50%) and also the access to markets by villagers. This was also believed to have had a positive effect in enabling villagers to get a better price for their fish, but it was also reported that increased sales of fish meant that sometimes villagers cannot find fish to buy in their village. The main benefits of the road were, unsurprisingly, associated with better access, either access by villagers to markets and other facilities or access to the village by external agents, including traders, extension staff and NGOs. These access benefits are similar to those reported by Hettige (2006) for rural roads.

In terms of species, the species reported to have changed in abundance were very similar by location. There was only one species that was considered by all respondent groups to have disappeared from catches, while several others were widely believed to have declined in abundance (Figure 8). No species were reported as having increased in abundance.
82. In summary, the structure (road) was felt to provide benefits to locals relating to water and fisheries in that it acted as an embankment to prevent substantial flooding from water moving up the floodplain. It was also able to act to retain water in the rice fields above the road, making water available for the rice crops and for livestock. Related to fisheries, the structure was not believed to be affecting fish abundance because water connectivity has been maintained due to the presence of culverts and gates and associated regulations that enabled water and fish to move up and down the floodplain. Any blocking effect was also reported to be mitigated by the presence of canals that also enable water and fish to move up and down. The structure (and also canals in the area) has provided new fishing opportunities that have been exploited by fishers. The structure has also assisted in the marketing of the fish caught by increasing access to the villages by middlemen purchasing fish and also access of villagers to the local markets. This has had a positive effect on the prices that fishers are able to get for their catch.

83. The negative effects of the structure were mainly indirect. There was a perception, particularly among those outside of the structure, that the water retention effect might actually contribute to flooding inside the area enclosed by the structure at times of heavy rainfall. It was also felt that the new fishing opportunities that have been created may also have enabled the use of the more efficient types of gears that are perceived to be contributing to declines in fish abundance. Finally, while the increased marketing opportunities that have been provided by the structure and price increases that have been observed have benefited fishers, they have reportedly had some negative effects on those in the villages looking to purchase fish for household consumption in that sometimes fish may not be available to those in the villages who want to buy it.
84. Asked about the hydrological changes that the scheme had brought about produced differing responses by location. Around Prey Dom, above the scheme, it was noted that development of the scheme had a negative effect in that it had led to increased flooding of the villagers’ rice fields and homesteads. Prior to the scheme water could be released from the nearby lake Boeung Chork into the river through the stream Ou Chork. With the development of the scheme, an embankment was created that blocked some of this flow, and the stream was channelised to create a canal linking the reservoir to the river downstream of the dam, and that could carry the water from Boeung Chork, which received water from three other upstream streams. However, the respondents reported that the canal is unable to carry sufficient water and that this has led to the flooding problems. The respondents also noted that this canal was an important part of the scheme in relation to fisheries as it allowed fish to move upstream and downstream past the dam and embankments. The reservoir was also noted as being a major hydrological effect of the scheme and it was felt that this would benefit the fisheries by providing additional habitat that would be perennially available. While the reservoir may bring additional habitat, it can be expected that fish diversity and abundance in irrigation canals will be less than in the unmodified river. For example, following the development of the Gezira irrigation system in Sudan there was a reduction in fish diversity of some 45%, with only 19 of the 34 species of fish present in the source waters (the Blue Nile) found in the minor and field canals (Coates 1984).

85. In La’ak village, above the scheme and on the other side of the reservoir from Prey Dom, the respondents indicated that the reservoir was the main hydrological change brought about by the scheme and that this enabled them to access water for rice and that the embankment associated with the reservoir prevented flooding of the village in the wet season. At the same time though this reduced flooding effect has reduced the flow of water to the rice fields. A similar effect has been caused by the new road that was built between the two rivers Stung Chinit and Stung Tang Krasang. As a result there is less water reaching the rice field areas and this has affected fish movement and abundance in these fields.

86. In both of these locations above the scheme it was reported that the scheme had also affected water quality, primarily due to the decomposition of flooded vegetation. While respondents reported that this did not appear to affect the fish or fishing, there were reports that it had negative effects on animal (50% of respondent groups) and human (25% of respondent groups) health. In other studies it has been found that anoxic waters from reservoirs containing rotting vegetation have caused mortality in river fish (Arthington 2004). However, studies by Lim and Lek (2005) suggested that there was little variation across the site in terms of total suspended solids in the water and that, according to French standards, the water quality regarding nutrients varies between “very good” and “good” quality and that in terms of organic matter the water quality is a bit lower with a “fair” water quality. The factor affecting water quality was attributed by Lim and Lek (2005) to organic inputs from the riparian villages. The water quality descriptions provided would not seem to account for the effects described by the respondent groups.
87. At Snao village in the middle of the scheme the main hydrological effects that were noted were that the scheme had created a larger flooded area above the dam, in particular the reservoir, and that these flooded areas remained flooded for longer. They also noted, as was stated in La’ak, that the physical structures that had been created had reduced the access by fish to the rice fields. As with the locations above the scheme, respondents indicated that the development of the scheme had affected water quality. In particular, the creation of the scheme had led to some flooding in the village and there was a unanimous view that during this flood period well water in the village began to become turbid and smell bad and that again this had had negative impacts on human and animal health in the village.

88. The perception of the change in hydrology was similar for all the locations downstream of the dam and canal. Here the main effect was that there had been changes in the volume and timing of water flow, resulting in reduced water flow in the river and less flooding of the downstream floodplain areas as a result. Respondent groups also noted that the water quality had also changed with water having a ‘bad smell’ and being more turbid. While it is possible that this is linked to the submergence and decomposition of vegetation upstream, the perception was that this change was due to the slower current in the river. Lim and Lek (2005) noted that the total suspended solids were higher in the downstream areas and that this was possibly due to an increase of the population density and an increase of soil erosion and runoff.

89. In terms of where people can fish, there has been a traditional system of access restrictions along the river that dictated who could fish and where. This access was allocated on a household basis and this access could be leased to others. With the introduction of the scheme, the traditional system above the main dam is no longer operating and the reservoir is at present a perennial open access resource. Below the dam the traditional system is still operating along the river in the same way as before.

90. There was universal agreement among the participating fishers that the development of the irrigation system has changed where people fish. This includes both fishers fishing at new locations as well as not fishing at others that were fished prior to the scheme. This is not surprising given the scale and extent of hydrological modification that has resulted. The effect that the scheme had on patterns of fishing effort depended however on where the fishers were located in the scheme (Table 4). The greatest change has, as might be expected, been above and in the middle of the scheme where the creation of the reservoir, canal and rice fields has provided a number of new fishing locations. For the villages above and at the centre of the scheme the reservoir represents an important a dry season resource as the lakes. It has also meant that fishers in these places are no longer travelling further afield to fish (e.g. in Stung Tang Krasang and Boeung Lvea) as the reservoir is much closer. However, it has been reported, particularly by the villagers in La’ak and Snao, that the reduced connection of the rice fields to the river system due to the creation of roads and embankments has led to a decrease in the abundance of rice field fish and made rice fields a less important place to fish. This could be important as in appraisals in Lao PDR, Nguyen-Khoa et al. (2005) found that such fields were important sources of fish and that it was therefore important to maintain the water levels and connectivity of the fields to support production.
91. There have been some benefits from the scheme for those living in Snao village in particular as fishers from there are able to fish the section of the river just below the dam, fish pass and spillway. This is a place where fish moving upstream are reported to congregate as their way upstream is blocked and many fishers take advantage of this.

92. For villages downstream from the scheme the picture is quite different and fishers in these villages are now reporting that they are traveling further afield to fish, including to the Tonle Sap Lake, because of reduced fish abundance nearby. These villages are also being affected by other changes that are related to other resources in the floodplain, for example the release of Boeung Krai Slao, Boeung Tamun and Peam Anchanh and the restriction of access to other lakes, such as Boeung Samreth and Boeung Chhkae Khamsvar, and these changes are reported as important in the downstream locations. In addition, these villages also related that the risk of gear theft also affected where they choose to fish. Both floodplain areas far from their village and the rice fields at the southern edge of the irrigation scheme were suggested as places where gear theft was an issue.
Table 6 Changes in patterns of fishing effort described by fishers from villages around the Stung Chinit scheme.

<table>
<thead>
<tr>
<th>Fishing locations created</th>
<th>Above</th>
<th>Centre</th>
<th>Edge</th>
<th>Below</th>
</tr>
</thead>
<tbody>
<tr>
<td>Now fishers can go fishing in the lakes that are all part of reservoir in wet season and expect to be able to in the dry season also.</td>
<td>Now fishers expect that they can go fishing in reservoir because this will hold water in dry season.</td>
<td>Fishers can go fishing at some lakes at present because these lakes were released for fishing people (after fishery reform, 2001).</td>
<td>Fishers have started fishing at Tonle Sap Lake due to fewer fish in nearby rice field and lakes.</td>
<td></td>
</tr>
<tr>
<td>Fishers can use some lakes that are part of reservoir because they will remain full in dry season and fish are more abundant in the reservoir.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before some of the lakes near the village dried out in dry season. Now, with the reservoir, there is a lake in both dry and wet seasons</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fishing locations no longer used</td>
<td>Fishing locations no longer used</td>
<td>Fishing locations no longer used</td>
<td>Fishing locations no longer used</td>
<td></td>
</tr>
<tr>
<td>Fishers stopped fishing after damming because this lake was far from village (50km) and fish are more abundant in the reservoir and rice fields close to the village.</td>
<td>No longer fishing in the rice field area under the irrigation scheme. Recently there have been fewer fish in these rice fields due to the scheme blocking fish migrations.</td>
<td>Location now restricted by private control for development of livestock/fish farming.</td>
<td>Fishers have stopped fishing at the southern rice field area of Stung Chinit because of the risk of gear theft.</td>
<td></td>
</tr>
<tr>
<td>No longer fishing in two lakes that are now very deep in wet season (after damming) and fish are now more abundant in lakes near by the village.</td>
<td>Fishers could not fish in rice field areas next to the village after damming in wet season due to less fish or no fish found in this type of habitat.</td>
<td></td>
<td>Now fishers cannot go fishing at a lake that has been become part of Fishing Lot #10 since 1995.</td>
<td></td>
</tr>
</tbody>
</table>
93. Within the villages around Stung Chinit there was a unanimous belief that in general there had been a decline in overall fish abundance. A number of reasons were put forward for this general decline in fish abundance (Figure 9). The reasons that were given were similar by location and there was only one notable variation, which was in the issue of barrages and electro-fishing gears strung across the river. This was considered an important cause of declining abundance in those villages below the dam but was not mentioned by fishers in villages either in the middle or above the dam. As with the other sites, the main reasons being put forward were to do with human/environment interactions. Increasing fishing effort through increasing numbers of fishers and increasing gear efficiency, for example the use of smaller mesh size nets, was unanimously cited as a reason for decreased abundance. Clearing of the flooded forest was also a widely cited reason for decreased fish abundance at the Stung Chinit site.

94. While it was felt that there had been a general decline in fish abundance at all locations over time, it was also believed by all the respondent groups that the scheme had affected fish abundance. At the upstream locations it was stated that the scheme had led to an increase in size and abundance of fish while at the downstream locations abundance was felt to have decreased. The upstream increase was believed to be due to the increase in habitat and food availability for the fish. However, there was uncertainty as to whether the increased abundance and resulting improved catches would be maintained in the future.

95. Downstream one respondent group in Sa’ang village indicated that they felt that the reduction of fish abundance in the river was such that during the dry season in the future the river might only be used as a source of subsistence fish. The decreased abundance of fish downstream was considered by all downstream respondent groups to be due to the flow changes caused by the scheme’s reduction in the number of fish that were traveling up the river from the Tonle Sap Lake. This connectedness was important, and it was also mentioned by respondents that local fish abundance was strongly correlated with the natural flooding from the Tonle Sap Lake. When there was a strong flood there would be a greater abundance of fish along the river. This is consistent with a widely found correlation between catches and flooding intensity (e.g. Baran et al. 2001). As well as changes in abundance it is
possible that a reduction in flow will also affect the species assemblage as the size of the stream has been identified as a potentially important factor in structuring fish assemblages (Grenouillet et al. 2004). Unfortunately, at this stage the structure has not been operating for long enough to be able to confirm any changes.

96. That respondents indicated that local fish abundance was dependent on fish traveling up the river, highlighting the fact that activities further downstream on the floodplain and in the main Mekong system may also be having a strong influence on fish abundance at the site. In this respect the villages at the lower edge and downstream of the scheme reported that a floodplain irrigation scheme further downstream (a structure developed during the Pol Pot time) from the Stung Chinit scheme was having a more significant effect than the Stung Chinit scheme itself. Walker (2003) has suggested that the development of such lowland irrigated agriculture often does not feature in the debate on water supply and utilization. Unfortunately, again because the structure at Stung Chinit has only started operating and because there was not enough time to also investigate the downstream structure, it was not possible to investigate this assertion.

97. The changes that the Stung Chinit scheme brought about in both hydrology and fish populations have led to changes in the patterns of exploitation with fishers in the upstream areas relating that they are now using larger mesh size nets to catch fish in the reservoir. In the downstream areas fishers relate that the reduced flow in the river due to the scheme has enabled fishers to use gears such as drift gillnets, cast nets and long lines that were used less in the past in these locations. The use of boats in the upstream and downstream area is also said to have increased with the development of the scheme.

98. There were interesting differences in the new gears that were reportedly used between the upstream and downstream locations. Downstream both electro-fishing and the use of fine mesh nets are perceived to have increased (100% of respondent groups) and it is also thought that the use of barrages across the river (50%) and the use of fine mesh traps (33%) have also increased. One group also noted that fishing with explosives was also sometimes happening. By contrast, only 50% of respondent groups upstream noted an increase in the use of electro-fishing gears or fine mesh nets. All of these gears represent an increase in gear efficiency and the differences between upstream and downstream perhaps reflect the perceived changes in fish abundance in these locations with fishers downstream increasing the use of efficient gears, such as the barrages, in pursuit of fewer fish.

99. Changes in hydrology, fish and patterns of fishing effort have also been accompanied by changes in fish price. Generally fish prices for small, medium and large fish have been increasing over time, but along with this trend there have been more local effects that were attributed to the development of the scheme. The nature of the reported local changes in fish price and the reasons for the changes also varied by location. In the downstream locations 100% of respondents reported that fish prices had increased due to the reduced catches that fishers are now getting. In the upstream locations, by contrast, 100% of respondents indicated that the development of the scheme had led to a decrease in fish price as fish were now more abundant and of a larger size (an example was given of Channa striata decreasing in price from Riel 7000/kg in 2005 to Riel 5000/kg in 2006). In addition it was also reported that the development of the roads associated with the scheme
meant that it was now easier for fishers to sell their catch, either by taking it to the market or selling to middlemen. In La'ak village, for example, it was reported that the roads had led to about a 30% increase in the number of middlemen coming to the village to buy fish.

100. The change in abundance in the downstream locations is also reflected through the traditional management system for the downstream locations. Decreased fish abundance downstream has meant that the price that can be charged for leasing a stretch of the river has also declined.

101. Against the backdrop of the generally perceived decrease in abundance there were some specific changes in abundance that had been observed by participants. These patterns of abundance across the Stung Chinit site were interesting. When the data on species changes was aggregated for upstream (Snao, La’ak and Prey Dom) and downstream (Sa’ang and Thnao Chum) there were significant differences between the species reported as having disappeared based on species that were reported by over 50% of respondents in either location ($X^2$, $P < 0.05$, df = 7). The patterns of decline in species abundance varied but not significantly ($X^2$, $P > 0.05$, df = 15). The spatial pattern of variation in species abundance is shown below in Table 5. These changes were attributed to the development of the scheme and in particular the dam that was constructed across the river reducing the connection between the upstream and downstream areas as well as the increase of food and habitat available upstream. In addition to the changes in abundance that had been observed it was also the view of respondents that the size of many of the species that had increased in abundance had also increased in the upstream areas. Elsewhere fish sizes were generally reported to have declined.
Table 7 Patterns of species abundance based on aggregated responses for upstream and downstream locations in relation to the dam at the Stung Chinit site.

<table>
<thead>
<tr>
<th>Location</th>
<th>Disappeared</th>
<th>Declined</th>
<th>Increased</th>
</tr>
</thead>
</table>

102. The species that are reported to have disappeared common to both upstream and downstream areas are predominantly white fish species. Those fish species that are reported to have increased in the upstream area are also classified as white and grey fish. As mentioned, the white fish are those that are considered most vulnerable to developments in the riverine and floodplain systems and might be some of those most affected. While it might be thought that the creation of additional upstream habitat would be likely to benefit black fish species most, it is the grey fish that have increased in abundance. There are several possible reasons for this. The first is that connectivity of the upstream and downstream has been maintained and the more migratory grey fish are still able to move up and down. Secondly, the reduced connectivity of the system to the rice fields that has been reported may have adversely affected the black fish. Finally, it may be that the blocking of the river has trapped fish in the reservoir and these fish are now being caught. The latter is possibly the most likely as fishers have reported increases in the size of these fish and also voiced concerns about the connection between upstream and downstream areas.

103. The issue of connectivity had been addressed to an extent in the design of the scheme through the inclusion of a fish pass, designed to ensure that fish could continue to move between the upstream and downstream stretches. According to MOWRAM/ADB (2002), The design of the fish pass was based on a number of ecological impact studies in the Stung Chinit site carried out by Warren (1999) and Schouten (1999), findings from successful vertical slot fish pass projects in Bangladesh (Bernacsek 1997a) and Australia (Stuart and Berghuis 1999; Mallen-Cooper 1992) where fish passes have been designed for warm-water slow-swimming fish species similar to those occurring in Cambodia. The more general aspects of the design for the Stung Chinit fishpass were prepared by using the guidelines and recommendations produced by Clay (1995) and Katopodis (1992).
The study by Lim and Lek (2005) suggested that the construction of fish pass will have positive impacts on migrating fish species. However, many of the fishers interviewed expressed some concern about the functioning of the fish pass and whether or not all species could easily move up and down it, particularly given the flow rates within the pass. This concern has been echoed in the report by Baran et al. (2001), who noted that the density of fish migrations in the Tonle Sap River means that fish passes are not realistic as a mitigation measure for dams. Respondents in the upstream areas, and in particular Prey Dom, felt that the canal that linked the reservoir and the river downstream on that side of the reservoir was in fact a more important connection between upstream and downstream for the fish and fish movement and that this connection should be maintained.

Respondent groups were also asked about what they felt were the effects of the scheme on fish and fisheries, how these compared with other influences and about possible mitigation measures (Table 6). This summary shows that those at the centre and upstream of the dam were the ones who were benefiting most from the development of the scheme, but that even here there were a number of concerns. Benefits to these villages (La’ak, Prey Dom and Snao) included the reservoir as a perennial fishing location and water for crops. However, there was uncertainty as to whether the benefits seen in the fisheries (larger fish and larger catches) would continue or whether the disconnection of the upstream and downstream sections of the river might affect fishing in the future. As a result most of the suggestions from these groups were about ensuring and enhancing this connection.

The picture downstream was less positive as while some villagers on the edge of the scheme might benefit from irrigation water in the dry season and possibly rice field fish at this time, there were no other benefits. Instead fish in the river had become less abundant and there was a fear that these would also be easier to catch and therefore vulnerable to overfishing. In addition, there was a concern within these groups that the control of the water flow in the river might also mean that their fields and villages will be more susceptible to flooding in the wet season. As a result, their suggested mitigation measures concentrated on the control of water release from the reservoir and the need to maintain flows in the river.
Table 8 Summary of the positive and negative effects of the Stung Chinit scheme on fish and fisheries, how these effects compared with others and suggested mitigation measures that could be taken to reduce the negative effects of the scheme.

<table>
<thead>
<tr>
<th>Positive effects of structure</th>
<th>Up</th>
<th>Middle</th>
<th>Edge</th>
<th>Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides water for dry season crops. Fish are also more abundant in accessible perennial resource nearby.</td>
<td>Provides larger fishing locations and new fish habitats upstream. Provides water for rice field in dry season.</td>
<td>Will provide some households with water for dry season rice farming, and wild fish from the reservoir may become available in these dry season rice field areas.</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Negative effects of structure</th>
<th>Up</th>
<th>Middle</th>
<th>Edge</th>
<th>Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks fish (including black fish) moving between river and rice field. Causes flooding in rice fields and houses close to reservoir and less water in some other rice fields. Poor water quality affects the health of humans and animals.</td>
<td>Affects fish migration to spawn and feed in the upstream area. Negative impacts on availability of fish in downstream areas and some rice fields. Affects flooding in rice field and houses, and poor water quality affects the health of humans and animals.</td>
<td>Fish migrations during flood season and dry season refuge are affected. Fishers easily catch fish as they aggregate in small, shallow habitats and brood fish could be fished out.</td>
<td>Blocks fish migration from Tonle Sap Lake to upstream. Rice fields and houses may be flooded when the gate is opened in the wet season. Cannot travel by boat to cut wood and collect secondary forest in upstream part.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comparison to other influences</th>
<th>Up</th>
<th>Middle</th>
<th>Edge</th>
<th>Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not yet know.</td>
<td>Do not yet know.</td>
<td>The irrigation structure has less negative impacts on fish and fishing than unsustainable fishing methods. But the scheme may lead to increases in use of unsustainable fishing methods.</td>
<td>The irrigation structure has less negative impacts on fish and fishing compared to destructive fishing methods. But the scheme may lead to increases in use of unsustainable fishing methods.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suggested mitigation measures</th>
<th>Up</th>
<th>Middle</th>
<th>Edge</th>
<th>Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enlarge the diversion canal and ensure functioning fish pass. If possible, re-establish the original fish route between Stung Chinit and Boeung Chork, as this lake has been a large and productive lake. Install technically appropriate number and size of culverts and gates along the main canal.</td>
<td>Ensure a route for upstream fish migration. Perhaps re-adjust fish pass position.</td>
<td>Gate should be managed to allow a reasonable amount of water to flow downstream.</td>
<td>Manage the release of water or create diversion canal to reduce possibility of flooding.</td>
<td></td>
</tr>
</tbody>
</table>

107. In addition to these suggestions regarding the scheme itself, the respondent groups also suggested that there should be a crack down on illegal fishing and that activities further downstream, including clearing of forests and operations of fishing lots, should be regulated to ensure that fish are still able to move up the river.

108. Because the effects of the built structure have been complex and spatially diverse, it is worth providing a brief summary of the outcomes as they were encountered at this early stage after the commissioning of the scheme (Table 7).
Table 9 Summary of the outcomes reported at the Stung Chinit site.

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant hydrological</td>
<td>Creation of reservoir; reduced connection to rice fields; reduced connection between upstream and downstream sections</td>
<td>Reduced flow</td>
</tr>
<tr>
<td>Water quality</td>
<td>Much poorer</td>
<td>Poorer</td>
</tr>
<tr>
<td>Fish size</td>
<td>Increased size of some fish</td>
<td>Same or decrease</td>
</tr>
<tr>
<td>Fishing effort</td>
<td>Fishing in reservoir; Not travelling so far to fish</td>
<td>Increased use of efficient gears; Fishing further afield</td>
</tr>
<tr>
<td>Fish price</td>
<td>Decreased</td>
<td>Increased</td>
</tr>
<tr>
<td>Fishing lease price</td>
<td>n/a</td>
<td>Decreased</td>
</tr>
<tr>
<td>Fish abundance</td>
<td>Some species increased</td>
<td>Declining</td>
</tr>
</tbody>
</table>

II.3.2.3 Prek Toal

109. It was found during the pre-survey and surveys that, while the fishing gear structures can be expected to have some effect on hydrology and fish, it is very difficult to separate the effect of the structure alone from the rules and patterns of behavior that are associated with the structure, and this should be borne in mind while reading the following sections.

110. The view was universal among the respondent groups that the structure had no effect on hydrology (in terms of flow, water retention and water quality). The same was also said of the larger Bor (<500 to 1000m in length) and Nor Rav (500 to 3-4000m in length) gears that are increasingly being used at this site. On the other hand, pumping activities and allied dyke construction by fishers, primarily by the subleasees in the fishing lots, but also in the community fishery areas, are believed by over 80% of the respondent groups to have had more significant impacts on water flow and retention. Both lakes and small streams were reported to have been emptied in this way and the result of this was a decrease in water flow in Stung Sangkae. The draining of small lakes and dyked streams is likely to reduce the available dry season habitat and this could have implications for a number of the floodplain resident species. It is also believed that this pumping affected the adjacent habitat with 100% of respondent groups saying that pumping increased the turbidity in the remaining habitat. Respondent groups also reported that the effect of this was to increase the water temperature and this was affecting fish and increasing fish mortality in refuge areas (over 80% of respondent groups) and also that the water had a “bad smell” (75%).

111. Overall, there was a unanimous view across all the villages that fish had declined in abundance in all areas with abundance estimated to have been reduced by 60-70% from levels in the past. This decline in abundance has led to changes in fishing practices in the area, and almost all of these changes to where fishers can access are due to rules and behavioral changes rather than the direct effects of the physical structure itself. There were strong differences between the community fishery and the fishing lot in terms of access to fishing grounds. The creation of the community fishery meant that villagers in all the villages (as well as migrants) now have access to fishing grounds during the dry season. In contrast, the fishing lot operation has not led to any new fishing opportunities for the villagers.
112. As well as creating opportunities, there have also been a number of examples where opportunities to fish have been reduced. In the community fishery the area of Roha Tra Num Chring was recently designed as a protected fish sanctuary where fishing is prohibited in the dry season. There was a high level of awareness of this sanctuary with over 85% of respondent groups citing it as an example of a change to where villagers can fish. This measure was taken in order to protect the fish broodstock. For Fishing Lot #2, 75% of the respondent groups related that the change in lot operator had reduced the opportunities to fish. There were three reasons for this. In the first place, the operator during the period from 1994 to 1998 allowed fishers to go fishing in many small lakes of Prek Stung Chas during open season (i.e. at a time when fish are generally more abundant), during the period of the current operator (from 1998 to present) the lot operator has stopped fishers from fishing these small lakes and instead has begun to offer them on subleases. The structure itself has had other direct effects as fishers could travel by boat to go fishing at Boeung Nob and To Tem prior to 1998 but now they cannot go fishing at these lakes because the fishing lot operator has blocked the way to these fishing locations with a long bamboo fence barrage. Finally, the fishing lot has also expanded by some 7-8 km, enclosing a larger area around Pek Kantel, making fishers' potential fishing location narrower and making it more difficult to access fishing in this area.

113. Respondents identified a number of reasons given for why abundance had decreased and many of these were common to both areas so that there was not any significant difference between the reasons given regarding the community fishery and Fishing Lot #2 ($\chi^2$, $P > 0.05$, df = 10). Common reasons, as with the other sites, were increasing numbers of fishers, an increase in the number, scale and efficiency of gears (including electro-fishing and pumping) and clearing of the flooded forest (cited by 100% of respondent groups). In addition, in the community fishery respondents also cited poor enforcement and corruption as contributing to reduced abundance (38%) by not preventing the increased use of large-scale and destructive methods, while in the fishing lot the long bamboo barrage fence (100%) and non-adherence to the conditions in the burden book (12%) were also described as contributory factors. There was also an overall perception that the activities in the community fishery, due to increased access and the use of efficient gears were having a greater impact on fish stocks than the fishing activities in the same area when it was managed as a fishing lot. An increase in the number and efficiency of the gears employed in the fisheries around the Tonle Sap has also been noted by Sithirith and Grundy-Warr (2005).

114. Respondents were asked about the changes in species abundance in the community fishery and in the fishing lot. In terms of the species that are considered to have disappeared or declined there were no significant differences between the two areas and indeed there was a high degree of correlation between the aggregated responses. Two species (Pangassius conchophilus and Barbonymus altus) are believed to have disappeared from the two areas and a number of others to have declined (Figure 10). In addition, there was one important difference between the two areas when it came to species that had increased in abundance. While no species were reported as having increased in abundance in the community fishery, there was universal agreement between respondent groups that three-spot gourami (Trichogaster trichopterus) had increased in abundance, or declined relatively less, in the fishing lot area.
115. Respondents believed that the biggest local effects that were causing species-level changes were the increased fishing pressure and the destruction of fish habitat, for example through clearing of flooded forest. Gears in both areas, and particularly the structure in the fishing lot and the increasing use of **Bor** and **Nor Rav** fishing gears in the community fishery, are considered to be affecting the migration of fish from the lake to the floodplain and off the floodplain to the lake.

116. The reduction in access and perceived decline in abundance of fish has led to changes in fishing practices beyond where people fish. In all areas respondents indicated that there had been an increase in the introduction of larger-scale and more efficient gears including the nylon mesh **Bor** and **Nor Rav** gears, pumping out of sections of the floodplain, electro-fishing and giant lift nets. However, while the trends and changes were similar in the first instance there were important differences in the institutional aspects between the community fishery and fishing lot that, when combined with the structure, suggest that there may be different outcomes for the fish populations.

117. Respondents complained that in the community fishery there was a lack of enforcement and that this, combined with availability and affordability of efficient gears (e.g. the nylon mesh **Bor**) and ease of access to the fishery, meant that fishing was effectively uncontrolled. The lack of enforcement together with fishing pressure has led to conflicts between different fishers, typified by an increased incidence of gear theft. On the other hand, the fishing in the fishing lot was described as very effective and well organized and the main complaint regarding the fishing activities was that the lot owner did not always control instances of illegal fishing gear use.

118. These changes, together with the increase in demand for fish over time, have had an effect on the price of fish. Generally, the price of fish has been increasing over time and it was noted that the price of fish from the community fishery during the period when it was operated as a fishing lot was lower than it is now (see also Table 8).
Table 10 Changes in fish price of fish for three size classes of fish at the Prek Toal site between 2000 and 2006. Standard deviation in brackets.

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean price before (2000) (Riel/kg)</td>
<td>400.0 (115.5)</td>
<td>1687.5 (439.5)</td>
<td>2531.5 (670.0)</td>
</tr>
<tr>
<td>Mean price now (2006) (Riel/kg)</td>
<td>1000.0 (103.3)</td>
<td>3000.0 (258.2)</td>
<td>4250.0 (632.5)</td>
</tr>
<tr>
<td>Mean difference</td>
<td>600.0</td>
<td>1312.5</td>
<td>1718.8</td>
</tr>
</tbody>
</table>

119. As can be seen, it is the smaller fish that have increased most in price (by a factor of 2.5). One contributory factor to this increase is the reduced availability of these smaller fish locally. In the past, villagers used to be able to buy small, low value, fish from the fishing lot (Lot #2) to make Prahok. As the price of this fish rose the villagers changed what they did with the fish and began to sell this to fish traders at a slight profit. Most recently, in the last couple of years, the lot operator has decided to stop selling these fish species and they are instead kept by the operator to make Prahok himself.

120. Respondent groups all gave the same reasons for the increasing price of fish of all sizes. These were increasing demand, both locally and from Vietnam and Thailand, increasing fisher numbers and, consequently, smaller catches and lower catch rates and a general decrease in the size of fish caught. There was no difference between the community fishery and Fishing Lot #2 in terms of responses, and the structure was not considered to have any direct effect on fish prices.

121. There were interesting responses regarding the positive and negative aspects of the two management systems (Table 9). None of these related to the structure itself but centered more on issues of equity, accountability and sustainability.
Table 11 Perceptions among respondent groups of the positive and negative aspects of the two management systems at the Prek Toal site.

<table>
<thead>
<tr>
<th>Positive aspects</th>
<th>Community Fishery</th>
<th>Fishing Lot</th>
</tr>
</thead>
<tbody>
<tr>
<td>People can access the fishery all year round and this provides opportunities for outsiders to fish (e.g. Battambang, Siem Reap, Banteay Meanchey, Pursat and Kampong Thom).</td>
<td>Flooded forest, birds and wildlife are better protected than in the community fishery, and fish habitat is more abundant. Fishing lot system provides better control over fishing activities than community fishery.</td>
<td></td>
</tr>
</tbody>
</table>

| Negative aspects                      | Decline in flooded forest (suggested to be at least 60%) because of use for firewood and increase in large-scale and illegal fishing gears and activities. Corruption, limited capacity and poor accountability of managers, inability to enforce regulations and lack of support from government. | Intensive fishing, expansion in fishing lot area and blocking fishers’ routes across Lot #2 to go fishing in public areas. Burden book not enforced (e.g. use of legal fishing gears, legal fishing time/periods, percentage of the fishing lot area that can be subleased) |

122. Interestingly, fishers in the respondent groups indicated that they felt that the fishing lot system provided better control over the fishery than the community fishery but that the lack of accountability of the lot operator meant that illegal fishing activities, the timing of fishing activities and expansion of the effective lot area (e.g. around Pek Kanteel and the exclusion of fishing activities several hundred meters outside the fence in the Tonle Sap Lake) remain unchecked.

123. Respondent groups had similar recommendations for the improved management of the two areas. Again, none of the recommendations involved the structure itself but focused on the negative aspects that were highlighted in Table 9 above. Thus over 90% of respondent groups advocated the banning of the nylon Nor Rav and larger, fine mesh Bor gears from both areas. They also wanted to see less corruption in, and increased cooperation between, the fisheries administration, police and local authorities (70% of respondent groups), better enforcement of the burden book, laws and by-laws (46%) and measures to prevent the clearing of flooded forest, including possible provision of alternative fuel sources (39%).
II.3.3 Outcomes of studies at the local scale

124. Because of the differences in the sites and in the nature of the structures, it is unsurprising that the outcomes were, in many cases, quite different. It is worth therefore dealing with each of the sites in turn before highlighting some of the common elements.

II.3.3.1 Pursat

125. The main effects of the road were on access and not directly on fish stocks. In comparison with other effects on the fishery, such as the demand for fish and use of destructive fishing methods, it was the perception of all respondents that the impacts of the road on fish abundance and species composition are insignificant. Any negative impacts attributable to the road were considered to be mitigated by the presence of gates and culverts that maintained water movement up and down the floodplain. Any impacts are also perhaps mitigated by the background trend of fishers tending to fish further down the floodplain. Respondents did indicate that the culverts and gates and canals have provided additional fishing locations but that these were often exploited using more efficient gears. It was also suggested that the road affected the hydrology locally by increasing water retention in the area enclosed by the road and that this was beneficial for rice production in that area.

II.3.3.2 Stung Chinit

126. It is too early to say what the full effects of the development at Stung Chinit will be and, from the evidence of this survey, it is likely that these will be spatially varied. Particular areas of importance would seem to be the reduced flows and connectivity of the system and the effect that this will have in the longer term on water quality and on fisheries in the main stream, reservoir and rice fields. It was also not possible at this stage to note the effects of the dry season rice culture. Increased use of agricultural inputs such as pesticides and fertilisers should help to boost agricultural production but could also very well negatively affect the fisheries (e.g. Nguyen-Khoa et al. 2005). The flows are an important consideration as studies have indicated that decisions related to water allocation and flow can be a primary source of conflict between fishers and farmers (e.g. Islam and Braden 2006).

127. What can be said at this stage is that at Stung Chinit there was a belief among all respondents that the structure had significantly affected the abundance, relative abundance and catches of fish. These changes had also affected local fish prices and the prices that could be obtained for leasing access to fishing in the river. However, the nature of the changes differed by location. In the downstream areas close to the dam many fish, in particular the migratory species, are reportedly aggregating as they cannot easily pass through the spillway, canal and fish ladder. While this may have negative effects for these species in the locality in the longer term, these aggregations currently provide a useful fishing opportunity. However, further downstream there are few benefits other than to those households that have access to irrigation water. Here the belief is that the structure has negatively
affected water quality, fish abundance and catches because the connection between the upstream and downstream areas has been broken and that this has had a negative impact, particularly on the migratory species. There are also concerns about the control of the release of water from the reservoir and the risk of flooding.

128. In the area above the dam, the most significant change is the reservoir and this has provided an important new fishing location, particularly as it is a perennial resource. It is too early to say what the final effects of this reservoir will be as the dam has only recently been closed but initial reports are that migratory fish species in the catches from the reservoir are larger sized. All fishers who were interviewed and who were living above the dam believed that the reservoir could become a productive fishing location as it provided a large perennial water body comprising a variety of fish habitats that could also provide more food for fish. The nature of the reservoir and the larger size of some of the fish have caused changes in the way that the resource is exploited with larger mesh nets now being used and an increase in the number of people now using boats to fish from. However, there are also a number of concerns, and among these was uncertainty over the longer-term effects of the scheme. Fishers in the upstream areas were concerned that the immediate gains in production may be a short-term effect due to the retention and growth of fish above the dam and that in the longer term the reduced connectivity to downstream areas will lead to a reduction in production. This is a very real possibility (e.g. FAO 2001; Bernacsek 1997a; Petrere 1996). The fish pass was another area that fishers highlighted during the surveys as they were not entirely convinced that it was working as it was designed to and they believed that this should be assessed.

129. Nguyen-Khoa et al. (2005) found in their study of irrigation systems that the reservoirs created by irrigation schemes did in fact boost fisheries production and that the increased reservoir production more than offset the reduced downstream production. However, in a scheme the size of Stung Chinit the distribution of these benefits and losses needs to be considered as it is not the same villages and households that are receiving the increased opportunities and benefits and bearing the costs.

II.3.3.3 Prek Toal

130. The situation in Prek Toal is also interesting from a management point of view. On the one hand, there is the fishing lot where there is an emphasis on productivity from the fishery and the fishing is considered by respondents to be comparatively well managed by the lot operator (although not all the management decisions favour sustainability or access) and very intensive (see also Sithirith and Grundy-Warr 2005). On the other hand there is the community fishery where access is much less of an issue but where enforcement is difficult and there is evidence that there is an increase in the use of destructive practices and in conflict between fishers and that the efficiency and, consequently productivity, is lower. A similar pattern was noted between an inland fishery in Indonesia where the fishers hold rights to fish and a more open access floodplain fishery in Bangladesh. As with the fishing lot, the fishing in Indonesia was more efficient and less competitive and, as with the community fishery, the fishing in Bangladesh involved fishers competing with one another (Hoggarth et al. 1999).
131. Productivity in the fishing lot comes at a cost to equity in that only those who can afford to fish there during the open season are allowed to. By contrast, in the community fishery there are, by design, fewer equity issues (this is not to say that such issues do not actually exist in practice, or that they do not actually affect the poorest to a far greater degree) but this means that there is competition for fish and, with a lack of enforcement, widespread use of illegal gears and gear theft. Thus, the community fishery is likely to be a less productive or efficient system overall than the fishing lot.

132. What cannot yet be said is how the systems compare in terms of sustainability with regard to the fish stocks. On the one hand the community fishery area would appear to be more ‘porous’ to fish than the fishing lot, i.e. to provide greater connectivity of the system overall, primarily because of the lack of the fence structure. On the other hand, there are considerable destructive gears and less controlled use in the community fishery, which is affecting fish and their habitats and may be affecting sustainability.

II.3.3.4 Common elements

133. The study highlighted one key aspect that is of importance and that is the common belief that fish abundance, species diversity and household catches are declining. While it may be that overall catch levels are actually remaining steady, the distribution of fish may be changing if there are increased numbers fishing (reducing individual household fish) and more export of fish (both reported by respondent groups at all locations). The effect therefore is to decrease the asset base of the rural households, potentially affecting livelihood options and strategies and increasing their vulnerability. The responses to this reported by the respondent groups have been that fishing pressure has increased though the use of larger and more effective gears (including illegal and destructive gears), exclusion of fishers from certain areas and exploitation of new fishing locations, often further from the fishers’ homes. These aspects and their implications are explored in more detail in the livelihoods report.

134. The study also highlighted the importance of habitat connectivity in fisheries. The level of connectivity of riverine and floodplain habitats can have a direct effect on fish abundance and species composition (Welcomme and Halls 2004; Miranda and Lucas 2004; Berrebi-dit-Thomas et al. 2001; Halls et al. 1998). All three of the structures that were considered in this study have the potential to reduce connectivity and in the cases of Stung Chinit (water and fish) and Prek Toal (fish) this connectivity was seen to be affected. This issue of connectivity is an important consideration and should be considered at a number of scales. As the results from Stung Chinit indicate, fishers were aware that what was happening downstream of them was affecting local fish abundance. In all three cases it was also found that there were similarities in the species that were cited as having reduced abundance and that these were mainly white fish species, fish for which connectivity at larger scales is of particular importance.

135. The importance of connectivity and flows is also important to consider given the vital role of water flows as a distributor of fish larvae and juveniles through passive
drift (Poulsen et al. 2002). Four types of flows have been identified in relation to fish fauna in river and floodplain systems: population flows, critical flows, stress flows and habitat flows (Chea et al. 2006; Welcomme and Halls 2004). Population flows influence biomass through density-dependent interactions with parameters such as growth and mortality; critical flows trigger lifecycle events such as migration and spawning; stress flows endanger fish either through excessive flow rates or insufficient water, and habitat flows are needed for maintenance of environmental quality including temperature, sedimentation and nutrient levels. However, it is more difficult to identify what percentage of flow needs to be maintained. This is because the relationships between flow and ecological conditions (e.g. fish abundance) can be linear or curvilinear over a wide range and thresholds and have not been established (e.g. Acreman 2005; Sheldon et al. 2000; Extence et al. 1999).

136. Another aspect emphasized by the study sites that again highlights the importance of connectivity and flows is the issue of stress flows and the need to maintain dry season habitat because built structures can potentially affect this habitat. The dry season is a stressful period for many species and maintaining adequate water in these habitats and protecting these species from excessive fishing pressure is considered an important conservation measure (Welcomme and Halls 2004; Halls et al. 2001). In Prek Toal these habitats were primarily affected by the clearing of the forest and pumping. Pumping is affecting dry season habitats directly by drying out areas and indirectly by increasing the turbidity in others.
III  CONCLUSIONS AND RECOMMENDATIONS

137. Development planning should consider connectivity and the maintenance of critical habitats in time and space prior to development and the introduction of mitigation measures that can preserve sufficient flows to maintain ecosystem integrity. This is a recommendation that can apply to all planned structures. This will also potentially provide more predictable outcomes as it relies on preserving existing habitat and system characteristics rather than enhancing habitats or creating new habitats (Roni et al. 2005; Roni et al. 2002).

138. This recommendation echoes the points made by Poulsen et al. (2002) and Coates (2001) who suggest that environmental management, and consideration of how development measures might affect water and fish, should be a prerequisite for fisheries management. Given that connectivity exists across a range of geographic scales and varies across a range of time scales, it important that the planning processes for built structures consider the wider environmental context in which they will operate. There is also a requirement that information that can support such considerations needs to be made more widely available.

139. The case studies illustrate some of the particular requirements in relation to this recommendation. For example, the Pursat case study highlighted that for roads it is important that the effects of the road on the hydrological regime are considered. In this study there were no negative impacts on fisheries attributed to the road but this was believed to be because the road design included gates and culverts that enabled water to move up and down the floodplain. However, it was also reported that these culverts and gates were being used as fishing locations and that more efficient gears were being employed in these areas. It is therefore recommended that road building should carefully consider the existing hydrological regime and how culverts and gates can best be placed to maintain this regime and preserve environmental flows. Because these locations may be exploited it is also recommended that attention be given to fisheries issues, such as the use of fishing gears in the culverts, by the road management committees that are responsible for the maintenance of the roads and culverts.

140. Water management regimes at Stung Chinit should consider the needs of fishers (across the scheme but particularly in downstream locations) and balance the flow requirements for fisheries against the water requirements for agriculture. Further information is needed on the effects of flows. At Stung Chinit maintaining environmental flows was again important for fisheries. Access and flows between the upstream and downstream sections of Stung Chinit appear to be important. These issues have been raised for irrigation schemes by a number of authors (e.g. Nguyen-Khoa et al. 2005; Welcomme and Halls 2004). While we know that there is a negative impact on fisheries downstream of the reduced flow, it is not possible to describe the relationship between the flows and the fisheries. The effectiveness of the connections between the downstream and upstream sections of the river should also be assessed. Access to the upstream areas by fish downstream (and vice versa) should take into account aspects such as water volumes and flows that will trigger or hamper movement, for example, the fact that the maximum short-term swimming speed of many fish species is less than 0.5 m/s (Clay 1995 – quoted in Nguyen-Khoa et al. 2005; Arthington et al. 2004).
141. Managing flows between the upstream and downstream sections should explicitly address the balance of benefits from water management to the upstream rice farmers and downstream fishers. In the first place, management that will benefit the downstream fisheries will require that water flows account for past natural hydrological variation as much as possible by releasing appropriate amounts of water at the right times. However, determining the appropriate amount is not straightforward as water releases potentially come at a cost to agricultural production or to fishers in the reservoir upstream. Given that the downstream villages appear to have borne a number of costs of the scheme and received fewer benefits, at least in terms of the fishery, these trade-offs need to be carefully considered.

142. Within the upstream area flows between the main channel and reservoir and the rice fields have been identified as important. While it is still rather too early to conclusively determine, the rice field fisheries appear to have suffered from poor flows, and modifications to water management practices may be able to improve the production potential of these fisheries.

143. The level of sustainability of the fishing practices in Fishing Lot #2 and the community fishery is uncertain and should be established to inform management decision-making. At Prek Toal there were issues with both maintenance of flows and maintenance of critical habitats (flooded forest and dry season refuges). While the structure did not appear to affect the environmental flows in terms of the hydrological regime, there was a clear effect on fish movement. What is less clear in this case is the overall effect on fish and levels of escapement of fish and fish larvae that would provide an indicator of the sustainability of current management practices. It is therefore a recommendation for the Prek Toal site that the relative sustainability of the fishing systems used in the Tonle Sap Lake in terms of their effect on fish recruitment and escapement be investigated.

144. In terms of dry season habitats, pumping in both the community fishery and the fishing lot appears to be a particular issue as far as illegal or intensive gears are concerned in that it seems to be a fairly destructive method. Habitat being modified to facilitate pumping, i.e. through the creation of dykes and dams across streams, and pumping also has wider effects, including increased turbidity in other water bodies and reduction in dry season habitat. These dry season habitats provide important refuge areas, particularly for grey and black fish, and structures and associated management measures that effectively reduce dry season habitats can result in a decline in fish production, as has been suggested by the respondents in this study and the results of Halls et al. (1999).

145. Flows and fisheries are not just a result of the physical structures but also of how these structures are managed and utilised. It is therefore important to examine the associated institutional arrangements. This is highlighted by examples from each of the study sites.

146. In Prek Toal there is a need to ensure the accountability of the management decision-makers and to improve the contact and collaboration between the various actors including fishers, management committees and the Fisheries Administration. In the fishing lot there has been an increase in activities such as pumping and expansion of the effective area of the fishing lot that require some form of control. At
the same time, there is a good deal of unregulated activity within the community fishery and an intensification of fishing as well as conflicts between fishers. There is a need also to develop a cost-effective enforcement system within the community fishery area. This will require cooperation and collaboration between the main fisheries stakeholders in the area and will be a challenge.

147. At the Stung Chinit site there was also clear evidence of the potential for conflict. Downstream villages are concerned about water management and how this will affect the fisheries and flood regimes and evidence from the pre-survey has highlighted that there have been conflicts between water use for agricultural use and for maintaining fisheries and this had been given as one reason that the scheme fell into disuse in the past. The potential for these water use conflicts has also been highlighted in other studies elsewhere (e.g. Nguyen-Khoa et al. 2005 and Huq 2005). Because of this potential, as well as the issue of how the increase in agricultural intensity and inputs affects fish production, it will be important to revisit the site in the future in order to assess the relative agricultural production gains and changes in fisheries.

148. The situation in Pursat was that the introduction of the road, gates and culverts provided new fishing opportunities. While there have been rules introduced by the road management committees that prohibit the blocking of these culverts by fishing gears these were not always adhered to and more intensive fishing gears have been deployed in these places.

149. Access to fisheries and to the benefits from fisheries is likely to become an increasingly contentious issue and requires an explicit consideration of what benefits are required from fisheries and how these should be shared within society. The investigation into built structures also highlighted some wider questions that it is worth drawing attention to. The almost unanimous response from respondent groups is that fishing effort is increasing through a combination of the increasing numbers of people fishing and the increasing scale and efficiency of the gears being used. The use of efficient gears, and in particular those classified as illegal such as electro-fishing, is reportedly widespread and there have been calls by many of the respondent groups for improvements in enforcement and clamp downs on illegal fishing. While this again highlights the issues around enforcement and how this can be achieved, there are some broader implications for decision-makers in this trend.

150. Clearly the fish resources themselves cannot sustain ever-increasing pressure and still maintain biological integrity. There are already concerns over a number of species including the giant river catfish and giant carp. However, there are also a great many people who are dependent on the resources for food and/or income. Thus, maintaining the productivity of the fishery and ensuring an equitable, or at least acceptable, sharing of the benefits is also a key consideration. Even so, increasing fishers chasing possibly fewer wish will mean lower individual catches, increasing the individual pressure to use more effective gears and raising the potential for conflict. At some point decisions will have to be made about access to fisheries. This point is highlighted by the contrast between the two fisheries in the case of Prek Toal.
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ANNEX A: AN EVALUATION OF FISH SPECIES AND GENETIC DIVERSITY OF THE TONLE SAP GREAT LAKE

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Summary

Fish has long been critical to all Cambodians. It is a major source of nutritious food in the daily diet, a primary source of income and has strong cultural and religious significance. Fisheries matter a great deal to the millions of people who live on the banks of the country’s rivers, particularly those living in and around the Tonle Sap Great Lake. Cambodians are considered one of the highest per capita consumers of freshwater fish in the world (a recent estimate of 67 kg per person per year from household surveys). Freshwater fisheries contribute 10 to 12% of Cambodia’s GDP accounting for 31% of the GDP contribution of the primary sector. Since 2000 Cambodian freshwater capture fisheries rank fourth in the world in terms of total catch (i.e. 400,000 tons per year). This is considerable as the country is rather small (181,035 km²) and its population is also small (13.6 million in 2005). Actually, with an average 30 kilograms of freshwater fish caught per Cambodian per year, the country has the most intense freshwater fisheries in the world.

The contribution of various ecotones to global biodiversity in Southeast Asia reaches the status of hotspot. The Indo-Burma region, including the Mekong River Basin, is no exception. The aquatic resources of the basin represent enormous biodiversity with at least 1,200 fish species. Its extremely diverse fish community reflects past climatic and geological processes, which have brought together the fauna of several river systems, and places the Mekong among the top three rivers in the world (after the Amazon and the Zaire/Congo). Cambodia’s Mekong River Basin harbors approximately 500 fish species, of which, about 200 fish species are found in the Tonle Sap Great Lake (the largest and most productive lake in Southeast Asia, being formed by subsidence about 5,700 years ago). The Tonle Sap Great Lake is the center of Cambodian fish production and it is globally significant ecologically, being nominated as a Biosphere Reserve in 1997 under the Man and Biosphere Program of UNESCO.

Fisheries from the Tonle Sap Great Lake contribute over 60% of the total freshwater fish catch in Cambodia. The Tonle Sap Great Lake has some of the smallest and largest freshwater fishes in the world, from the minute carp Oreichthys parvus (maximum length 2.5 cm), to huge species such as the Mekong giant catfish Pangasianodon gigas (maximum length 300 cm) and the giant barb Catlocarpio siamensis (maximum length 200 cm). The more familiar fish groups comprise carps (Cyprinidae – 39%), catfishes (Ariidae, Bagridae, Clariidae, Pangasiidae, Siluridae and Sisoridae – 24%), herring (Clupeidae – 3%), snakeheads (Channidae – 2%), featherbacks (Notopteridae – 2%), gouramis (Osphronemidae – 2%), and climbing perch (Anabantidae – 1%). The remaining 27% consists of needlefishes or garfishes, tongue fishes, soles, leaf fishes, archerfishes, drums, threadfins, snooks, anchovies, eels and many other fish species. A very recent first research result is that “white” fish species constitute about 37% of the total number of Tonle Sap Lake fish species, “grey” fish species 50%, and “black” fish species 13%. The catch composition of “white” fishes and “grey” fishes is about 60% of total
catch, while “black” fishes contribute about 40% to total fish catch. The previous estimates of composition of catches of top ten fish species (i.e. *Henicorhynchus lobatus/siamensis*, *Channa micropeltes*, *Cyclocheilichthys enoplos*, *Labiobarbus* spp., *Osteochilus* spp., *Cirrhinus microlepis*, *Pangasianodon hypophthalmus*, *Barbonymus gonionotus*, *Paralaubuca typus*, and *Channa striata*) in commercial fisheries (i.e. large- and middle-scale fisheries) by the Mekong River Commission – Fisheries Program reveal that “white” fishes (i.e. six of the top ten fish species) contribute about 45% of total catch and 27% of total value, “grey” fishes (i.e. two of the top ten fish species) 7% of total catch and 4% of total value, and “black” fishes 11% of total catch and 25% of total value.

The many fish species of the Tonle Sap Great Lake encompass 90 genera and 32 families with a diversity of form, feeding habits and modes of reproduction. As a result of the high diversity in the Tonle Sap Great Lake, fish occupy all available aquatic habitats and exploit many kinds of foods. Biodiversity is a crucial element in high fishery production, providing to some extent a natural “safety-valve” each season, so that loss of any species (e.g. from a disease or over-fishing) will be compensated for by increased production of other species. The high diversity of species, the great range of habitats, and the variation in catches over time and space make wild freshwater fish available to a wide range of people, thus a high degree of participation in Cambodian fisheries.

Within fish species, diversity might be partitioned into variation within and among populations. It is necessary to maintain both types of variation to minimize the frequency of extirpation of local populations and to sustain species stability since genetic diversity is a requisite for evolutionary adaptation to a changing environment. So far, genetic stock structure and differentiation at the population levels has proven to be the best method to manage the conservation of species, including fisheries. However, their application, particularly in tropical regions, is still in its infancy. In Cambodia, there is very little scientific knowledge of fish population genetics (i.e. genetic diversity and stock structure). The first research study is on population genetics of the two large migratory Pangasiid catfish species *Pangasianodon hypophthalmus* and *Pangasius bocourti* in the Mekong River (including Cambodia, Laos, Thailand and Vietnam) using both mtDNA and microsatellite markers by Cambodian DoF/KULeuven. The recent study on mtDNA stock structure of the two small migratory Mekong River carp species *Henicorhynchus siamensis* and *H. lobatus*, collected throughout Cambodia, Thailand and Vietnam, was conducted by MRC/QUT/ACIAR. In addition, there is an on-going mtDNA phylogenetic study on the Mekong giant catfish *Pangasianodon gigas* by NACA.

So far in the Mekong region, there are nine microsatellite markers in the SE Asia catfishes *Pangasianodon hypophthalmus* (4) and *Claria batrachus* (5) developed in 1999, twenty-seven microsatellites for the migratory Asian catfish family Pangasiidae (i.e. five species: *Pangasius krempfi*, *P. bocourti*, *P. conchophilus*, *P. pleurotaenia*, and *Helicophagus waandersii*) developed in 2002, and recently twenty-four microsatellites in the captive Mekong giant catfish *Pangasianodon gigas* developed in 2006. In the past decade, there have been several studies on population and phylogeographic structure in SE Asia fish, i.e. the catfish *Hemibagrus nemurus* in SE Asia using mtDNA markers published in 1995, the climbing perch *Anabas testudineus* in Thailand using allozymic markers in 2000, Pangasiidae catfishes in SE Asia using both allozymic and mtDNA markers in 2000 and using mtDNA markers in 2003, the four species of the catfish genus *Clarias* (i.e. *C. batrachus*, *C. macrocephalus*, *C. gariepinus*, and *C. meladerma*) in Thailand using allozymic markers in 2002, the river catfish *Hemibagrus nemurus* in Malaysia using microsatellite DNA markers in 2003, and the cyprinid fish *Barbonymus gonionotus* in SE Asia using mtDNA and microsatellite markers in 2004.
To date, the genetic approach for identifying discrete gene pools (i.e. stocks or populations) of fish, and hence effective management units, has not been trialed in Cambodia and so the basis for developing management principles and practices is limited. Therefore, population genetics programs are needed to (1) demonstrate the utility of molecular population genetic data for fisheries and aquaculture management in Cambodia, particularly in the Tonle Sap Great Lake and (2) develop both human (expertise) and physical (DNA laboratory) capacity in Cambodia in undertaking and interpreting such programs. This approach will provide a major boost to the level of scientific knowledge available to managers for developing successful long-term management plans for Tonle Sap Great Lake fish species. In parallel it will develop expertise in Cambodia in the practice and interpretation of such data sets in fisheries and aquaculture management where previously it was largely absent. Together this should provide a powerful impetus to develop and apply similar technologies more widely on Lower Mekong River Basin fish species and ultimately promote the level and quality of fish stock management in the region.
ANNEX B. SURVEY FORMS

Built Structures Fisheries Survey Form

COMPLETE 1 FORM FOR EACH INTERVIEW

Section A. - DETAILS OF THE INTERVIEW

<table>
<thead>
<tr>
<th>Date</th>
<th>Respondents</th>
<th>Gender/Age</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td></td>
<td></td>
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<tr>
<td>Structure type</td>
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<td></td>
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<tr>
<td>Village name</td>
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<tr>
<td>Commune</td>
<td></td>
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<tr>
<td>District</td>
<td></td>
<td>Who identified them?</td>
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<tr>
<td>Province</td>
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</tbody>
</table>

Section B. - TYPE OF INVESTIGATION

B1. Is this a before/after investigation?  

Yes/No?

If answer to B1 is "Yes" then fill in sections C, D, E and F
If answer to B1 is "No" then fill in sections C, E and F

Section C. - MAPPING THE CURRENT SITUATION

Guidelines:

We get the respondents to draw a map of the area as it is now (use large piece of paper).

Important aspects to include are:

1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Highlight which ones are new or have changed. Location name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that are in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.

Now go to section D or E.
Section D. - MAPPING THE SITUATION BEFORE THE BUILT STRUCTURE

Guidelines:

We get the respondents to draw a map of the area as it was before the built structure was put in place (use large piece of paper). Important aspects to include are:
1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing.  Local name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that were in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.

Now go to section E and to ask about changes.

D1. Is there anywhere that you are fishing now that you were not fishing before?  
If D1 = yes then describe why?

D2. Is there anywhere that you were fishing before that you are not fishing now?  
If D2 = yes then describe why?
Section E. - CHANGES IN THE FISHERY

E2. For each of the locations that are still being fished, what changes have there been in catches and fishing and why, e.g. change in depth, number of fishers, gear types, scale of the gear, species etc.

1. total catch - how much changed in %? overall, small- and big- sized fish groups and why changed?

Did/does the built structure affect catches? What level?

2. fish size - how much changed in %? overall, small- and big- sized fish groups and why changed?

Did/does the built structure affect fish size? What level?
Section E continued

3. catch composition - how much changed in %? overall, small- and big- sized fish groups, by species and why changed?

Did/does the built structure affect catch composition? What level?

4. fish movement and migration - why changed? (white, grey and black fishes)

Did/does the built structure affect movements and migrations? What level?
Section E continued

5. fishing effort - why changed?

Did/does the built structure affect fishing effort? (gear types used)

6. fish price - how much in %?: overall, small-sized fish group and big-sized fish group. Why changed?

Did/does the built structure affect fish prices?
Section F. - EFFECT OF THE BUILT STRUCTURE ON HYDROLOGY & HABITATS

F1. How do the fishers feel that the built structure has affected/affects the water flow and water quality? For examples: extent and duration of flooding, amount of fish disease, water colour and turbidity.

1. How water flow affected?

2. How water retention affected?

3. How flooding areas affected?

4. How water quality affected? (e.g. fish disease, water colour and turbidity)
F2. How do the fishers feel the built structure has affected/affects the habitats or fishing locations?
For example: new habitats or fishing locations created, change in size/area, access to fishing locations

1. New habitat or fishing location created?

2. In the past could you access to many locations easily?
F3. Is there any other information about the built structure or the fishery that the fishers would like to share with us?

Recommendations/suggestions for protecting your fisheries resources

Are built structures having positive or negative impacts on fisheries resources? Why?
In case of negative impact, how do you minimize it?

Form completed by:
Fisheries Ecology Survey Form

COMPLETE 1 FORM FOR EACH INTERVIEW

Section A. - DETAILS OF THE INTERVIEW

<table>
<thead>
<tr>
<th>Respondents</th>
<th>Gender/Age</th>
</tr>
</thead>
</table>

Date  
Location  
Structure type  
Village name  
Commune  
District  
Province  

Who identified them?

Section B. - MAPPING THE CURRENT SITUATION

Guidelines:

We get the respondents to draw a map of the area as it is now (use large piece of paper).

Important aspects to include are:

1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Highlight which ones are new or have changed. Location name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that are in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.

Now go to section C.
C1: For each location records gear and main gear used by season, scale and mesh size of the gear, species caught (see pictures), and catch per day

<table>
<thead>
<tr>
<th>Location</th>
<th>Main gear</th>
<th>W/D season</th>
<th>Scale</th>
<th>mesh size</th>
<th>Species caught</th>
<th>kg w sea</th>
<th>kg d sea</th>
<th>kg total</th>
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</tbody>
</table>
C2: Record the fish species caught by season, catch per season and average size of the fish in that season

<table>
<thead>
<tr>
<th>Species</th>
<th>Wet season (6-10)</th>
<th>Dry season (11-5)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td>cm</td>
<td>kg</td>
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<tr>
<td>Riel</td>
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<tr>
<td>Andetchhkae</td>
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<td>Chhkaok</td>
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<tr>
<td>Pra Thom</td>
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<td>Kae</td>
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<td>Po</td>
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<td>Chhveat</td>
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<tr>
<td>Kros</td>
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<tr>
<td>Changva</td>
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<tr>
<td>Prual</td>
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<td></td>
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<tr>
<td>Kambot Chramos</td>
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<tr>
<td>Brama</td>
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<td>Ros</td>
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<td>Chhdaou</td>
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<td>Srakakdam</td>
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<td>Kantrop</td>
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<tr>
<td>Slat Srae</td>
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<td>Kanhchos Chnot</td>
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<td>Khman</td>
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<td>Ta Aon</td>
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<td>Linh</td>
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<tr>
<td>Kanhchrouch</td>
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<tr>
<td>Sanday</td>
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<tr>
<td>Sleuk Reusei</td>
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<td>Ka Ek</td>
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<tr>
<td>Kahae</td>
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<tr>
<td>Chipin Prak</td>
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<tr>
<td>Proloung</td>
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<td>Kranh</td>
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<td>Kantho</td>
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<td>Kray Sre</td>
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<td>Kampleenah Sre</td>
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<td>Chhlounh</td>
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<td>Kcheng</td>
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<td>Angdeng</td>
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<td>Khman</td>
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</tbody>
</table>
### Section D - LOCAL MIGRATIONS AND SPAWNING

D1. Use the local map and transparencies to show the location and timing of migrations and where the fisher perceives the source of young fish to be (e.g. local, tributary or Mekong).

<table>
<thead>
<tr>
<th>Species</th>
<th>Where the young fish come from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pra Thom</td>
<td></td>
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<tr>
<td>Prual</td>
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<tr>
<td>Riel</td>
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<td>Chhpin</td>
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<td>Ta Oan</td>
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<td>Kanh Chos</td>
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<td>Kanthou</td>
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<tr>
<td>Kray Srae</td>
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<tr>
<td>Proloong</td>
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</tbody>
</table>

D2. Have there been any changes in migrations and movements because of the built structure? If yes, which species and why do they think this has happened?
Section E - NEW INFORMATION ON FISH ECOLOGY

H1. Ask fishers for which species they have knowledge of spawning, nursing, feeding and migrations within the basin. For those fish that they have knowledge, complete the following table. For the ecology type (black/white/grey) you will need to identify this yourself.

<table>
<thead>
<tr>
<th>Species name</th>
<th>Type of Spawning habitat</th>
<th>Name of Spawning location</th>
<th>Type of Feeding habitat</th>
<th>Type of nursing habitat</th>
<th>Ecology type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andet Chhkae</td>
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<tr>
<td>Kanhchos Bay</td>
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<tr>
<td>Kanchras Thom</td>
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<tr>
<td>Bandoul Ampov</td>
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<tr>
<td>Reus Chek</td>
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<tr>
<td>Kasan</td>
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<td>Phtoung</td>
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<td>Chlaing</td>
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<td>Ka Ek</td>
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<td>Angkor Prak</td>
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<td>Dorng Khteng</td>
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<td>Chunteas Phluk</td>
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<td>Ampil Tum</td>
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<td>Stuk</td>
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<td>Kra Morm</td>
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<td>Ka Uk</td>
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<td>Krum</td>
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<td>Chunluanh Moan</td>
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<td>Kantrang Preing</td>
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<td>Kampleav</td>
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<td>Khlaing Hay</td>
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<td>Kes</td>
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Form completed by:
ANNEX C. PRE-SURVEY REPORTS

Kampong Thom Province

Objective of the trip: To select sampling locations and test the fisheries component questionnaire at Stung Chinit site in Kampong Thom province

Duration of the trip: 3 days (21-23 August 2006)

Persons involved: Dr. So Nam, Dr. Robert Arthur, Mr. Leng Sy Vann, Mr. Prum Sitha, and Miss. Pom Sok Hort.

The site:

The site at Stung Chinit in Kampong Thom Province represents an irrigation scheme comprising a number of built structures that include a barrage across a river (Stung Chinit River), sluice gates, canals (including channelised rivers), embankments, roads, a fish pass, an irrigation reservoir and paddy fields. This is an example of a development that has rehabilitated an existing, but disused, irrigation scheme that dates from the Khmer Rouge period. From the available information it seems that the scheme was in use (gates closed) between 1981/82 and 1989/90 after which the barrage was broken (gates open). There have been a number of reasons given for this including conflict between fishers and water users but the true reason remains unclear. The scheme remained out of operation until June 2006 when the present, renovated and extended, scheme came into operation (gates closed once more).

Progress report:

1. Consulting with Provincial Fishery Officers

The team met with provincial fishery officers to inform them about the purpose of the visit to Kampong Thom. This was also an opportunity to get additional information from them regarding the built structure at Stung Chinit, especially about the patterns of fishing activity for the villagers who fish in the affected river. From discussions with the livelihoods component team and with the provincial fishery officers, it was decided that the team would visit four communes: Chaeng Daeng, Kampong Thmor, Boeung Lvea and Thnoat Chum commune. Within these four communes six villages were identified that would be visited:

- Tek La’ak, Snao, and Sang village in Kampong Thnor commune,
- Prey Dom village in Chaeng Daeng commune, and
- Thnoat Chum village 1, 2, 3, or 4 in Thnoat Chum commune,

1. Consulting with commune/village head and commune council members

We met with the chiefs of three communes (Kampong Thmor, Thnoat Chum) to consult with each of them about fishery situation around the irrigation scheme at Stung Chinit. This information was given by representative of each commune through mapping and interview techniques.

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Tek Laak, Snao and Sang villages were identified based on discussions about an earlier visit by the livelihoods component.
Kampong Thmor commune

We went to meet the Chief of Kampong Thmor commune accompanied by Kampong Thmor Fishery Inspector (Mr. Keo Sitha, phone number: 012 716 339). The head of the commune (Mr. Men Chin, phone number: 012 596 235) provided information regarding the location of fishing villages and his views on the fisheries situation at Stung Chinit.

- La’ak village is a village where villagers fish in both Stung Tang Krasang and Stung Chinit irrigation reservoir. Snao and Sang villagers go fishing mainly in the irrigation reservoir.
- Regarding the fishery situation in Stung Chinit, before the closure of the gate following rehabilitation of the irrigation scheme there were many fish in Stung Chinit upstream of the dam and fishermen could at this time catch large fish, including species such as *Mystus wyckioides*, *Wallago Leerii*, *Probarbus jullieni*, and *Catlocarpio siamensis*. These species are now rarely caught.
- The head of the commune relates that there are still many fish both below and above the gate that can easily be caught (more above than below). Some parliamentary people came recently to see how the abundance of fish had increased but he is not sure whether the abundance is due to an actual increase or just fish concentrating at these sites.
- The fish ladder is considered to be beneficial if it allows fish to get up but there is no evidence for this.
- Before any irrigation scheme was created there were many pools in the upstream area that were an important source of fish as a lot of fish congregated in these deep pools. During the period when the gate was open the pools silted up. The reason given for this was that the forests were being cleared along the river. The larger trees are prized for their wood and because the roots make good plowing implements. Removing the trees has a big effect in making the river and pools shallower and both water temperature and turbidity increase.
- Regulation of the water using the gate means that the forest downstream no longer gets inundated in the same way. This makes it easier to exploit. Development of the irrigation scheme has had an effect on trees with a lot of palm trees around Snao village being removed.

After discussions with the commune head, the team went to see the heads of each of the three villages within the commune and to discuss with groups of three fishers from each in order to get a more detailed picture of the fishing activities, and changes in fishing activities in each village.

La’ak village

La’ak represents a village upstream of the irrigation scheme, in particular the dam across Stung Chinit. According to respondents at La’ak village fish were abundant during the time when the dam of Stung Chinit was not broken (i.e. was closed). After the dam was broken in 1989/90, the number of fish declined too. With the dam closed large aggregations of fish such as *trey riel* are seen below the dam, where they can easily be caught. Everyone from the downstream areas fishes just below the dam as the fish get stuck there and cannot pass. Fish from upstream are also less able to move downstream and some have been observed spawning at the edges of the irrigation reservoir. This is a benefit for the fishers upstream. It is also good because in the dry season there were not so many places to fish but now they can fish easily because there is water in the reservoir.
Villagers have been fishing in both Stung Tang Krasang and Stung Chinit. With the dam closed again the fishers use the reservoir more because it is closer. In La’ak village there are five or six households that go to fish all the time, the others just fish occasionally with cast nets or with gillnets set overnight. Over time there have been changes in fishing with the number of fishermen increasing; in some places there is even fishing in rotation. There were two, interrelated, reasons given for this. The first is that people see that there are fish and that more fish are being caught so they also want to go fishing. Also, after planting rice, farmers have more free time so the opportunity is there and the numbers of fishers increase. The fishing gears have also changed with mesh sizes decreasing. In the past nets with 3-4 cm mesh sizes were used but now 2.5 cm mesh sizes are common and fishers are catching many more small fish.

There have been some differences identified between the two rivers with fishers mostly catching black fish species in Stung Tang Krasang. They report that *Wallago attu* is present in both rivers: Stung Tang Krasang and Chinit. There have also been changes in the composition of fish in the rivers over time; particularly notable is the decline in snakeheads, especially *Channa micropeltes*. However, this is due more to harvesting for aquaculture than the dam. The fishers weren’t able to catch much in the reservoir this year because there is a larger area of water and the fish are less concentrated so more difficult to catch. They hope to catch more next year because the broodstock were not caught this year and the increase in fish will mean that they can use larger mesh sizes and not have to set gillnets overnight. In the wet season (May/June) fish (i.e. black and grey fish) move and migrate from the stream (i.e. both rivers) to rice fields, lakes, and other floodplain areas though canals and tributaries to feed and spawn (an upstream migration according to local knowledge). In the dry season (November/December) fish move from the rice fields, lakes, and other floodplain areas to the stream through canals and tributaries (a downstream migration according to local knowledge) in order to find refuge (e.g. in deep pools) where the fish can hide and feed. When the dam was open fish (i.e. white fish) moved and migrated down the river to feed in the floodplain and lake.

**Snao village**

Snao village is adjacent to the irrigation scheme dam and therefore represents a village in the middle of the scheme. Fishers from the village fish for household consumption and have generally been fishing below the dam. This is a general thing that people downstream of the dam do not really fish above the dam and the fishers report that there is some sort of unofficial regulation that if you are from downstream you fish downstream and if upstream you stay upstream. (According to the fishers, there was also an allocation of fishing locations along the river with traditional family locations that were all identified a long time ago. This was all along the river and this fishing location system is still in place in the downstream areas). The main fishing gear used in this village was the cast net.

When the dam was closed this changed as there became a large area upstream to fish all year and fewer opportunities downstream. The fishing downstream was affected as there was less water and the fishing was only good while there was water, particularly from November to January, while fishing upstream could continue all year round. It is the opinion of the fishers that fishing will become better upstream compared to down for this reason and already they say that there are generally more people fishing upstream compared to down. The effect of the closure was that the larger area upstream meant that there were no longer regulations there and fishers from downstream could fish in the reservoir. However, the restrictions remain in place.
downstream where there is still partitioning and it can get quite crowded but where the catches can be quite good for the few months that there is sufficient water. Fishers from upstream are still not allowed to fish in this area.

They were also able to inform us that there were more fish upstream than downstream when the dam was not broken, with bigger fish, for example a *Wallago lerri* of up to 20 to 30 kg, and more fish at this time compared to when the dam was open. When the dam was broken (opened, the fishers say through natural erosion of the base of the dam), there were fewer fish and catches were smaller but they could catch more in the downstream areas. However, in the future they do not expect catches to return to the levels they experienced before when the dam was closed because of the modern, smaller mesh, fishing gears, the increase in numbers of fishermen and the clearing of the flooded forest. Before in Snao village some people used to buy fish and about a third went fishing after rice planting; now they all fish. In addition, before it was just adults who fished but now younger people from Snao are also fishing using hooks and line.

In the wet season the catches were lower than those in dry season because at this time the river was full of water and very deep, making it difficult to fish. In the dry season villagers always went fishing in the river’s deep pools and in the irrigation reservoir, and especially in October to November they could catch a lot of fish. The reason given for people not catching much in the upstream areas at the moment is that when the dam was closed the fish in the reservoir were quickly caught. After the dam was closed, the water downstream was reduced and so fewer people were able to go and fish there at that time.

Regarding the structure, it was the opinion of the fishers that some fish are able to get up the fish ladder but these are larger fish and that smaller species such as *trey riel* cannot move up the pass as they are not strong enough.

The above information is the first information obtained from the village head only. This information may be different from that obtained from experienced fishers.

**Sang village**

Sang village is downstream from the Stung Chinit dam and represents a village at the edge of the irrigation scheme. Fishers at the village informed us that before the Khmer Rouge dam on Stung Chinit had been broken, there were many fish species in Stung Chinit. At that time the majority of the people living in the village always went fishing upstream below the dam where fish congregated and a few (the minority) fished around the irrigation reservoir. At this time many fish species were caught (e.g. *Morulius chrysophekadion*, *Osteochilus melanopleurus*, *Micronema micronema*, *Pangasius lamnudi*, *Henicorhynchus siamensis*, *Thynnichthys thynnoides*, *Barbonymus gonionotus*, *Mystus wyckioides*, *Wallago attu*, *Hampala spp*, *Channa striata*, and *Channa micropeltes*).

Fishers report that they are now catching less and using more gears or fishing for longer.

After the dam was broken, some fish species were no longer caught (e.g. *Mystus wyckioides* and *Channa micropeltes*) and some were caught in smaller numbers than before (such as *Wallago attu*, *Hampala spp.*, *Channa striata*, *Henicorhynchus spp.*, and *Thynnichthys thynnoides*). Overall fish abundance is believed by the fishers in this village to have declined since the time before the dam was broken. Reasons given for why fish abundance has declined included: increasing numbers of fishermen, increasing fishing effort (i.e. time spent fishing and
number of gears), and new and potentially unsustainable fishing gears (including gears made from filamentous mesh net).

The fishers were also able to provide some information on fish movements and migrations, reporting that there are two peak periods of fish migration: (1) upstream migration in November/December and (2) downstream migration (May/June). Interestingly, according to them, the migration patterns in Stung Chinit are completely different from the patterns in Stung Tang Krasang due to its different water regime.

**Boeung Lvea village/commune**

We met with the chief of the commune to consult with him about the general situation in the commune. He told us that this commune started out as a single commune but is now divided into two parts (Old Boeung Lvea (in the upland area) and New Boeung Lvea (this village). New Boeung Lvea was established around 1980 and is situated along the main irrigation canal leading from the irrigation reservoir and, as such, represents a village in the middle of the scheme. According to the commune chief, the main occupations of villagers are related to collecting secondary wood and non-timber products from the upland areas around Old Boeung Lvea and rice cultivation around New Boeung Lvea. The reason for this is that they do not have much land. According to him only about 30% of households are engaged in fishing activities and mostly in Stung Tang Krasang although they also use the reservoir area of Stung Chinit when the dam is closed as anyone can fish there. The villagers thus split their time between the two locations and, according to the chief of the commune, would continue to do so even with the operation of the irrigation scheme. Because there was not a high degree of reliance on fishing in the village and villagers did not have long fishing experience it was decided not to include Boeung Lvea as a study location for the fisheries component.

**Chaeng Daeng commune**

We met first with the vice-chief of the commune and the secretary of the commune at the commune office. We informed them of the purpose of our visit and asked for information about the commune, especially about villages within the commune that were particularly dependent on fishing or were recognized as having particular knowledge about fish and fishing. We were informed that Prey Dum village is an active fishing village and that this village was located about one kilometer from the river. Because it is also a lowland village, the village is at risk from flooding due to the dam that can affect the rice fields every year. Before the new scheme was developed, there was a large natural canal that allowed water to escape from the land around the village to the river downstream of the dam. During the renovation of the scheme the canal was channelised and when the water is high this canal does not transfer the water away sufficiently and local flooding occurs affecting both the village and surrounding rice fields.

When the dam was not broken (post Khmer Rouge period), there was a high abundance of fish and many big fish also. For example, a *Wallago leerii* could weigh 0 to 20 kg. Since the dam was broken fish abundance has declined strongly and some fish species were not found in some places, in particular they mentioned *Barbomyxus gonionotus* and *Hampala spp*. The commune officials thought that with the reconstruction of the scheme fish stocks may recover in the future.

**Prey Dum village**
Prey Dum is similar to La’ak village in being upstream of the dam. However, it is located on the other side of the river and irrigation reservoir, away from Stung Tang Krasang, and instead near the channelised canal. The village is comprised of 182 households according to the village chief. He complained that his village and the nearby rice fields get flooded due to the dam because the new channelised canal is not able to take away sufficient water. Last year households in the village lost some rice through flooding and this year it has been much worse and they expect that this will be the case also in the future. The canal used to be a tributary that ran from a lake in the flooded wetland area to the river downstream of the dam and water would move quickly down this tributary. With the development of the scheme this tributary became a canal that now acts as a link between the irrigation reservoir upstream and the river below the dam. The villagers would like to enlarge the canal so that it is able to remove the water more effectively to reduce the flooding and, according to the village chief, the MoWRAM is considering this. However, the MoWRAM had also apparently agreed to compensate villagers between 1000 (productive lowland areas) and 500-700 (less productive areas) US dollars per hectare for the damage that might result to their fields from the renovation of the scheme. Up to this point the villagers complain that they have not received this money from the MoWRAM.

The village chief considers that the overall the scheme provides more benefit for people living downstream because they can do 2-3 crops from their rice fields, but upstream people get less benefit from their rice fields, which are irrigated by rain water rather than from the reservoir, and indeed suffer from the flooding. During the dry season there is some irrigated rice cultivation with water pumped from the reservoir but not much. The general feeling is that the scheme provides very little benefit.

In this village people go fishing mainly for subsistence purposes rather than commercially, although they may sell a small amount at the local market. Traditionally many in the village have been growing rice and collecting forest products and making baskets. There are also some who move down to the lake and who either fish in the fishing lot after the lot owner, work as fishing a lot owner or take the opportunity to buy cheap fish there. When the dam was open there were many small water bodies around the village (including many lakes such as Chung Keang, Takeng, Ambeksrov, Rolouch, Tangbang and Ptachas). These water bodies were easy to fish and gears used in them included small scale fishing gears such as cast nets, gill nets, hooks and lines and bamboo traps. When the dam is closed these water bodies become part of the irrigation reservoir and in the dry season villagers go fishing mainly in the irrigation reservoir where the fishing gears used were similar to those in the water bodies and the upstream river. In the wet season fishing is mainly in rice fields and the flooded wetland areas that are created. Most of the villagers do not like fishing in the reservoir because they can catch less fish. However, there are two families (with boats) who have to go fishing there a lot because they have little or no land for rice fields.

Most of the fish that villagers catch are black/grey as they move and migrate. In general there was a perception that fish abundance has been declining over time. The village headman thought that when the dam was closed in the past this resulted in plenty of fish in the upstream area because the flooded forest provided habitat for the fish. However, while he thinks that this will also be the case in the future he believes that it will be less because a lot of the flooded forest has become rice field. He thinks that perhaps after the dam has been closed for two or three years the fish will have become more abundant. However, species diversity has decreased over time and now the diversity of fish species is less than it was in the past. This, and the decline in abundance, is due to two factors: firstly, there is illegal fishing activity using electro-fishing, dynamite and small mesh nets and, secondly, there has been the effect of the changes in hydrology over time. Before the dam fish could move freely. When the dam was
closed the upstream area benefited, while fish from downstream could not move up. When the dam was broken, the fish could move again and there was also a benefit to the people downstream.

Related to the current irrigation scheme, the headman informed us that almost all fish species can continue to move upstream and down because of the canal, particularly important for upstream movement. The canal, which is always open, means that fish can get to the irrigation reservoir as well as to the wetlands around the village and to the deep pools further upstream. In the rainy season fish migrate down from the river to rice fields, floodplains (also through the network of irrigation canals) and lakes. These species include the climbing perch (*Anabas testudineus*), *Mystus wyckioides*, *Channa striata*, *Hemibagrus spilopterus*, *Henicorchynchus siamensis*, *Dangila spp.*, *Barbonymus gonionotus*, and *Clarias spp*. Fish moving upstream reach the dam and either aggregate below the dam or else move up through the canal. This aggregation effect is a benefit to those downstream who have more fish to catch during this period. Generally, the village is not worried about the fish but is concerned at the loss of rice production.

**Thnot Chum commune**

We met with the chief of the commune and Thnot Chum villages to consult with him about the fishery situation in Thnot Chum commune and impacts of the irrigation scheme in Stung Chinit. This is a commune located downstream of the dam and outside the irrigation scheme. Thnot Chum itself is made up of four villages (1st, 2nd, 3rd, 4th Thnot Chum village) and consists of a total of 550 households. There is a researcher from the GRET project to monitor the fish catch in the village. Some 40% of people from these villages fish regularly (either part-time or full-time) and 20% fish all year round. Fishing is generally local and fishers don’t go downstream very much. As with Snao village, it was reported that in the past the fishing area downstream of the dam was subject to access restrictions. Households had their own particular fishing areas that were passed down and spots where people fished, using cast nets and gill nets, were often signposted. As the numbers of fishers has increased over time (due to population increases) this system has stopped. As a general rule the number of fishers increases as one moves downstream. Before, when the dam was closed, households also used to fish above the dam, but not much as it is quite a long way away. At present, with the dam closed again, they are not sure whether the fish are very abundant in the reservoir yet so they have not started fishing there again yet. Generally, the river is preferred as flowing water is different to standing water and the river is nearby and has fish in it.

The dam broke in 1985/86. Before this, when the dam was not broken, fishing in the river was better than when the dam became damaged because the water level was lower and the river was narrower, making it easier to catch fish. There were not really any problems with the fishery then because the upstream area had enough water for spawning fish. Fish in the river generally came from upstream although there was also another dam lower down in the floodplain that kept water in the floodplain and which meant that fish could travel upstream to Thnot Chum. After the downstream floodplain dam broke there were fewer fish traveling upstream.

The river at Thnot Chum provides something of a nursery area and there are usually plenty of *Wallago attu* because of the many small fish in the area. This year there has been a lot of *trey riel* in the river, more than last year although in general the abundance of *trey riel* has been declining over time. The reason for the abundance this year is not clear but someone has suggested that it is because there are fewer predators and another reason that has been suggested is reduced fishing with mosquito netting that has allowed more of the fry to survive.
Regarding this, the DoF patrols have meant that there is less illegal fishing but if the patrols were to stop there would be lots. They have wanted to try to create a community fishery for conservation and to improve production. There are a number of small water bodies near the villages and they have created some regulations to help manage these resources. While it is still allowed for people to fish in these there are regulations such as conservation zones in place.

On the 20th of January 2006, the southern embankment was broken and at that time water was shallow, making the water very turbid. As a result, a lot of fish, especially *Wallago attu* (with a single fish of 5-8 kg) died and could be found with silt in their gills. There are many deep pools and they are 4-12 m of depth in the downstream part of the village (e.g. Ta Ouk, Ta Tra and Prek Ampov deep pools), and deeper than 12 m in the upstream part (e.g. Thnot Chum deep pool with 15 m in depth). These pools represent important refuges because they are difficult to fish (depth and water eddies) even in the dry season.

In terms of the effect of the built structures for Thnot Chum the downstream dam had a larger effect for fisheries as it made the floodplain area larger and so more fish would come into the river. The upstream dam did not affect the fish abundance so much but when it was closed it affected the river and also meant that fish would concentrate in the river. There will always be water in the river and fish will still be able to move up and down the river when the dam is closed so they expect that there will be no negative impact on the fishery in Thnot Chum. With the closure of the dam this year the village will benefit from the concentration of fish but they will not benefit from the irrigation. However, it is planned that another canal will be built during a second phase and they expect to benefit from this.

**Battambang (Prek Toal)**

**Objective of the trip:** To select sampling sites for the project area of Prek Toal and pre-test the questionnaires in Prek Toal village of Battambang province

**Duration of the trip:** Two days (24-26 August)

**Persons involved:** Dr. So Nam, Dr Robert Arthur, Mr. Leng Sy Vann, Mr. Prum Setha, and Miss. Pom Sok Hort.

**Progress report:**

The site:

The site at Prek Toal village of Battambang province provides a different sort of built structure from the other sites. Here the structure is a fishing gear consisting in a large part of a large bamboo fence (36 km long) that is in place from January to June in order to channel fish returning to the lake from the floodplain area as the water recedes into fishing gears. This type of structure is associated with the fishing lot system where the enclosed area of the lake and floodplain is leased for fishing. This lot system and the fence gear is a traditional system of management. Prek Toal provides an opportunity to examine an operational fishing lot (Lot #2, the largest (50,134 ha) and most productive lot in Cambodia) and a fishing lot (Lot #3) where the structure was removed and the management system changed to a ‘community fishery’ system that has fewer access restrictions in 2001 in order to examine the effect of the structure. This is slightly complicated by the fact that the management system and structure are so closely related, making it difficult to clearly separate the impacts of the two.
1. Consulting with Provincial Fisheries Officers, Village Heads and Commune Council Members

We met and discussed Prek Toal with the local Fishery Inspectors: the First Vice-chief of Koh Chivang commune (Mr. Kuy An, his phone number, 016 715 986) and heads of Kampong Prohok (Mr. Keo Sovann) and Prek Toal (Mr. Pum Chin, his phone number, 016 328 721) at the Prek Toal Fishery Inspection Unit in order to discuss our plans for information collection, introduce ourselves, distribute the criteria for the selection of fishers for the interviews we would be conducting and also gather some general information regarding the fishery situation around Prek Toal. At this site there are four floating villages along the Stung Sankae: Prek Toal village, Anlung Taour, Kampong Prahok, and Khvang. In addition, there is a further village, Prek Kanteal, that is not officially recognized and which is located on the other side of Fishing Lot #2. During the discussions they were able to inform us that:

- This source of water around Prek Toal village is from the Stung Sangkae and Mekong River during the wet season. At the start of the wet season (June to August), the standing water in the floodplain area also starts being described as having a bad smell. The water’s smell is reduced as fresh water flows into the floodplain area as the flood level rises. The bad smelling water is also described as being present again in November and December when the inflow of fresh water stops. This spoiled or bad smelling water in June and August results from flooded water from Stung Sankae and the rain over grasslands, and the water’s smell is reduced when the Mekong River arrives.
- The Mekong River is a major factor relating to the abundance of fish in the Prek Toal area. When flooding from the Mekong River arrives late, i.e. starting in July/August, the abundance of fish is low. In contrast, when the flooding arrives early (June/July) then the abundance of fish in the area is much greater.
- There are a variety of fishing locations in the Prek Toal area but these can be summarized as being Fishing Lot #2, the community fishery (formerly Fishing Lot #3), the Tonle Sap Lake and the Stung Sankae main channel. Where people go fishing is not fixed and is instead related to the gear and resources of the fishers, access to the fishing lot and the flood level (see Table 1). Small-scale fishers are allowed to fish in the fishing lot area up to 15th October, after which access is restricted and the area comes under the control of the holder of the lease. The area controlled by the lease-holder includes the floodplain and also the lake area adjacent to the built structure (bamboo/nylon net fence) extending some 1 km into the lake. Within the fishing lot and community fishery fishers gradually move inland across the floodplain from the lake with the rising water and movement of the fish. Areas within the lot are subleased after 15th October so there is still some fishing activity within the fishing lot after this date. In the wet season fishers go fishing in the lake from May to July, and in the four community fisheries (previously Fishing Lot #3) and Fishing Lot #2 from August to the middle of October. Fishing is much more difficult during the months of November and December because in those months there is the bad smelling water from the Tonle Sap Lake that affects the fish and the water level is still high, making it difficult to fish. The bad smelling water causes fish to die, especially white fish and grey fish. In the dry season (in particular from January to May) they go back fishing in the Tonle Sap Lake and Stung Sankae main channel.
Table 1: Fishing location of Community Fisheries Members by Season

<table>
<thead>
<tr>
<th>Community Fisheries</th>
<th>Closed Season May-October</th>
<th>% of CF members</th>
<th>Fishing location</th>
<th>% of CF members</th>
<th>Fishing location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khvang</td>
<td></td>
<td>- 20</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
<td>- 80</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
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<tr>
<td></td>
<td></td>
<td>- 30</td>
<td>CF’s fishing domain (ex-Fishing Lot No.4)</td>
<td>- 20</td>
<td>Open access around the village, including Stung Sangkae</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 50</td>
<td>Fishing Lot No.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kampong Prahok</td>
<td></td>
<td>- 70</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
<td>- 80</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 30</td>
<td>Fishing Lot No.2</td>
<td>- 20</td>
<td>Open access around the village, including Stung Sangkae</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anlung Taour</td>
<td></td>
<td>- 50</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
<td>- 50</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 50</td>
<td>Fishing Lot No.2</td>
<td>- 30</td>
<td>Go fishing at the lake</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- 20</td>
<td>Leasing fishing location of Fishing Lot No.2 (Dong) from middle of December to May</td>
</tr>
<tr>
<td>Prek Toal</td>
<td></td>
<td>- 50</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
<td>- 30</td>
<td>CF’s fishing domain (ex-Fishing Lot No.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 50</td>
<td>Fishing Lot No.2</td>
<td>- 40</td>
<td>Go fishing at the lake</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- 30</td>
<td>Leasing fishing location of Fishing Lot No.2 from middle of December to May</td>
</tr>
</tbody>
</table>

Source: field trip, August 2006

The fishing gears that are used in the floodplain areas are *Bor* (small or big barrage with mesh net), gill net, and long hook and line. Over 90% of the gears used are *Bor*, and gill nets and long lines make up the rest. This *Bor* gear can be divided into three categories based on the scale of the gear: small scale (100-500 m); medium scale (>500-1000 m); and large scale (>1000 m). Table 2 provides a summary of fish catches by gear and location.
Table 2: Fish catch by Bor gear around the Lake and Fishing Lot No.2

<table>
<thead>
<tr>
<th>Scale of Bor Fishing Gear (m)</th>
<th>Total catch/day In TS Lake (Kg/time)</th>
<th>Total catch/day In Fishing Lot Number 2 (Kg/time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May-July</td>
<td>August</td>
</tr>
<tr>
<td>100-500</td>
<td>10-20</td>
<td>20</td>
</tr>
<tr>
<td>&gt;500-1000</td>
<td>50-60</td>
<td>50</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>400</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: field trip, August 2006

A wide range of fish species are caught at the Prek Toal site including from the three ecological groups (i.e. black, grey and white fish, for the details see Table 4). When these fish species are caught depends on the season (see Table 3). During the closed season (particularly from May to July), grey and white fish are caught in the lake while black fish are caught in Fishing Lot #2 and the community fishery from August to October. White fish are again caught in the open season from the middle of October to November and grey fish are also caught from November to December. Fish species from all the ecological groups are caught from December to May, both in the floodplain areas and in the lake.

Table 3: Fish Species Caught by Season and Location

<table>
<thead>
<tr>
<th>Closed season</th>
<th>Open season In fishing lot No.2 and lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake</td>
<td>Fishing Lot #2/CF</td>
</tr>
<tr>
<td>May-July</td>
<td>Fishing Lot #2/CF</td>
</tr>
<tr>
<td>Grey and white fish</td>
<td>Black fish</td>
</tr>
</tbody>
</table>

Source: field trip, August 2006

In addition to fishing, some of villagers also go to work for the lease-holder of Fishing Lot #2 from February to May.

2. Discussing with knowledgeable fishermen

Two groups, comprising a total of six fishers, were convened to discuss local fish ecology and their perception of the effect and impact of the built structure. This discussion was held in Prek Toal village and the information was obtained through a combination of interviews based on the fisheries survey form and mapping.

Prek Toal village has been in existence for a long time and the fishing lots themselves were developed during the French regime. Within the fishing lots, as the water starts receding, the lease-holder of the fishing lot starts subleasing fishing locations along natural canals and lakes within the lot (from the middle of October to December/January). Other locations along the edge of the Tonle Sap Lake are similarly subleased from January/February to June. The reason for this subleasing is that the fishing lot lease holder does not have enough labor to be able to fish all these locations himself. However, fishing lot operators also go fishing with bamboo fences (i.e. a fence barrage of > 30 km long) installed at the Tonle Sap Lake from February to June. The fishing lot lease-holder starts putting up the fence barrage from middle of January and this
remains in place until June. In Lot #2 the fence has a length of 36 km, stretching from Koh Chinuk (10 km), along the edge of the Tonle Sap Lake (20 km) and up to Pak Kanteal (6 km).

The people in the Prek Toal area informed us that they face serious problems in fishing. During the closed season (June-October), the provincial fishery officer does not allow them to fish in both the floodplain and the fishing lot, and in the open season (middle of October-June) the owners of the fishing lots do the same too within and around the boundary of their fishing lots. Several fishing gears are used in this area and these gears are classified into 3 types based on their fishing scale. Members of the community fishery use fishing gears such as gill nets, long hooks and lines, cast nets, *Lae, Bor, Samras*, and giant dip nets as well as various illegal gears, including electro-fishing. Lessees (*Dong*) always use middle-scale barrages, long gill nets, *Bor*, pumping machines, and electro-fishing. Fishing lots use large-scale barrages and electro-fishing.

A wide range of important fish species were caught in both seasons in Fishing Lot #2 and the community fisheries (before 2001 called fishing Lot #3 adjacent to Lot #2). They include white, grey and black fish species (for details see Table 4). On average, fish catch by species varied from 0.5 kg to 8 kg per day per household.

### Table 4: Fish species caught at Prek Toal

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Khmer name</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Henicorhynchus siamensis</em></td>
<td>Riel Top</td>
</tr>
<tr>
<td><em>Henicorhynchus cryptopogon</em></td>
<td>Riel Angkam</td>
</tr>
<tr>
<td><em>Euryglossa</em> spp.</td>
<td>Andetchkhae</td>
</tr>
<tr>
<td><em>Cyclocheilichthys enoplos</em></td>
<td>Chhkaok</td>
</tr>
<tr>
<td><em>Pangasianodon hypophthalmus</em></td>
<td>Pra Thom</td>
</tr>
<tr>
<td><em>Pangasius conchophilus</em></td>
<td>Kae</td>
</tr>
<tr>
<td><em>Pangasius lamaudii</em></td>
<td>Po</td>
</tr>
<tr>
<td><em>Pangasius</em> spp.</td>
<td>Chhveat</td>
</tr>
<tr>
<td><em>Osteochilus waandersi</em></td>
<td>Kros</td>
</tr>
<tr>
<td><em>Labocheilos melanotaenia</em></td>
<td>Changva Ronoung</td>
</tr>
<tr>
<td><em>Rasbota tornieri</em></td>
<td>Changva Moul</td>
</tr>
<tr>
<td><em>Cirrhinus microlepis</em></td>
<td>Prual</td>
</tr>
<tr>
<td><em>Amblyrhythmicthys truncatus</em></td>
<td>Kambot Chramos</td>
</tr>
<tr>
<td><em>Boesemania microlepis</em></td>
<td>Brama</td>
</tr>
<tr>
<td><em>Channa striata</em></td>
<td>Ros</td>
</tr>
<tr>
<td><em>Channa micropeltes</em></td>
<td>Chhdau</td>
</tr>
<tr>
<td><em>Cyclocheilichthys apogon</em></td>
<td>Srakakdam</td>
</tr>
<tr>
<td><em>Pristolepis faciata</em></td>
<td>Kantrop</td>
</tr>
<tr>
<td><em>Notopterus notopterus</em></td>
<td>Slat Srae</td>
</tr>
<tr>
<td><em>Mustid</em> spp.</td>
<td>Kanhchos Snot</td>
</tr>
<tr>
<td><em>Hampala macrolepidota</em></td>
<td>Khman</td>
</tr>
<tr>
<td><em>Ompok hypophthalmus</em></td>
<td>Ta Aon</td>
</tr>
<tr>
<td><em>Thynnichthys thynnoides</em></td>
<td>Linh</td>
</tr>
<tr>
<td><em>Botia modesta</em></td>
<td>Kanhchrouch Krahorm</td>
</tr>
<tr>
<td><em>Wallago attu</em></td>
<td>Sanday</td>
</tr>
<tr>
<td><em>Paralabuca typus</em></td>
<td>Sleuk Reusei</td>
</tr>
<tr>
<td><em>Morulius</em> (<em>Labeo</em>) <em>chrysophkedacion</em></td>
<td>Ka Ek</td>
</tr>
<tr>
<td><em>Barbonymus altus</em></td>
<td>Kahae</td>
</tr>
<tr>
<td><em>Barbonymus gonionotus</em></td>
<td>Chpin Prak</td>
</tr>
<tr>
<td><em>Leptobarbus hoeveni</em></td>
<td>Proloung</td>
</tr>
<tr>
<td><em>Anabas testudineus</em></td>
<td>Kranh</td>
</tr>
</tbody>
</table>
Fishers informed us that fish catch and size drastically declined due to an increase in fishers, more gears, including small, medium and large-scale barrages bamboo/nylon net fences and illegal fishing gears such electro-fishing, filamentous nets and pumping, new gears (i.e. Bor, mosquito net fence traps), and good security (no fear of Khmer Rouge soldiers). Some fish species have not been seen in the catch such as *Amblyrhynchichthys truncates*, *Puntius orphoides*, *Belodonthichthys dinema*, and *Dasyatis laosensis*. The giant snakehead *Channa micropeltes* declined very much in the catch because of an increase in the use of electro-fishing and collection of its juvenile for stocking the floating cages; however, there was an increase in the murrel snakehead *C. striata* due to its proliferations and multiple spawning, and difficulties from catching in the wet season, and clarrid catfishes because currently its juveniles have not been collected for aquaculture. It was stated that the number of fishers increased in the past years because of a lack of job opportunities and alternative livelihoods for the floating village households, and these people have to depend solely on fishing as their main occupation. The price of all fish species has dramatically increased in the recent years due to an increase in demand for household consumption and both internal and external markets, and in price of other goods.

Lots of flooded forests have been cleared to create new fishing locations by both small- and medium-scale fishers, and large-scale fishers (fishing lot operators). In past years fishers did not go fishing in many small natural lakes, in which, they are fishing now due to the increase in the number of fishers and fish demands, and the decrease in fish productivity in Fishing Lot #2. They complained that some locations particularly in the core zone areas were restricted to fish in the wet season by the environmental sector due to biodiversity conservation. Moreover, fishers informed us that there is a complaint from Fishing Lot #2 that core zone areas within the lot were also restricted to fish in the dry season (i.e. open season) by the environmental sector.

Regarding the fishers’ perceptions of the effect and impact of the built structure (i.e. large barrage or bamboo/nylon net fence) on:

1. fish migration, this gear had a significant impact on fish migration and spawning of all groups of fish species (i.e. black, grey and white fish) to the lake during the early dry season when water recede to the lake from the floodplain and from the lake during early wet season when the water enters the floodplain from the lake. This leads to retarding the spawning and foraging time of the adult fish and rearing/nursing time of the young of black and grey and white fish species. However, the level of such an impact cannot be measured.

2. water flow, the barrage had little effect on water flow at Prek Toal.

3. flooding areas, furthermore the pumping method accompanied by partitioning of the tributary (another type of built structure made by lessees) to harvest fish, especially in Fishing Lot #2 has a significant effect on the level of flooding by preventing water flow.
into the floodplain in the early wet season, and fish migration into the lake in the early dry season.

(4) water quality, harvesting fish by the pumping method causes many fish, particularly small fish species, to die due to water turbidity as silt is sealed their gills. Bad-smelling water caused by rain water is found in the floodplain (dry grassland in dry season) in the wet season (May/June); this water does not cause fish to die as grey and white fish can stay in the lake, tributaries, and floodplain lakes away from the bad-smelling water on the floodplain and can enter the floodplain when the Tonle Sap Lake water enters the floodplain or mixes with floodplain water to remove the bad smell (i.e. buffering). Bad-smelling water entering from the Tonle Sap Lake is found in the floodplain in the dry season (November/December); such light brown colored water causes fish to die, particularly grey and white fish.

Interestingly, fishers provided their perceptions of the advantages and disadvantages of the built structure (i.e. Lot #2) and community fisheries management system as follows.

**Fishing Lot # 2**
- Advantage:
  - Flooded forest, fish and other aquatic animals and plants, and birds in the lot were well protected by the lot as the lot operator can hire may guards to patrol the lot;
  - Fishers can have access to some far distant fishing locations to fish if they ask the lot for permission to fish there; and
  - Prevents fishers from using electro-fishing method to fish in the lot.
- Disadvantage:
  - The lot harvested fish using pumping method;
  - The lot owner expanded the boundary of the lot;
  - The lot harvested fish using large-scale bamboo/nylon net fence trap (i.e. barrage); and
  - The lot fished with electro-fishing device.

**Community Fisheries**
- Advantage:
  - Small-scale fishers had more freedom to fish.
- Disadvantage
  - During the transitional period, fishers fished with illegal fishing gears such as electro-fishing, filamentous nets and brush park fishing, and other most effective fishing gears, e.g. the Bor; and
  - Fishers had too much right to use all types of new and unsustainable fishing gears.
Objective of the trip: To select sampling sites for the project area and test the questionnaires in Ou Taprok and Chong Khlong village of Pursat province.

Duration of the trip: 2 and half days.

Persons involved: Dr. So Nam, Dr Robert Arthur, Mr. Leng Sy Vann, Mr. Prum Setha, and Miss. Pum Sok Hour.

Activities of the trip:

1. Consulting with Provincial Fishery Office

We met with provincial fishery officer to inform him of the purposes of our visit to Pursat province and then we consulted with PFOs to select the sites within the project area through the map of Pursat province. Six villages within three communes were selected that would be visited during the field trip. All the villages are located close to National Road No. 5 in the south of Pursat province. They consist of:
- Ou Sandan commune, Ou Tabroak, Chong Khlong, and Doung Chhua villages;
- Snar Ansar commune, Krang Veng village; and
- Kampong Po commune, Moat Prey and Kampong Law village.

2. Consulting with Commune Council

We went to meet the chiefs of each of the three communes to consult with them and get information about general situation in each commune. This information was given using mapping combined with interviews:

**Ou Sandan commune**

We met and consulted with the chief of Ou Sandan commune as well as the head of all the three villages in the commune. The villages within this commune are Chong Khlong (158 HH), Ou Taprok (195 HH), and Daung Chhua (99 HH). They provided general information about Ou Sandan commune:
- Ou Sandan is a commune located 150 m from National Road No. 5 and consists of seven villages.
• In this commune there are plenty of small streams, lakes, canals, track roads and cow roads and these structures have existed since ancient times. There are two main canals that are used for rice field irrigation, as fishing locations, and as a route for fish migration from the mountains during the wet season, getting water from Stung Thlea Ma-orm. These canals have water in the wet season with 1 m depth and are dried up during the dry season.

• The commune is divided into two parts. The top part is in the upland area and the living standard of people in this area is lower than the bottom part (lowland) because people in the lowland area are able to cultivate rice in both wet and dry seasons and are getting high rice production. In addition, they are able to fish in both the dry and wet season. People in the upland areas go fishing in the wet season and the majority of their fishing locations are in the rice fields.

• In the wet season, approximately 30% of villagers go fishing around the rice fields, 20% of them go fishing along the small streams and canals, and the other 50% go fishing in the floodplain areas and in the lakes. In the rice fields, canals and small streams the fishing gears being used are similar and are small-scale fishing gears such as cast nets, gill nets, long line hooks, and bamboo traps. But there are different gears used in the floodplain and lakes where they use small barrages, electro-fishing, gill net with big mesh net (5-10 cm), and trawls.

• In the dry season, there is fishing in the lake (10%) and Tonle Sap River (90%) only.

• Fish species caught along the canal include Barbonymus gonionotus, Notopterus notopterus, Henicorchynchus siamensis, Hemibagrus spilopterus, and many other fish species.

• The built structure (road) does not affect fish migration because fish can migrate through the gates and the culverts (holes of cement) along the road. These gates are not allowed to be blocked and people are not allowed to fish with nets or bamboo barrages. This has been prohibited by the commune council.

**Snar Ansar commune**

The team met with the first vice chief of the commune as well as the head of Krang Veng village to consult with them about the general situation, especially fishery resources in the commune. This information was obtained through mapping. Krang Veng village has 162 HH. Then they informed us that:

• Snar Ansar is a commune located along National Road No. 5 bordering the west of Ou Sandan commune, the east of Anlung Thnaot commune, and the north of the Tonle Sap Lake.

• This commune is not different from other communes where there are canals, small streams, and roads from ancient times. Some roads were renovated in 2002 and 2005. There was also a new canal dug in 2002. This canal dries out in the dry season and in the wet season it has a depth of 1.5 m.

• Besides cultivating rice and fishing, they have other jobs such as collecting palm juice, collecting vines, making bamboo baskets, weaving mats, and raising livestock.

• In this commune, there are three villages that are professional fishing villages both dry and wet season. These villages are Beng, Krang Veng, and Kampong Prak (floating house). However, if we compare ethnic villages (i.e. Cham or Islamic villages) they are still lower than these villages in terms of fish caught. For example, in the dry season Beng village went buying Prohok (fermented fish paste) from ethnic villages but Ou Taprok and Chung Chlong village went back buying palm sugar from Beng village. In other words, ethnic villages also become suppliers for livestock to other villages and their living standard is better than other villages.
• In the dry season villagers go fishing at small streams, canals, floodplains, and the lake but especially rice fields. They use different fishing gears in the different fishing locations. In rice fields they always use cast nets, bamboo traps, and long line hooks, but at the lake and floodplain they use cast nets, gill nets, and barrages with bamboo traps.

**Kampong Po commune**

We met with the secretary of Kampong Pou commune and the head of Moat Prey and Kampong Lor. We consulted with them through asking and mapping in the commune. In this sense two villages are proposed for the survey: Moat Prey (183 HH) and Kampong Lor (264 HH). They informed us that:

• This commune is located along National Road No. 5 and borders the west with Anlung Vil commune, the east with Ou Sandan commune, and the north with the Tonle Sap Lake.

• The east area of this commune is better than the west area because the east is a lowland area. This lowland area gets higher rice production and can also produce more fish because it is closer to the Tonle Sap.

• This commune has three primary canals (Prolay 17 Mesa), which get water from either Stung Pursat or Stung Thlea Ma-orm. These canals were built during the Pol Pot regime (1976). So far they are still useful for irrigation and fish migration from upstream and are a fishing location for the villagers during the wet season. But they are dried out during dry season. Moreover, Kampong Lor commune has a new canal that was dug in 2000 crossing Prolay 17 Mesa from Stung Thlea Ma-orm and it gives more benefits for rice farming and fishing, especially fish migration from upstream. In May through June fish migrate upstream, and they migrate downstream from October.

• The commune also has some big lakes and a lot of small lakes. These lakes are not dried out during dry season and they are advantageous for villagers fishing there because they can be used in both dry and wet seasons.

• The main occupations of people in Kampong Lor are rice field cultivation and fishing. Fifty percent of Kampong Lor villagers do both rice farming and fishing, and the other 50% do fishing only. As for Moat Prey village, the majority of villagers make their living both fishing and rice farming, but the minority do fishing only.

• Villagers in this commune always go fishing during the wet and dry season. In the wet season, they go fishing at rice fields, small streams, streams, canals, floodplains, and the Tonle Sap Lake with small-scale fishing gears. However, these gears are used in a different manner depending on the fishing location. Rice field gears consist of long line hooks, cast nets, and bamboo traps. Cast nets, bamboo traps, and small barrages with bamboo traps are used in streams and canals. Gill nets, cast nets, and small barrages with bamboo traps are used at the floodplain areas and Tonle Sap Lake. During the dry season, they go fishing in the lakes, Ou Taprok stream and the Tonle Sap Lake with different fishing gears based on fishing locations. *Samras*, bamboo traps, cast nets, circular seine nets and small barrages with bamboo traps are used in floodplain lakes. Cast nets, gill nets and bamboo traps are used in streams. Circular seine nets, *Samras*, cast nets, and long barrages with bamboo traps are used in the Tonle Sap Lake.

• For fishing gears, they bought them from Cham villages (Ou Taprok and Chung Chlong villages) and sometimes they went to buy fishing gears in Pursat town.

• They thought that before there were plenty of fish, but now there is a dramatic decline in both the quantity and size of fish. Moreover, some fish species have disappeared, especially larger fish.
3. Discussing with fishermen groups

We have two groups (a total of six fishermen) to discuss fish ecology and fishing information related to the build structure in their villages. The first group is in Chong Klong village, talking about the built structure, and another group is in Ou Taprok, talking about fish ecology. This information is detailed as below:

Chong Klong village

This village is a village close to Ou Taprok village, which is in the east of Ou Taprok. This village has some primary and secondary canals which were built during the Pol Pot regime and they were renovated in 1996 and 2003. In addition, there are some rural roads that were built in 1994 and renovated in 2002 due to the flooding from 2000 to 2002. Another road linking Ou Sadan road was underwater during the flood from 2000 to 2003.

Chong Khlong village is a village that favors fishing because of the many floodplain lakes. These are Boeung Tro Chek, Veng Tun, Pro Lakva, Charb Kul, Kbal Skouv, Tys Peay, Tro Borklun, Kouch, Locheung, Tro Pengkros, Tro Pengksarch, Pseurt Knung, Chhes, Dach Krolech, and Boeung Bath Pdil. In the wet season villagers always go fishing in rice fields, small streams, canals, and floodplain areas with family-scale fishing gears and their fishing gears are different owing to fishing location. At rice fields they like to use gill nets and hooks and line. Cast nets and bamboo traps are used in small streams and canals. Gill nets, bamboo traps, and circle grill nets, electro-fishing (September to November) is used in floodplain areas. But in the dry season villagers go fishing in floodplain lakes and the Tonle Sap Lake only and their fishing gears consist of cast nets, circular seine nets, electro-fishing, and Samras.

Ou Taprok village

Ou Taprok village is next to Chong Klong village and is also a professional fishing village. This village also has many floodplain lakes, and these lakes have permanent water. Villagers always go fishing in rice fields and canals in the wet season, and the floodplain and Tonle Sap Lake in the dry season. The fishing gears they are using are not different from Chong Khlong village in both dry and wet seasons.

Fishers’ perceptions of fish and fishing in Chung Khlong and Ou Taprok villages

In general, there has been a dramatic decline (i.e. 50-70% from the past catch rate) in either fish abundance or fish size in both villages. Several similar reasons for the decline are (1) use of illegal fishing gears such as electro-fishing, fine mesh nets and brushparks, (2) clearing flooded forests, and (3) illegal fishing activities such as collection of snakehead eggs. It was reported that there is an increase in the abundance of other aquatic animals such as small shrimp (i.e. Kampeus) and mollusks. However, amphibians (i.e. frogs) similar to all fin-fish species had declined. It is clearly reported that the price of fish is increased over time due to a decline in fish abundance, high market demand, and population growth. Interestingly, the price of small-sized fish has dramatically increased compared to big-sized fish.

Fishers’ perceptions of the effect of the built structures (i.e. roads and canals) on hydrology, fish, and fishing in Chung Khlong and Ou Taprok village

It is strongly believed that the built structure (i.e. road) has no negative effect on water flow and water quality in the villages as water gates and culverts have been installed along the roads.
Fish can move up and down the floodplain through these gates and culverts. The structure provides more fishing opportunities in terms of new fishing locations and different fishing gears used, especially around water gates and culverts. Canals are another type of built structure that could create new fishing locations, fish habitats and/or migration routes.
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

*Environment Component*

**IMPACT OF BUILT STRUCTURES ON TROPICAL FLOODPLAINS WORLDWIDE**

Prepared by

**Mikaela KRUSKOPF**

Biota BD, Finland

December 2006
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<thead>
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<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADB</td>
<td>Asian Development Bank</td>
</tr>
<tr>
<td>IEE</td>
<td>Initial Environmental Examination</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>CIA</td>
<td>Cumulative Impact Assessment</td>
</tr>
<tr>
<td>SEA</td>
<td>Strategic Environmental Assessment</td>
</tr>
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<td>INPA</td>
<td>National Institute of Amazonian Research</td>
</tr>
<tr>
<td>IUCN</td>
<td>The World Conservation Union</td>
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<tr>
<td>MRC</td>
<td>Mekong River Commission</td>
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<tr>
<td>FAP</td>
<td>Flood Action Plan</td>
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<td>World Commission Dam</td>
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<td>PCB</td>
<td>Polychlorinated Biphenyls</td>
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<td>Dichloro-diphenyl-trichloroethane</td>
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<td>World Bank</td>
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<td>Marine Resource and Fisheries Consultants</td>
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<td>Integración de la Infraestructura Regional Suramericana</td>
</tr>
<tr>
<td>SEMRY</td>
<td>Secteur Expérimental de Modernisation de la Riziculture de Yagoua (later renamed to Société d'Expansion et de Modernisation de la Riziculture de Yagoua)</td>
</tr>
<tr>
<td>BCAS</td>
<td>Bangladesh Centre for Advanced Studies</td>
</tr>
<tr>
<td>PIRDP</td>
<td>Pabna Irrigation and Rural Development Project</td>
</tr>
<tr>
<td>FCDI, FCD/I</td>
<td>Flood control, drainage and irrigation scheme</td>
</tr>
<tr>
<td>CPP</td>
<td>Compartmentalisation Pilot Project</td>
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<td>IRN</td>
<td>International Rivers Network</td>
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<td>SEARIN</td>
<td>Southeast Asia Rivers Network</td>
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<td>SEI</td>
<td>Stockholm Environment Institute</td>
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<tr>
<td>CBD</td>
<td>Convention on Biological Diversity</td>
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<td>NEPA</td>
<td>National Environmental Policy Act (USA)</td>
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<td>EMS</td>
<td>Environmental Management System</td>
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<tr>
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EXECUTIVE SUMMARY

This review discusses the recorded impacts of built structures on the environment and fisheries of tropical floodplains worldwide.

Riverine floodplains cover more than two million km² globally. The floodplains in various parts of the globe vary considerably in terms of their physical, chemical and biological characteristics. However, the majority of all floodplains share one quality; they are highly productive due to the exchange of energy and nutrients between different groups of organisms, terrestrial and aquatic. Moreover, all literature describing floodplains mentions their undisputable importance for fisheries.

Floodplains are among the most biodiverse environments known. Apart from being biodiverse, tropical areas also display a high percentage of endemism. Tropical riverine fauna generally include a large number of migratory species, which are highly vulnerable to human impact, including modifications of lateral or longitudinal connectivity to their habitat. Many of these species are both riverine and lacustrine, depending on the season, and therefore dependent on the availability of both habitats.

Floodplains are rapidly being destroyed through reclamation of the land for other purposes. Today, rivers and wetlands are valued with regard to all ecosystem goods and services they provide, and as such are estimated far higher in value than e.g. forests or grasslands. In Europe and the USA, where most floodplains have been lost, restoration of regulated wetlands is increasingly taking place, and at a great cost, to return these long-term benefits and ecosystem services provided by the wetlands.

One of the highest valued “direct use value ecosystem services” of floodplains is fish, while inputs to agriculture (nutrient rich deposits) and nursery functions of fish and other organisms, are considered the most important “indirect use value services”. Some, albeit few, studies concerning the value of specific ecosystem services in tropical floodplains have been carried out, and these studies make it clear, that the conservation of the flooded forest habitats is of critical importance, also financially, to ensure a sustainable future for local economies.

Predictions suggest that in the near future, the most threatened floodplains will be those in Southeast Asia, Sahelian Africa and North America. Without beginning to preserve existing floodplains and to restore hydrological dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity, dramatic extinctions of aquatic species and ecosystem services will be faced within the next few decades.

Hydrology is clearly the single most important driving variable in tropical floodplains, based on which the flood pulse concept defines the river and its floodplain as an indivisible unit. Any long-term change to the pulse affecting the hydrodynamics of the flood, such as timing, height, duration, amplitude, smoothness or the rapidity of change of the flood pulse, will result in fundamental ecological changes in the affected areas and also influence the living conditions of the local human population. It is now generally accepted that the conservation of most species in the aquatic system, as well as biodiversity in its broader sense, depends on the maintenance of the flood pulse.
Impacts of different types of built structures such as embankments, roads, canalization, and mining and fishing gears, is discussed in this review. Of these, dams and canalization have been discussed most in literature, due to their significant impacts on floodplain environments, fish and fisheries.

The main effects of dams include changes in discharge downstream, desiccation of floodplains, riverbank erosion, changes in water quality, and changes in flora and fauna.

The following effects of stress caused by built structures, such as dams or levees, on fish have been identified:

- Obligate migratory species will tend to disappear in systems where the main channels are locked by large dams.
- Floodplain spawners are selected by channelisation or other stream regulation processes that reduce or eliminate the annual flood.
- Within modified channels there is a tendency to lose obligate migratory species although management is usually directed at their protection through installation of fish pass structures or through stocking.
- There is a tendency for dominance in fish assemblages to shift from floodplain spawners toward main channel spawners.

Because of the negative impacts, and the difficulty in finding effective mitigation measures, the environmental flow requirements methodology (which includes managed flood releases) is increasingly used to reduce the impacts of changed stream flow regimes on aquatic, floodplain and coastal ecosystems downstream.

Recorded impacts of built structures on floodplain environments have been reviewed based on case studies worldwide.

In the South American floodplains, deforestation has, and continues to be, the most severe and debated threat to the vast floodplains. Built structures are still relatively few, and the impacts thereof less discussed. However, large-scale infrastructure projects are increasingly planned, and feared to have major impacts on the floodplains. The most significant threats to the Amazon floodplains are summarised as 1. modification of the hydrological regime, 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species and 4. pollution. Examples of projects for which impacts have been recorded are discussed.

In Africa, water needs for irrigation, domestic and industrial uses have caused construction of numerous reservoirs affecting the downstream flow and floodplains. The changed hydrological regime of rivers has adversely affected floodplain agriculture, fisheries, pasture and forests that constituted the organising element of community livelihoods and culture. In many cases, the desiccation caused by dams has been enhanced by natural drought.

Impacts of flow alteration on fish species have been documented for numerous artificial reservoirs in Africa, which have replaced running water habitats resulting in the disappearance of lotic species and the proliferation of species adapted to lentic systems. Many of these species are exotic, which has had further impacts on the ecosystem.
The case of the Waza Logone floodplain is discussed in detail due to it being an important example of a successful initiative to restore the lost ecosystem services of a floodplain impacted by dams. The restoration was based on an ecosystem approach and carried out through planned releases of water. The return of the flood was of greatest value to pasture and fishing, while it has also significantly benefited agriculture, the state of other natural resources and surface water reserves.

In general, there are many lessons to be learnt with regard to the restoration of floodplains in Africa. Opening of structures unnecessary changing flooding patterns, as well as artificial flood releases, in connection with a participatory approach utilising local knowledge, have achieved successful results. Despite these experiences, it has been shown that it is extremely hard to recover the complete variety of ecosystem services, once lost.

In Australia, wetland habitats are decreasing mainly due to modified flood regimes, floodplain isolation and increasing salinization. The following factors have been listed as key pressures on the aquatic ecosystems:

- changes in natural flow regimes due to water extraction and supply
- direct modification or destruction of important habitats
- barriers to the movement of plants and animals upstream
- effects of poor water quality
- competition from introduced and exotic animal and plant species

Common built structures in Australia include dams, weirs, regulators, farm dams, floodgates, causeways, culverts, pipes, channelised streams, bridge footings, and erosion control works. These barriers have been observed to isolate fish communities, restrict passage and result in changes in the fish community structures as many native fish need to migrate up and down river systems to breed, disperse and travel to spawning grounds.

Bangladesh has one of the richest and largest floodplain systems in the world, floodplains constituting about 80% of the country. Because of the large damage to the human population caused by floods, many flood control programs have been built to mitigate the adverse impacts of flooding. These structures have affected the floodplain environment and fisheries, most strikingly through the drastic reduction of floodplain area by over 2 million hectares in the past 30 years, which has severely impacted floodplain dependent fish species.

Numerous studies carried out in Bangladesh point to decreasing inland fish catches due to water resources development projects, as well as decreasing fish diversity. In general, whenever flood control projects reduce the area of flooded land, there will be a loss of habitat for fish production and a subsequent loss in annual fish yields or catch per unit area. Flood control programmes have been found to affect reproduction and larval fish drift, block fish migration and dispersal routes, and reduce species diversity by up to 30%, most of which is due to the loss of the more valuable white fishes. Sluice gates have proven to be fatal for many fish species. Water control projects have substantially reduced fisheries on the floodplains. Flood control, drainage and irrigation schemes have been found to negatively affect fish species assemblages and stock values by reducing the accessibility of impounded floodplains to migratory fish. The fish production
from inland capture fisheries has been in decline in Bangladesh for some time. A major reason is the flood control projects, while pesticides and industrial pollution are also mentioned as important factors impacting the fisheries. Flood control and drainage projects have been implemented partly to increase rice production, but it has turned out that they have been of little value for rice production, whereas their effects on fisheries have been devastating (in some cases reducing indigenous floodplain fisheries by over 70%).

In the Mekong area, several large dam projects have brought insights into their impacts on the environment. As in Africa, there are some encouraging examples of participatory approaches in connection with the rehabilitation of lost ecosystem services through managed releases of water. However, better management of environmental and social safeguard perspectives are commonly called upon to avoid impacts on the environment and fisheries. Suggested management practices are discussed based on the knowledge base collected through this review.

Final recommendations are as follows:

**Modification of the hydrological regime** has been found the first and foremost threat toward floodplain ecosystems, based on numerous experiences in tropical floodplains worldwide. Therefore, any structure affecting the all-important hydrology of a floodplain should be assumed to influence the environment, and treated with consequent caution. Most impacts are directly or indirectly combined with aspects of changing hydrological regimes, and cannot be separated from this. Any assessment must take into account impacts on integrative processes such as the flood pulse and alterations to any aspect of it; these include its **magnitude, timing, amplitude, duration, modality, smoothness and rapidity of change**. In general, the loss of flooded areas and hydrological connectivity should be minimized.

Another general recommendation concerns the importance of a systematic, professional and serious EIA process. This entails, among other things, to accommodate **adequate baseline collection** (to be extended over at least two years) and present a comprehensive collection of proposed **mitigation measures**, to ensure that these be taken into account in the design phase of the project, rather than later at a significantly greater expense. The incorporation of an **Environmental Management System** (EMS) is a central part of the EIA process and the resulting EMS must be adhered to throughout the project cycle, including setting of milestones, response plans to detected changes and an evaluation of the functioning of the EMS. Also, **Strategic Environmental Assessments** should be developed for relevant sectors.

The following recommendations have been drawn from the case studies considered in this review:

1. **Indirect impacts** of large-scale construction sites may be enormous in comparison to the actual structures. Land-use change, potentially induced by project activities in the area surrounding the project site, and their impact on the environment should be considered in EIAs.

2. **Small-scale canals and natural water channel modifications** are possibly the most common type of built structure and therefore lead to many **cumulative impacts**. Taking these into account in connection with new built structure assessments is of importance.
3. The main causes of freshwater aquatic biodiversity loss have been identified as flow modification, habitat alteration, water pollution, introduction of exotic species and over-exploitation of certain species. All these issues are, directly or indirectly, linked to built structures, and therefore EIAs relating to built structures should include a component considering biodiversity issues at as many levels of the ecosystem as possible.

4. In connection with river regulation such as dams, as well as other large structures blocking migration routes and causing fragmentation of habitats, fish biodiversity has decreased in most reported cases. In connection with new built structures it is therefore of importance to consider this probable impact at an early stage and prepare mitigation measures during the entire project cycle. Planning of structures should take into account the movement of fish, as well as securing the presence of sanctuaries/protection times. The design of sluice gates and other modified passages should take into account that for many fish an overshot mode regulator is less destructive than an undershot one, while e.g. various designs of turbines for hydropower differ with regard to the mortality of passing fish.

5. Lessons learnt have shown that the destruction of floodplains affects specialized artisanal-type fisheries, often operating on a small-scale. This type of small-scale fisheries livelihood is very hard to replace and it is therefore of importance to assess and value in the course of the EIA process. The spread of invasive plant and animal species (often occurring as a result of changed hydrology or intended introductions of e.g. fish to reservoirs) can lead to surprising and dramatic losses/changes and also affects local livelihoods that depend on other ecosystem goods than fish.

6. When assessing the impact of built structures on e.g. fish catches, it is of importance to evaluate the distribution of the catches between subsistence fisheries and professional fisheries. In many cases, it has been shown that e.g. flood control structures have benefited groups of people that have the ability to invest in fish farming, while the opportunities for natural open water fisheries have diminished, either through changes in species composition or fish production in the affected area. Unlike land, floodwater usually belongs to all. Therefore, the risks connected to reduced floodwater availability are significant especially for non-land owners, the poorest section of the rural population.

7. The value of other ecosystem goods, such as forest and plant resources, pasture, wildlife etc. are often underestimated until these are lost with degenerating floodplain conditions. Even though fisheries are indisputably the most significant resource of the floodplains, other natural resources are of great importance in view of diversification of food resources and livelihoods, and often play an important part especially for the poorest people. Also e.g. the value of wetlands as natural purification filters for water is surprisingly high. The use of integrative approaches, such as the ecosystem approach, is highly recommended in complex environments such as floodplains.

8. Valuation of ecosystem services should be developed and integrated into project planning and EIA procedures. This type of valuation yields figures and a numerical measure that can be integrated into more conventional economic cost benefit analyses of the proposed investment, and allows a more thorough economic analysis of the predicted returns for different investment options.

9. Lessons learnt have demonstrated the sensitivity of tropical floodplain environments to increased nutrient runoff. Recent research has illustrated the
importance of phytoplankton to tropical floodplains in Australia and South America. This has important implications for the management of floodplains. Attention should be directed to the control of water quality changes (nutrients, but also turbulence, herbicides, metals, etc.) influencing phytoplankton productivity and species composition of the floodplains, which could have a profound impact on the entire food chain including the species composition of fish.

10. In connection with road construction, it is of importance to assess how to reach a compromise between construction costs and the need for including e.g. culverts and other means to facilitate floodwater flows and the passage of flora and fauna. In many cases where the needs of the ecosystem functions have not been taken into account during the planning phase of the construction, fitting of culverts has been done at a later stage (and at a significantly higher cost) to e.g. enable fish passage.

11. In connection with any built structure in floodplain areas, the effects of increased access to the wetlands should also be assessed. It has been shown that improved access due to lessened flooding, improved road networks and consequent increased human habitation in the floodplain areas will inevitably lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road accessibility. Increased access has also had drastic effects on wildlife due to intensified poaching in areas previously less accessible. Similarly, the newly accessible areas will be subject to new agricultural activities or improved agricultural methods (including irrigation, flood control works, and other infrastructure, as well as new crops or varieties), which in turn will cause changes in the hydrology and increased runoff of pesticides and herbicides.
1. INTRODUCTION

This report forms part of the ADB TA 4669, “Study of the Influence of Built Structures on the Fisheries of the Tonle Sap” project, presenting part of the Environmental Component. The intention of this component is to assess the side-effects of built structures on the (aquatic) environment.

The key outputs of this component are:

1. Literature review (this product, references in Annex 1) including recommendations based on lessons learnt in tropical floodplains worldwide.
2. Table of data concerning recorded, and quantified, impacts (in the form of an Excel file with collected metadata on selected reference cases, Annex 2)
3. Review of IEEs and EIAs in the Tonle Sap Basin (to be produced by Sophie Nguyen Khoa, available in November 2006)
4. Synthesis report based on this review and the analysis of IEEs and EIAs on the Tonle Sap Basin.

This report reviews documented short-term and long-term influences of built structures on selected tropical floodplains worldwide, from an environmental and social safeguard perspective. It reviews mainly impacts recorded after a built structure project has been realised, while predictive information such as Environmental Impact Assessments (EIAs), Cumulative Impact Assessments (CIAs) and Strategic Environmental Assessments (SEAs) are only dealt with occasionally when information on post evaluations have not been found in the literature. Lessons learnt and recommendations based on this literature review will be combined with the second part of the environmental component, which aims to synthesize the findings and recommendations from EIA processes conducted for development projects in the Tonle Sap Basin. The final output will be a joint effort to produce a set of recommendations based on this literature review and the findings from the EIA analysis. These will feed into the policy briefs to be produced as part of the “Informing policy and decision makers” component.

2. METHODS AND SUMMARY OF MATERIAL

2.1. METHODS USED

The following approaches were used to identify literature and other materials concerning the impacts of built structures:

- Internet based search engines
- Library searches at the University of Turku, Finland, and especially in the Amazon library hosted at the same university
- A questionnaire (Annex 3) sent to experts identified during the preliminary literature review
- Correspondence with floodplain experts through the email, phone and other means (Annex 4, Persons Consulted)
2.1. SUMMARY OF INFORMATION SOURCES REVIEWED

Information on general aspects of floodplains is extensive and readily available. However, quantitative information is scarce. The review collected quantitative information (presented in Annex 2), but qualitative data has also been reviewed and summarised in this report. The review concentrates on selected, important and well-documented floodplains around the world.

- >300 journal articles/reports were reviewed
- 9 books were reviewed
- A number (>120) of web pages were reviewed

The questionnaire contained 10 questions (Annex 3 displaying questions and a summary of quantitative answers) regarding floodplains and observed impacts of built structures within them was sent to altogether 62 recipients, mainly scientists known (through the review process) to have worked in floodplain environments. Twenty-three replies were received (of which 19 answered most questions) out of the 62 recipients (31% response rate). The replies received considered floodplains on all continents and major river basins.

3. FLOODPLAINS – GENERAL ISSUES

3.1. Definition

The most common and referred to definition of floodplains is: “Areas of low lying land that are subject to inundation by lateral overflow water from rivers or lakes with which they are associated” (Junk and Welcomme 1990). The “Glossary of terms related to floodplain management” defines floodplains as “low lands adjoining the channel of a river, stream or watercourse, or ocean, lake or other body of water, which have been or may be inundated by flood water, and those other areas subject to flooding” (FMA website [http://www.floodplain.org/glossary_of_terms.htm](http://www.floodplain.org/glossary_of_terms.htm)). In the literature, several more specific definitions are used for different types of floodplains. The terminology varies, including names such as floodplain, flooded forest / shrub land / savannah, inundated forests, várzea and igapó, seasonal floodplain and wetland, being used depending on flooding characteristics, geographical area, and vegetation of the floodplain or other characteristics of the environment. In the Amazon, the floodplains are defined according to the origin and type of the water flooding the forest; várzea forests are fed by sediment rich “white water” rivers, igapó forests border the blackwater (high humus content) and clearwater tributaries (Goulding et al. 1995). The várzea forests are the most common, the most nutrient rich, and have the tallest trees, and therefore are probably the ones that correspond the closest to the nutrient rich Asian monsoon-driven floodplains.

This review concentrates mainly on tropical riverine freshwater floodplains (thus excluding e.g. marine and brackish deltas and mangrove swamps) that are, or have been, regularly inundated by seasonal floods, and where development has taken place and the impacts thereof have been recorded. The review concentrates on some well studied and documented areas, and it does not by any means present an exhaustive inventory of floodplains or structures built on them.
3.2. STATUS OF KNOWLEDGE REGARDING TEMPERATE VERSUS TROPICAL FLOODPLAINS

Riverine floodplains cover more than two million km$^2$ globally (Tockner and Stanford 2002). The tropical floodplains of the world are scattered over all continents with tropical areas, occurring along numerous tropical rivers and lakes. The floodplains in various parts of the globe vary considerably in terms of their physical, chemical and biological characteristics. However, the majority of all floodplains share one quality; they are highly productive due to the exchange of energy and nutrients between different groups of organisms, terrestrial and aquatic (Junk 1997). Moreover, all literature describing floodplains mention their undisputable importance for fisheries.

Another trait shared by most floodplains is their rapid destruction through reclamation of land for other purposes. Due to the special features of the floodplains, oscillating between aquatic and terrestrial phases, they have proved difficult environments for human utilization, and for this reason they have been eliminated or strongly modified by human activities. In highly industrialised countries in North America, Australia and Europe, most floodplains have been lost to agriculture, industries, infrastructure and housing; all the while the understanding of the importance of floodplains and other wetlands has increased. Today, rivers and wetlands are valued with regard to all ecosystem goods and services they provide, and as such are estimated far higher in value than e.g. forests or grasslands. According to Constanza et al. (1997) the estimated average global value for ecosystem goods, services, biodiversity and cultural considerations of wetlands is US$14 785 million while forests are estimated at US$969 and grasslands at US$232 million respectively. In both the USA and Europe, restoration and recovery of regulated wetlands is increasingly taking place, and at a great cost, to return these long-term benefits and ecosystem services provided by wetlands. The restoration efforts have even included decommissioning of dams due to environmental concerns. Much of the restoration effort has concentrated on rehabilitation of wetland habitat and fish migration routes. A recent example is the restoration plan for the Everglades Wetlands in Florida. The documented negative impacts of water diversions through dikes and canals included diminished water retention capacity of the watershed, topsoil loss, runoff from developments leading to raised phosphorus levels, salinity intrusion, loss of biodiversity and proliferation of invasive species. The first phase of the restoration plan is estimated to cost US$7.8 billion, mainly due to the restoration of natural hydrological patterns to increase the capacity for storing water within the watershed. This includes the removal of long stretches of canals and levees, and the installation of gates and culverts to roads presently interrupting the ability of many animals to find suitable habitats timed to their lifecycle (WRI 2000).

In the near future, the most threatened flood plains will be those in SE Asia, Sahelian Africa and North America. There is an urgent need to preserve existing, intact flood plain rivers as strategic global resources and to begin to restore hydrological dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity. Otherwise, dramatic extinctions of the aquatic and riparian species and of ecosystem services and faced within the next few decades.

Tockner and Stanford 2002

Apart from restoration programs, research activities are also currently taking place in connection with e.g. flood control and its implications for fish and fisheries in temperate areas (e.g. the Living Murray initiative in Australia, the recent symposium in Austria on
the topic “Hydropower, flood control and water abstraction: implications for fish and fisheries” held in June 2006). The abstracts submitted for presentations during this conference indicate that a clear majority of the work in temperate rivers and floodplains reports decreasing fish catches, increased larval mortality, reduced or strongly altered species diversity as common consequences of built structures on rivers and floodplains. To remedy these losses, fish passes, bypass channels, spawner transportation, flood simulation and weir operation have been studied in connection with migratory fish rehabilitation programmes.

Research concerning implications of flood control and other built structures on floodplains in tropical areas, mostly located in less developed countries, is in comparison with temperate floodplain research in short supply. In addition, given the differences between tropical and temperate riverine systems, theories and conservation strategies that have been developed based on studies in temperate environments may not be applicable or effective in tropical environments (Pringle 2000). For example fish ladders, which have been developed and used extensively in temperate regions to facilitate the migration of especially economically important fish species, have on many occasions proven to be a failure in tropical regions (Roggeri 1995 and references therein).

There are well-studied exceptions, however. The Amazon floodplains have long received much attention from both natural and social scientists. Research has been conducted especially in the areas of Manaus, Brazil, due to the presence of the National Institute of Amazonian Research (INPA), while other, more remote, parts of the basin remain largely unexplored. Extensive studies have been done by the tropical ecology group of the Max Planck Institute on the floodplains of Brazil, but also the Pantanal in the Paraguay River Basin. In Africa, floodplain related research is mostly quite recent, with the exception of some thorough studies carried out in the 1970s by e.g. Welcomme and colleagues, who demonstrated the relation between the fish catch per kilometre of river related to the floodplain area in km², and discussed the importance of floodplain development to the variation between catches (Welcomme 1975). Some recent and valuable efforts have been made by independent researchers as well as research organisations such as the IUCN (water and wetlands programme) in Africa. Environmental research including aspects of floodplains has been done extensively in the Senegal valley, Barotse floodplains in Zambesi, Tana River floodplains in Kenya, Waza Logone floodplains in the Niger Basin, and in Kenya and Tanzania on eastern African wetlands (Duvail 2004), while the Congo Basin is largely unexplored. In Asia, recent studies on floodplain ecosystems and their fisheries have been carried out for instance in Bangladesh (in connection with the Flood Action Plan studies) and the Greater Mekong region (MRC work, other ADB projects on the Tonle Sap / Mekong floodplains).

3.3. TROPICAL FLOODPLAINS - HYDROLOGY AND PRODUCTION

Hydrology is clearly the single most important driving variable in tropical floodplains (Tockner and Stanford 2002), based on which the flood pulse concept defines the river and its floodplain as an indivisible unit (Junk 1997). Any long-term change to the pulse affecting the hydrodynamics of the flood, such as timing, height, duration, amplitude, smoothness or the rapidity of change of the flood pulse, will result in fundamental ecological changes in the affected areas and also influence the living conditions of the local human population (Junk and Cunha 2005).
A positive correlation between the height of flood pulse / inundated area of the flood and fish catches has been reported for a number of tropical floodplains (Welcomme 1979, de Graaf 2003a and de Graaf 2003b and references therein, Halls and Welcomme 2004, and Tockner and Stanford 2002). Studies in both the Amazon and Africa have shown that the growth of tropical floodplain fish is maximal in the high water season (Hoggarth et al. 1999). However, not only the height of the flood pulse (amplitude) is of importance, but also other flood pulse characteristics such as timing, continuity, rapidity of change and duration of flood, as well as dry season water levels, have been shown to be related to fish production (Welcomme and Halls 2004). The productivity of floodplain environments in indisputable in comparison to any other freshwater system: Jackson and Marmulla (2000) conclude that while shallow, managed reservoirs yield on average 30-150 kg/ha/year of fish, deep reservoirs 10-50 kg/ha/year, and slow flowing rivers 30-100 kg/ha/year, floodplains averaged 200-2000 kg/ha/year. Baran (2005) summarises the productivity of some known floodplains in Asia and South America, reporting yields varying between 25 and 230 kg/ha/year.

Much is still unknown concerning tropical floodplain ecosystems. The high biodiversity and intricacy of the environment leads to complex ecological interactions. For example, only recently has the evidence of the importance of autochtonous (produced within the system) carbon, and especially microalgae, in tropical riverine systems increased, as opposed to the earlier belief that allochtonous carbon was the driver of floodplain ecosystem functions (Douglas et al. 2005). In the Amazon, it has been shown that some plant groups contribute more to the primary production of a floodplain in comparison to others, which are more important as food resources for adult fish (Forsberg et al. 1993). Flooded forest trees, certain macrophyte leaves, periphyton and phytoplankton as a group produced only 48% of the organic matter of the floodplain, but accounted for 82-98% of the carbon in adult fish, due to selective feeding by the fish themselves, or by herbivores and detrivores lower in the food chain. In numerous other tropical rivers it has been shown that microalgae are the main driver of aquatic food chains (Douglas et al. 2005 and references therein). Therefore, algal production in floodplain lakes may play a critical role in sustaining commercial fish production (Forsberg et al. 1993). Algae are sensitive to even small changes in nutrient loads (Douglas et al. 2005). In case of high light and temperature conditions, increases in nutrients are likely to trigger rapid increases in primary production and lead to changes of species composition, thereby affecting the entire food web productivity. This means that attention should be directed to the control of water quality changes (nutrients, herbicides, some metals like copper especially) influencing phytoplankton productivity and the species composition of floodplains (especially in connection with structures involving aqueous effluents), which would have a profound impact on the entire food chain including the species composition of fish.

3.4. FLOODPLAIN BIODIVERSITY

Floodplains are among the most biodiverse environments known, due to the high level of spatiotemporal heterogeneity as well as the diversity of habitat types, representing a variety of successional stages (Ward et al. 1999). Junk et al. (2000) regard the floodplain forest to be the system with the highest biodiversity, since it consists of many endemic highly adapted tree species, which offer habitat and food for a highly diversified, but mostly unknown, community of invertebrates. This applies most probably to the Tonle
Sap area as well, not only regarding the fish diversity but also other floodplain organisms.

Apart from being biodiverse, tropical areas also display a high percentage of endemism. In the Amazon, 90% of the over 2000 known fish species are endemic, and in the Congo, 70% of the 700 species are endemic. The corresponding figures for temperate rivers are significantly lower; in the Mississippi River 30% out of 250 species are endemic, and in the Danube only 10% out of 70 species are endemic (Pringle 2000). This entails that even local disruption of a habitat in tropical rivers and floodplains can lead to devastating impacts for certain endemic populations. In the Amazon it is thought that damming of rivers has most likely resulted in numerous species extinctions, especially of highly confined endemic species (Goulding et al. 1995).

Tropical riverine fauna generally include a large number of migratory species, highly vulnerable to human impact including modifications of lateral or longitudinal connectivity to their habitat. Many of these species are both riverine and lacustrine, depending on the season, and therefore dependent on the availability of both habitats (Pringle 2000).

The ichthyofaunas of North America (about 1500 species), Europe (about 360), and Australia-New Guinea (about 500) are the most thoroughly documented, but new species continue to be described based on discovery of previously unseen forms and species-level taxonomic splits of known species. The ichthyofaunas of tropical Asia (perhaps >3000), Africa (perhaps >3000) and South and Central America (perhaps >>5000 species), are species-rich yet incompletely known. Tropical freshwaters are hot spots of recent and likely future ichthyological discoveries. Especially in the tropics, discoveries of species that signal new generic-level taxa are common, and new family-level groups are found occasionally. Everywhere ongoing phylogenetic studies often suggest or reveal unsuspected relationships. These are times of exciting discovery and advancement of knowledge in freshwater ichthyology. New discoveries beckon us to seek the many remaining unknowns in the diversity of life on our planet. These are also times of rapid and destructive change in freshwater habitats around the globe. These threats alert us to the increasing potential for permanent loss and ignorance of much of our planet’s rich aquatic biota.

Lundberg et al. 2000

According to Bayley (1998), it is now generally accepted that the conservation of most species in the aquatic system, as well as biodiversity in its broader sense, depends on the maintenance of the flood pulse. It also depends on the maintenance of connectivity, both longitudinally within the river channels and laterally between the main river and the floodplains. Longitudinal connectivity is necessary to keep migratory pathways open for the long and medium distance migrants. Lateral connectivity is necessary so that the floodplain environments, including the associated higher vegetation, are sustained and fish can move from their dry season habitats to the wet season spawning and feeding areas. Generally, the effects of excessive fishing are insignificant relative to the damage that can be caused by changes in connectivity, and water quantity, quality and timing (Bayley 1998). Conservation of the biodiversity of floodplains is also of importance for retaining other ecosystem services. Recently, experimental research provided proof of
the importance of one single migratory fish species to the carbon flow in a tropical river in South America (Taylor et al. 2006). The authors showed that *Prochilodus mariae* modulates the carbon flow and ecosystem metabolism of a river in the Orinoco Basin. Removal of the species decreased downstream transport of organic carbon and increased primary production and respiration. Therefore, besides being an important harvested species, *Prochilodus* is a critical ecological component of South American rivers, and dependent on both latitudinal and longitudinal access to floodplains (spawning during wet season) and the river (feeding in dry season).

It has been shown in temperate rivers and floodplains that the impoundment of river channels does not have a significant impact on the species richness of molluscs, crustaceans or insects, but the species composition changed. However, disconnecting the floodplain from the main river channel led to a severe impact on biodiversity, reducing the species richness in all studied groups from 494 species in a connected floodplain to 149 in a disconnected floodplain (Ward et al. 1999). Moyle and Leidy (1992), and later numerous other researchers (summarised in Dudgeon et al. 2006) categorised the causes of the loss of freshwater aquatic biodiversity into five broader units (built structures relating to these units in parenthesis):

1. Competition for water / flow modification (most built structures, dams, impoundments, dikes, levees, irrigation, canals),
2. Habitat alteration, destruction or degradation (impoundments, canals, irrigation),
3. Water pollution (all built structures with effluents, but also irrigation, dams),
4. Introduction of, and invasion by, exotic species (canals, dams, reservoirs) and
5. Commercial (over)exploitation (selective fishing gears).

Each of these five causes can be connected to built structures; thus built structures will impact biodiversity. The first three causes mentioned often act in concert, and are the principal causes of the loss of aquatic biodiversity, but are often exacerbated by the introduction of exotic species and overexploitation. The effects of all of these factors are also both additive and cumulative.

### 3.5. Ecosystem Value of Floodplains

Ecosystem valuation (as presented by Barbier et al. 1993 and Constanza et al. 1997) has fairly recently been introduced in connection with ecosystem services provided by wetlands, including some floodplains. According to Constanza *et al.* (1997) wetlands are one of the most valuable landscape types in the world. One of the highest valued “direct use value ecosystem services” of floodplains is fish, while inputs to agriculture (nutrient rich deposits) and nursery functions of fish and other organisms, are considered the most important “indirect use value services” (e.g. Turpie 2000). Destruction of floodplains has been found to lead to diminished water storage during floods (Junk 1997) and subsequently reduced release of stored water during the dry season, another important ecosystem service of all floodplains, which is hard to value without complicated hydrological models. Dudgeon *et al.* (2006) conclude that freshwater biodiversity in general provides a broad variety of valuable goods and services for human societies, some of which are irreplaceable. Nonetheless, there is a paucity of empirical data showing how the value of goods and services derived by retaining habitats in relatively natural conditions compares with that obtained when they are converted for human use. The uses of fresh water, including non-consumptive use,
underscore the importance of considering the perspectives of a wide range of stakeholders in environmental valuation and in the development of effective conservation policies (Dudgeon et al. 2006).

African floodplains provide a host of goods and services; these include floodplain recession agriculture, fish production, wildlife services and goods, livestock grazing, ecotourism, biodiversity as well as natural products and medicine. Not one of these goods and services has been valued completely. Estimates abound for individual floodplains, but no systematic evaluation for the economic valuation of floodplain services has been carried out continent wide, nor has this been linked to floodplains resilience to stress. It is this lack of information on the economic value that has been a major contributory factor in the destruction of floodplains. Decision makers and politicians see floodplains, as areas without use, to be “developed”. 

Christopher Gordon, 2002

In the Amazon floodplains in Brazil the annual flooded forest revenue related to *Tambaqui* production has been estimated (Araujo-Lima et al. 1998) at US$13 million, of which US$8.2 million originated from floodplain areas. As such, the revenue from this one specific species of fish was larger than the concomitant poultry and rubber production in the Amazonas State, and close to the value recorded for the logging industry in 1992 (US$9 million). In Cambodia, a valuation of the flooded forests in Kandal Province (Navy et al. 2001) estimates that the flooded forest brings a 33% higher net income (predominantly through fishing, but also including fuel wood and vegetables) compared to converted land (mainly through rice and some other crops). In the Waza Logone floodplains in Nigeria, the economic loss of a decrease of 30% in flooding was estimated at US$2.4 million per year. These studies make it clear that the conservation of the flooded forest habitats is of critical importance also financially, to ensure a sustainable future for local economies.

This type of quantification of ecosystem services can contribute significantly to more accurate calculations of actual benefits created by a certain built structure, taking into account both losses and benefits of ecosystem services and natural resources resulting from the development.

4. IMPACTS OF BUILT STRUCTURES ON TROPICAL FLOODPLAINS

In this section, impacts recorded in connection with certain types of structures are briefly discussed. More specific impacts of certain selected structures are discussed in the following chapters dealing with specific floodplains.

Major human impacts on tropical floodplains are according to Tockner and Stanford (2002) caused by hydrological change and urbanisation.

Rosenberg et al. (2000) summarised the environmental effects of large-scale hydrological alterations in general as follows:
- habitat fragmentation within dammed rivers,
- downstream habitat changes, such as loss of floodplains, riparian zones and adjacent wetlands and deterioration and loss of river deltas and ocean estuaries,
• deterioration of irrigated terrestrial environments and associated surface waters and dewatering of rivers, leading to impaired water quality because pollution cannot be adequately diluted.

Furthermore, he mentions the following less conspicuous impacts:

• genetic isolation through habitat fragmentation,
• changes in processes such as nutrient cycling and primary productivity,
• impacts in biodiversity,
• methylmercury contamination of food webs and
• greenhouse gas emissions from reservoirs.

4.1. DAMS

The largest and most discussed and debated built structures affecting floodplains are indisputably large dams. Much has been said on the topic, while few quantified and objective studies have been made. According to an inventory made in 2002 there were over 45,000 large dams (dams over 15 m height, or with reservoirs containing 3 million m³ of water), and total annual freshwater withdrawals were estimated at 3800 km³, twice as much as 50 years earlier (de Sherbinin 2002). Existing dams retain approximately 10 000 km³ of water, the equivalent of five times the volume of all the world’s rivers (Dudgeon et al. 2006). Dams are constructed for hydroelectric power, flood control, irrigation, and water supply, and many dams serve multiple purposes. Even though dams per se make up only a small percentage of total land cover, these artificial water bodies often facilitate other forms of land cover change, such as development of large-scale irrigated areas and urbanization, which impact far larger areas.

4.1.1. Impacts of dams

Since the 1980s there has been a well-organised international movement opposing dam building which does not comply with the San Francisco Declaration of 1988¹, resulting in much discussion concerning the costs and benefits especially of larger dams. The World Commission on Dams (WCD) collated a significant pool of information on issues regarding dams during its activities since 1998 until the release of the WCD report in 2000. According to this report, large dams have numerous impacts on ecosystems. These include:

• the loss of forests and wildlife habitat, the loss of species populations and the degradation of upstream catchment areas due to inundation of the reservoir area;
• the loss of aquatic biodiversity, of upstream and downstream fisheries, and of the services of downstream floodplains, wetlands, and riverine, estuarine and adjacent marine ecosystems; and
• cumulative impacts on water quality, natural flooding and species composition where a number of dams are sited on the same river.

Furthermore, dams and reservoirs impact the hydrological cycle by increasing evaporation (dams in arid areas can lose 5% of total withdrawals to evaporation) and

¹ In June 1988 the International Rivers Network sponsored an international conference in San Francisco for citizens organizations concerned with protecting rivers and water resources from their most immediate threat – construction of large dams. The position statement adopted by the conference and subsequently extended by network organizations forms the San Francisco Declaration, including 22 points which can be accessed at e.g. http://www.irn.org/basics/ard/index.php?id=sfdeclaration.html
loss of downstream aquifers due to reduced replenishment (de Sherbinin 2002). The extension of irrigation systems has also been shown to lead to habitat fragmentation and destruction, e.g. in the Senegal valley floodplains and delta (Daffé web citation).

Bernacsek (1984) summarised the main effects of dams as changes in discharge downstream (volume, timing and amplitude), desiccation of floodplains, riverbank erosion, changes in water quality (especially low oxygen conditions), and changes in flora (including aquatic macrophytes) and fauna (especially changes in fish biodiversity and composition).

In a synthesis based on studies presented at the international symposium concerning large rivers, Welcomme et al. (1989) summarised the effects of stress caused by built structures, such as dams or levees, on fish:

- Obligate migratory species will tend to disappear in systems where the main channels are locked by large dams, while
- Floodplain spawners are selected against by channellisation or other stream regulation processes which reduce or eliminate the annual flood.
- Within modified channels there is a tendency to lose obligate migratory species although management is usually directed at their protection through installation of fish pass structures or through stocking.
- There is a tendency for dominance in fish assemblages to shift from floodplain spawners (phytophilous species) toward main channel spawners (mainly litophils).

More recently, in a contributing paper to the World Commission on Dams, Bernacsek (2000) reviews the impacts of dams on fish and fisheries. He lists the following direct and indirect impacts:

- Clogging or creating hazards to migration in upstream and downstream directions, and by mortality or damage when fish pass through dam discharge structures.
- Indirect impacts on fish biodiversity, fish stocks and fisheries through modifying and/or degrading the upstream and downstream aquatic environments, such as floodplains, including: (i) thermal stratification of the reservoir and release of cool and anoxic hypolimnion water downstream; (ii) downstream flood alteration and termination of inundation of downstream floodplains; (iii) sediment and nutrient trapping in reservoirs; (iv) release of contaminants from trapped sediment into the reservoir food chain; (v) infestation of the reservoir with floating aquatic plants; (vi) ghost fishing by nets snagged on drowned trees in the reservoir; (vii) long distance recession of the shoreline during drawdown; and (viii) pesticide contamination arising from agriculture on the reservoir drawdown zone.

The potential of reservoir fisheries is often listed as one of the benefits of dam construction, creating new fisheries opportunities in the area affected. However, the yields obtained from reservoirs are very variable, and tend to be higher in smaller reservoirs than in larger impoundments. On average, reservoir fisheries are far less productive than river fisheries on a per unit area basis (Jackson and Marmulla 2000).

Petrere (1996) points out the potential benefits of dams with regard to water quality in the river, if constructed in a highly polluted river (example River Tietê in Brazil), where downstream dams can have a positive effect through deposition of dissolved solids in
the reservoirs and forced water aeration through spillways. However, the author acknowledges the detrimental effects of large dams on floodplains both above and downstream of the dam. He also discusses fish ladders, lifts, canal locks, transportation of spawning schools and spawning channels as mitigation measures for the impacts of dams on fish migration. However, fish ladders have been shown to have a low efficiency even for the selected species that can, at all, use them. In addition, fishways designed to promote fish passage past dams are in many instances used by fishers to capture fish (Jackson and Marmulla 2000). Fish lifts are not very common as they are expensive to build and operate. Canal locks may have a marginal effect on assisting in fish movements. The transportation of spawning schools is comparatively inexpensive but requires short distances and efficient water oxygenation apparatus in the transporting vehicles. Spawning channels have been found to be effective but require much maintenance and care taking (Petrere 1996).

Because of the negative impacts recorded, and the difficulty in finding working mitigation measures, the environmental flow requirements methodology (which include managed flood releases) is increasingly used to reduce the impacts of changed stream flow regimes on aquatic, floodplain and coastal ecosystems downstream (de Sherbinin 2002).

There is a need for fundamental research linking abiotic processes to changes in ecology, particularly in tropical environments, where much of the remaining potential for “new” river regulation resides. For all new large dams pre and post construction studies should be conducted in order to assess the environmental impacts and to determine the effectiveness of mitigating measures.

McCartney et al. 2000

4.1.2. Impacts of dams on fisheries

In Africa, studies have been made on the sequence of events after damming. According to Lévêque (1997), the results of these studies conclude that in general, and in tropical areas (as opposed to temperate, where the consequences of dams can be quite different), the closure of the dam is followed by a marked increase in fish populations favored by the new lacustrine conditions. After some time, the fish biomass decreases sharply as predators reduce the inflated population. The change in species composition is marked, and hard to predict, but the obvious change is the disappearance of riverine fish in the reservoir, while species adapted to life in open waters, such as small clupeids, become abundant. Although the number of species in a reservoir may be equivalent to the number inhabiting the original river at the reservoir site, native forms often disappear (Lévêque 1997). Apart from changes in fish diversity, the reservoirs are often subject to a succession of increasing pollution, eutrophication, algal blooms, extensive growth of water weeds, deoxygenation of the water and subsequent fish kills.

4.1.3. Water-related diseases and chemical pollution

An important indirect effect of dams is the increase in water-related diseases through the creation of suitable habitats for vectors in reservoirs and irrigation schemes. Well documented examples include the Akosombo and Kainji dams, man-made lakes of the
Tana River, Lake Volta regions after the construction of the dam, and the Senegal River Delta after the construction of the Diama Dam (Roggeri 1995). Irrigated agriculture worldwide is by far the largest user of freshwater and, consequently, impacts on freshwater ecosystems and the fisheries they support are stronger than for most other human activities (Nguyen Khoa et al. 2005). Irrigation, in combination with the potential increase in the use of pesticides (such as PCBs, DDT, dieldrin, chlorodan) and other chemicals related to increased agricultural activity, can lead to indirect impacts on the environment and fisheries. The bioaccumulation of these compounds through the food chain and their persistence in nature also impacts people using fish as a resource.

4.1.4. Environmental standards for dam construction

Regarding dam construction, environmental standards have been set both by institutions related to the construction (such as ICOLD, International Commission on Large Dams) as well as those which facilitate funding for construction (e.g. World Bank). ICOLD calls for a “comprehensive EIA” to be standard procedure as part of dam construction (ICOLD web pages, accessed in June 2006) but guidance on what should be included in this is not provided, except mentioning that “special attention should be paid to any effects on biodiversity or the habitat of rare or endangered species”. The WB applies the same environmental standards to any project, i.e. pre-project environmental assessments. The only specific guidelines applying to dams seem to relate to water quality standards, implying that releases from reservoirs must comply with acceptable water quality standards (McCartney et al. 2000).

4.1.5. EIA on dam construction

In connection with Environmental Impact Assessments related to dam construction, only recently has attention been drawn to the downstream impacts of dams (much as a result of the work done by the WCD, including the impact on floodplains), while most attention is still given to the direct impacts of dams and the reservoirs created upstream. Indirect impacts such as infrastructural works in connection with dam construction (such as clearance of forest for accommodating machinery, temporary or permanent roads to enable access to the building site, temporary housing for staff working on the building site, etc.), as well as the general development of socio-economic activities connected to dam construction that tends to attract people and industry, are still largely ignored, especially in connection with developments in tropical areas. Generally, river ecosystems containing dams and other built structures must contend with pollution and increased exploitation of their resources, pressures independent from, but adding to, the direct influence of dams and reservoirs (Jackson and Marmulla 2000). The same applies, even more so, to the assessment of cumulative impacts, even though in connection with impoundments it is generally agreed that several impoundments in the same river catchment can result in synergistic negative impacts on downstream fisheries. E.g. Roberts (1995, cited in Jackson and Marmulla 2000) discussed impacts from 12 hydropower projects in the mainstream of the Mekong River and stressed that the combined impact on fisheries from these dams is greater than the sum of the individual impacts.

4.2. EMBANKMENTS, ROADS

Embankments are, like dams, structures opposing water flow. Roggeri (1995) lists at least the following types of embankments: dikes (submersible or not, with water inlet and
outlet, or without), river embankments (man-made levees along a watercourse, raising the riverbanks), water–body embankment (for flood-control, creation of a stable water-body), basin embankments (floodwater storage in an annual or seasonal, man-made lake), floodwater storage dikes (often built in a crescent-shape to increase the dry-season agricultural area by storing water when the flood recedes, common in west Africa), controlled flooding dikes (usually for shortening of the flood pulse through delaying the flood), horseshoe dikes (open embankments), polders (closed embankments protecting land against flooding altogether), groynes (stone or gabion dikes, decreasing flow velocity and increasing filtration into the soil and sedimentation), bunds (usually constructed of local materials such as earth or stones) to increase flood duration or spread floodwater, for irrigation or aquaculture basins, and for infiltration purposes, and contour bunds and water spreading bunds. All these structures affect the water flow in some way, and have been used for centuries to manage floodplain hydrology for human needs. Some embankments occur in most inhabited floodplain environments. The cumulative effects of these types of structures must be significant, but have not been studied much, based on the literature reviewed. However, embankment of long stretches of major rivers, such as the Senegal River, has been documented and the negative effects of drying out of agricultural and pastoral land noted (see details in chapter 5.2.3). Collectively, the impacts of drainage by various means, embankment and subsequent landfilling, often results in worsened flood problems due to reducing the volume of floodwater which can be stored and evenly released later on (Roggeri 1995). Another effect can be reduced filtering and natural water purification of the water due to reduced floodplain vegetation.

Roads crossing floodplains are typically built on an embankment, and hence they have a similar impact on the floodplain environment and fisheries. Roads, forming long and continuous barriers to the natural movement of aquatic organisms, lead to fragmentation of habitat. The construction of roads along embankments has been argued to be a cheaper alternative compared to alternation between roads and bridges, or including culverts in the road construction (Vaz 2000). Roads crossing floodplains have been recorded to disturb natural migration routes of floodplain organisms amongst other things in Florida, USA (WRI 2000), India (Mathur et al. web citation) and Mozambique (Vaz 2000). Little specific information is available on the impacts of roads in tropical floodplain environments, but potential impacts in Ireland have been listed as follows (O'Neill, J. web citation): increased sediment runoff or loading, interruption of (ground)water flow, channel straightening, deepening and widening, stream flow/water level changes, loss of riparian and wetland associated vegetation, severance of habitat, increased risk of toxic runoff, modification of faunal behavior, spread of alien species and loss of spawning habitat.

4.3. CANALIZATION

Canalization (also called, especially in connection with larger-capacity canals, channelization) typically involves the realignment, clearing, widening, and lining of the stream channel, usually for flood control through improvement of flows and drainage of land. When a river is channelized, it is usually also embanked (Roggeri 1995). Canalization can also entail the construction of completely new canals for bypass, water transfer, drainage, flood control and recession or inundation purposes (Roggeri 1995). Among other effects, canalization may reduce stream length, create uniform habitat conditions, modify the hydrological cycle, drain adjacent wetlands, eliminate instream cover and riparian vegetation, degrade water quality and alter trophic relationships.
(Moyle and Leidy 1992). In the industrialised world, many temperate rivers have been canalized along vast stretches. For instance in the USA, the Minnesota and Missouri Rivers are channelized for much of their lengths, which has led to the elimination of shallow-water habitats as well as adjacent riparian habitats that flooded annually, resulting in agricultural, urban and industrial encroachment on wetland habitats on 95% of the former floodplains of the Missouri River, and shortening the river by at least 120 km. Construction of the floodplain and reservoir structures has reduced the input of organic matter by 65%. Channelized sections of river have fewer fish and lower species diversity. In general, habitat alteration encourages the invasion of “weedy” fish and exotic species, with high reproductive rates and aggressive behaviour which allows them to invade adjacent less disturbed habitats and displace native species (Moyle and Leidy 1992). In the Mississippi River floodplain 80% of the hardwood forests have declined and the land has been turned into farms. As a consequence, only 20% of the floodplains can sustain fish populations, and standing biomass within this area declined from 170-340 kg/ha in undisturbed streams to 13 kg/ha. The cumulative effects of channelization and forest or wetland clearing are a watershed-level phenomenon not limited to the immediately adjacent floodplain. Rather, such activities often negatively affect hydrology, deposition of sediments, water quality, productivity and biotic diversity of all downstream aquatic habitats. In the Mississippi River Basin, these activities have increased catastrophic flooding, silted reservoirs, and eroded coastal wetlands, often creating the perceived need for further canalization and levee construction (Moyle and Leidy 1992). Similar experiences have been reported from Australia (Ball 2001).

4.4. MINING, INDUSTRIAL PLANTS
Pollution in the form of chemical pollutants stemming from human constructions (in the form of effluents and sewage) is widespread and serious in all parts of the world. This type of impact is fairly well monitored in temperate regions, while information on the type and magnitude of aquatic pollution is in many tropical environments non-existent. In the Amazon, one of the main concerns with regard to fish populations, apart from habitat destruction and over exploitation of certain species, is the mercury pollution of rivers, caused by gold and tin mining. It is estimated that more than a thousand tons have been released in the Amazon in just two decades (Araujo-Lima and Rufino 2003). In Mexico, it has been shown that unique freshwater fishes and fisheries are in sharp decline due to environmental degradation caused by pollution from human settlements and water competition. Of 44 native fishes, 3 are extinct, and 23 greatly reduced in abundance or range. The fisheries for several valuable native species have declined or collapsed, and exotics constitute a major portion of the catch. In the Ayuquila River, several species have been locally eradicated, and major untreated industrial and municipal discharges, coupled with substantial water withdrawals for irrigation, preclude fish life during the dry season in 20 km of river that once supported an important subsistence fishery (Lyons et al. 1998). In the Everglades wetlands in Florida, increased runoff from agriculture and irrigation water, and effluents from industry and settlements have lead to serious eutrophication causing repeated algal blooms (and resulting fish kills), and *Typha* invasions in areas previously dominated by indigenous grasses (WRI 2000).

4.5. SMALL STRUCTURES, FISHING GEARS
Smaller built structures, such as small-scale irrigation channels, small dams and weirs, floodwater storage systems, waterspreading dams, and fishing weirs, have received little attention regarding their impacts on the environment and fisheries.
Research carried out regarding flood control and regulator structures (sluice gates, weirs) has shown the structures to have a lesser impact on larval fish mortality if operating in an overshot mode rather than in deeper layers (de Graaf et al. 1999). In cases where it is not possible in the short to medium term to modify weir height or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wet and dry regimes (Living Murray, web citation).

Fishing gears left permanently or semi-permanently (e.g. during a certain season) in the water, may be considered built structures, and naturally have a marked effect on fisheries. In many areas selective fishing has lead to a decrease in the most valuable (often also the largest) species, and a shift toward smaller species has occurred. Due to the natural variability of floodplains, the gear types used are also adapted to this variability and include numerous different types. Baran et al. (2005a) describe at least 41 types of fishing methods commonly used in Laos and Cambodia. According to a study done in Bangladesh, Indonesia and Thailand, twenty different gear types were observed within nine broader classes (namely: Static barriers/Fykes, Active Filters/Seines, Lift Nets, Gill Nets, Cast Nets, Portable Traps, Hoods, Dewatering and Spears), and used according to the flood cycle. Some of these gears form static filtering barriers, fykes, which can form barriers for long stretches at the floodplain-river margin, the catch representing up to 32% of the total fishery (MRAG 1994). In cases where the floodplain environment has been reduced due to impacts from structures altering the hydrology of the area, this type of intensive and targeted fishery may have destructive results on species migrating from the floodplain back into the main river channel.

4.6. IMPACTS OF BUILT STRUCTURES – RESULTS OF QUESTIONNAIRE

During this desk review, a questionnaire regarding impacts of built structures was sent to 62 recipients (details in Annex 3). The recipients were selected based on the review. Only 23 replies were received, of which 19 answered most questions (31% response rate). In some instances it was reported that no built structures were present on the floodplains the recipients were working on, and therefore they could not answer the questions. This concerned especially floodplains in Venezuela and Peru. However, based on the few replies received, some general conclusions can be drawn. The number of answers per question is very low and can therefore be considered of indicative value only.

- Replies considered floodplains on all continents, with a small majority from Brazil. Floodplains mentioned included Amazon, Pantanal, Orinoco and Rio Mapire in South America; Ganges, Brahmaputra and Meghna, Bangladesh, Mekong and Tonle Sap in Asia; Senegal, Okavango and Kafue flats in Africa and several floodplains of Australian tropical rivers (4 responses).
- Most floodplains considered had seasonal flooding, and consisted of large river floodplains with slow, ample and predictable floods, or flooded forests.
- Concerning ecosystem goods in the floodplains considered, fish was reported very significant or significant in all cases. With regard to other ecosystem goods and services, most suggested options scored “significant” except for game, rubber and medicinal plants, which were mainly classified as “not significant”.
- Of ecosystem services, nutrients and fertile soils for agriculture were valued the most, followed by ecotourism potential and transport and navigation. Recreational and aesthetic value was considered less significant.
• The dispersal of answers regarding ecosystem goods and services illustrates the variety of ecosystem goods and services that different floodplains provide.

• Regarding built structures recorded in the floodplains, the following were listed: structures related to flood protection, mining, hydroelectric plants, channellization, dikes, "hydrovia", large roads, dams, irrigation schemes, raised canals, gas storage facilities, levees, weirs, seasonal sand dams, bridges, culverts, and caseways.

• Regarding EIAs and SIAs most answers reported either no assessments made, or not in sufficient detail. Environmental Management Strategy was suggested to be incorporated into any built structure proposals. One reply indicated that a growing number of assessments are being done, but several pointed to weak implementation of the recommendations made during assessments.

All (12) respondents indicated that fish were impacted by structures, and 92% (11) noted that the environment had been impacted.

5. CASE STUDIES AND LESSONS LEARNT IN SPECIFIC FLOODPLAINS

This section gives an overview of some important tropical floodplains in South America, Africa, Australia and Asia.

A list of specific built structures and their environmental impacts, if quantified, is attached in Annex 2. This section discusses some of these cases in more detail, or other cases where only qualitative impacts have been recorded.

5.1. SOUTH AMERICA

5.1.1. Amazon floodplains

About 20% of tropical South America is wetlands (Junk 2002), including a great number of floodplains occurring in areas with low population and in remote areas where little human impact has taken place (Figure 1). In total, 6% of the entire basin area is periodically inundated. Flood control measures per se do not exist in the Amazon floodplains due to the high flood amplitude of the Amazon River (between 4 and 20 meters). Sometimes small, very local, flood protection measures are taken but they do not affect the ecosystem (Junk et al. 2000).

5.1.1.1. Large structures

Roads and other built structures are still scarce in large parts of the Amazonian floodplains. Despite this attempt to intensify the utilisation of natural resources have led to the construction of roads and other infrastructure to stimulate the agroindustrial development of the region. Operation Amazonia in Brazil (1966-1967) led to a significant increase in the road network in the Amazon to facilitate the occupation of northern parts of Brazil. These road constructions have been reported to have impacts on the floodplains through e.g. increased turbidity of rivers due to increased erosion from deforested areas. Waters of the previously Clearwater Rio Ji-Paraná became milky in colour after the construction and colonisation along the Cuiabá-Porto Velho Highway, which cut across its headwaters.
Many of these construction projects have demonstrated the vulnerability of the region especially to erosion and subsequent sediment loading of rivers and floodplains (Junk 2005). One of the major indirect impacts discussed in connection with e.g. road and gas pipe construction through remote and isolated floodplains is the introduction of the floodplains to human impact in general, introducing previously pristine areas to immigration and development of settlements, agricultural activities and ranching with livestock.

Figure 1. Map of the Amazon rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: www.iucn.org/themes/wani/eatlas/index.html

Comparatively few hydropower plants have been built in the Amazon region, and even fewer have had complete pre- and post-filling evaluations done regarding their impact on the environment and fish. One of the most documented cases is the Tucurui Dam. Recorded impacts include a reduction in species richness of fish and catch per unit of effort both in the reservoir as well as downstream of the dam, an increase in the abundance of piscivorous species and a decrease in frugivorous and detrivorous species, while migratory species disappeared altogether (Araujo-Lima and Ruffino 2003). The situation was unstable for a number of years after construction, improving somewhat in the reservoir, while downstream fisheries did not show a similar recovery. Anoxic environments were created through decaying vegetation left in the reservoir (Fearnside 2001). Assessing the impacts of the dam is made complicated due to the differing points of view and impacts reported by different authors (see Annex 2 with list of...
impacts recorded). Araujo-Lima and Ruffino (2003) conclude that the impacts of the reservoir on fish varies between fish species, some being negatively affected while others respond positively to the habitat change. However, a common trend observed was the reduction in fish diversity. The only mitigation measure that has been generally adopted seems to be the establishment of hatcheries to stock the reservoirs with native species, but little follow up has been done to monitor stock densities (Fearnside 2001).

One of the most controversial, discussed and disputed construction projects in South America, apart from large dams, has been the Camisea Gas Project in Peru. The 731 km-long Camisea pipeline runs from the Amazon, over the Andes, to the Pacific Coast. EIAs and independent reviews by local organisations point to massive erosion caused by the construction and operation. The erosion causes loss of topsoil, siltation pollution of the aquatic river systems and landslides on inclines. As of March 2006 there have already been 5 spills along the Camisea pipeline since it became operational in August 2004 (Wikipedia internet encyclopaedia2).

The experiences related to the gas pipe constructions in the Amazon has led to attention being directed toward the social and environmental impact assessments involved. The Bank Information Centre USA prepared (Hamerschlag 1999) a set of recommendations based on the experiences derived from a 3000 km gas pipe construction from Bolivia to Brazil. The recommendations point to emphasis of information, public consultations, environment and indigenous peoples, project monitoring and compliance. However, specific instructions for consideration of different ecosystems, such as floodplains, are not specified.

Despite difficult experiences during massive infrastructural construction projects, the future of the Amazon Basin will still include several extensive projects focussing on fluvial transportation and road construction, e.g. within the programme “Iniciativa para la Integración de la Infraestructura Regional Suramericana” (IIRSA web citation).

5.1.1.2. Identified threats to Amazon floodplains

According to Goulding et al. (1995) the main threat to the remaining floodplain forest in the Amazon is deforestation, which has already affected most areas of the floodplains. The area of flooded forests on the floodplain has decreased dramatically. Intensive logging of valuable species in the flooded forest, as well as clearing of land for cattle farming, are the main reasons for the deforestation. Clearing of trees is also the first step in agriculture and mining.

Bayley and Petrere (1989) consider that in the case of the Amazon várzea, hydrological alteration due to hydroelectric dams may lead to more severe impacts on fisheries than deforestation during the next 10-20 years. The well-documented cases in Africa (Bernacsek 1984), in particular the inability of reservoir production to replace losses of floodplain fisheries and agriculture production downstream, have according to Bayley and Petrere (1989) been largely ignored in connection with the planning of new reservoir developments in the Amazon.

Bayley (1998) summarises the major threats to Amazonian aquatic biodiversity as follows:

- The conversion of várzea floodplain to pasture and crop agriculture;
- Changes in flood regimes and system connectivity through hydropower dams and navigation channels ('hidrovias'); and
- Deterioration of water quality through mercury used in gold mining, petrochemical effluents, drug processing wastes and sewage discharges.

Of these, Bayley (1998) considers várzea conversion to be the greatest short term threat, while the most fundamental long-term threat is unsustainable water-use, principally construction of navigation channels and dams, which reduces biological productivity by altering the floodplain inundation regime and curtails longitudinal and lateral connectivity. Junk et al. (2000) classifies (the same) human impacts on the várzea in different categories, with decreasing destructive effects: 1. modification of the hydrological regime, 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species, and 4. pollution.

5.1.1.3. Threats to Amazon fish and fisheries

Large-scale ranching with cattle and water buffalo is at the moment a serious threat to the primary economic resource of the floodplain: the abundant and diverse fish. The number of known fish species in the Amazon is around 2500 species (Araujo-Lima and Goulding 1997) of which only a fraction, mainly economically important species, have been studied. The impact of development on the Amazon fish fauna is therefore still poorly understood. The main impacts apart from over fishing (of certain high value species) are, according to Araujo-Lima and Ruffino (2003), mercury pollution and deforestation caused by gold and tin mining and habitat destruction including built structures such as dams and reservoirs. Although most of the Amazon fish catches are harvested in the main river channels and far downstream, they ultimately rely on the floodplain for spawning areas, food and cover (Goulding et al. 1995). The location of a built structure in the river channel is of importance, and can lead to a stronger impact on some species than others. For instance some larval fish species are predominantly transported into floodplains during rising waters, mostly along the riverbanks, in which case a structure changing riverbank attributes will affect migration patterns (e.g. canalization creating abrupt and steep riverbanks), while others are flushed out of floodplains more evenly during the water recession (Araujo-Lima and Oliveira 1998).

5.1.2. Floodplains of the Paraguay/Paraná River Basins

The “El Gran Pantanal” or the larger La Plata Basin is an expanse which encompasses more than 2 million km² and a population of more than 100 million inhabitants, and extends through Brazil, Bolivia, Paraguay, Argentina and Uruguay in the Paraguay River Basin (Swarts 2000). The Pantanal is the largest South American seasonally flooded land, composed of the floodplains of the Paraguay River and effluents (Figure 2). During the dry season, the Pantanal is covered by dense to open savannah and riparian forest at river edges, while during the flood, the plains are covered by water up to two meters deep that stays for several months (da Silva et al. 2000). The Pantanal is increasingly threatened by large development programs, including agroindustries and hydropower reservoirs, plans for canalization of the Paraguay River (hidrovia) and increasing industrial and livestock developments. These developments negatively affect habitat and
species diversity, scenic beauty and also the hydrological buffer capacity of the Pantanal (Junk and Cunha 2005).

Figure 2. Map of the Paraná rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: www.iucn.org/themes/wani/eatlas/index.html

The high Paraná floodplains in Brazil cover an area of 230 km between Itaipu and Porto Primavera reservoirs, with a width of about 20 km. The floodplain has been affected by intensive reservoir constructions (25 reservoirs larger than 100 km²), but due to water from several unregulated tributaries, the flood regime still maintains and this remaining stretch of the high Paraná floodplain ecosystem still supports considerable biodiversity (Agostinho et al. 2000). This floodplain area is the last unimpounded section of the river within Brazilian territory. In Argentina, the Paraná River is highly regulated, the water in reservoirs of the Upper Paraná Basin currently comprising more than 70% of the mean annual discharge at its confluence with the Paraguay River (Quirós 2004). The expansion of hydroelectric generation in the Upper Basin has brought with it an increase in industry, agriculture, transport and settlements. These in turn have resulted in significant increases in deforestation, soil erosion, changes in water quality and reduced fisheries opportunities in both the Upper and Lower Basins (Quirós 2004). A study done by Terraes et al. (1999) in connection with the Yacyretá Dam, located in the Upper Paraná River, confirmed that the reproduction of many species of fish was negatively affected by the dam through a change in the male-female ratio, as well as a shortened
reproductive period. The fisheries in the Paraná River Basin were traditionally based on large potamodromous fish caught from a fish community containing a relatively high frequency of the detritivorous *Prochilodus* (Quirós 2004). The catch per fisher per day now ranges from 11 to 30 kg for reservoirs situated in the Brazilian Upper Basin to more than 110 kg in the Lower Middle Parana River. Striking differences in the fish species structure of the catch are noticeable between reservoir and floodplain fisheries and among floodplain fisheries themselves. Quirós (2004) identified three main fishery states in the Plata Basin across broad temporal and spatial scales:

1. A relatively undisturbed state corresponds to the unregulated river, when fishing effort was relatively low to moderate, the catch being mainly dominated by high value large siluroids and characins. This state is represented by fisheries at the Pantanal floodplains and the Parana-Paraguay confluence and to a lesser extent by some of the remnant lotic reaches at the Upper Parana.

2. A second fishery state corresponds to the developed river, with floodplains disturbed by river regulation and other developmental activities. Here the fisheries are still supported by potamodromous fish but fish size at capture is usually lower. Fishing effort is usually higher. The contribution by weight to the catch of less valuable *Prochilodus* has increased, and exotics are usually included in fish catches. The disturbed floodplain fishery state is represented by fisheries of most of the Lower Basin and at the few unregulated reaches of the Upper Parana.

3. Fisheries in riverine reservoirs represent a third, relatively highly disturbed fishery state. The catch of potamodromous fish frequently descends well below 50% of the total catch and fish catches are often dominated by blackfish species, less dependent on river flows, and with an increasing importance of exotic fish species. Fish size is lower as well as fish value at landing.

The Plata Basin fisheries represent almost all of these states at the same time in different parts of the basin, and provide a unique opportunity to study different stages of disturbance and its effect on floodplain fisheries.

### 5.2. **Africa**

Nearly all African rivers are accompanied by large fringing floodplains and several internal deltas occur. Forty-three large floodplains have been reported and described to some extent (Junk 2002). In most parts of Africa, water availability is sufficient only in the moist equatorial belt. Therefore, water needs for irrigation, domestic and industrial uses have caused construction of numerous reservoirs affecting the downstream flow and floodplains (Junk 2002). Most large rivers of Africa have at least one main stem dam and some, such as the Nile and the Zambezi, have more. There are also a large number of medium-sized dams (reservoir sizes 10 -100 km$^2$) for irrigation, urban water supply and small-scale power generation. The larger dams are the major causes of degradation of the aquatic environment and disruption of the livelihoods of communities dependent upon farming, fishing and grazing along the river valley (Welcomme 2003). The changed hydrological regime of rivers has adversely affected floodplain agriculture, fisheries, pasture and forests that constituted the organising element of community livelihoods and culture (World Commission on Dams Report 2000). In many cases the desiccation caused by dams has been enhanced by natural drought.
Impacts of flow alteration on fish species have been documented for numerous artificial reservoirs in Africa, which have replaced running water habitats resulting in the disappearance of lotic species and the proliferation of species adapted to lentic systems. Many of these species are exotic, which has had a further impact on the ecosystem (Revenga and Kura 2003). Only in a few cases has remediation action taken place, e.g. in the Phongolo (South Africa), Senegal and Waza Logone (Cameroon) floodplains.

5.2.1. Congo River Basin

The Congo River Basin is the largest watershed in Africa, and the second largest (after the Amazon River Basin) in the world. Due to the unstable political situation that has prevailed in the area for a long time, little information is available on this vast floodplain area. Only minor infrastructure development is present and therefore it is probable that large parts of the wetlands are still intact (Junk 2002).

5.2.2. Niger River Basin

The Niger River traverses four countries, but the basin covers 9 countries of West Africa (Figure 3). The Niger has been comparatively well studied. Welcomme has conducted comprehensive studies in many African floodplains, including the Niger. Already in 1975 Welcomme published calculations showing the importance of floodplains for fish production in the Niger and Benue Rivers, indicating that the floodplain area of a river accounts for 72% of the variance of actual catch per km of river. This relationship has been improved and extended in newer literature (e.g. Laë 1992, Laë 1994). Differences in the yield within one river system can thus be attributed both to the development of the floodplain in the various river reaches and to differences in the water chemistry of the various tributaries (Welcomme 1975).

Figure 3. Map of the Niger rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: www.iucn.org/themes/wani/eatlas/index.html
The floodplains along the Niger River have been much affected by built structures, especially the building of dams which has reduced the area of large floodplains and floodplain lakes. According to Laë et al (2003), there are four major dams built on the Niger, as follows:

- A hydroelectric dam was built in 1980 in Selengue on the Sankarani River upstream of Bamako to provide electricity for the Mali capital. The reservoir surface area is 400 km$^2$ and during the flood the flow rate of the river entering the reservoir is estimated at 123 m$^3$ s$^{-1}$.
- The Markala Dam was built in 1943 250 km downstream of Bamako in Mali in order to store water for gravity irrigation of a depression that was formerly an arm of the Niger. This new area, known as the “Office du Niger”, allowed a significant development of agriculture and currently produces rice and sugar cane. For this purpose up to 158 m$^3$ s$^{-1}$ of water is used, representing 5 percent of the river flow during the flood. There is only one hydroelectric dam in Niger at Kandaji, except for a submersible dam that provides the capital Niamey with drinking water. As the hydrological cycle is disrupted downstream, a co-operation agreement between Mali and Niger allows for artificial flood releases at low waters to maintain a minimal flow.
- The only mainstream impoundment on the Niger River is Lake Kainji in Nigeria, located about 1200 km upstream from the mouth of the river. The hydroelectric dam was built from 1962 to 1968 and the surface of the reservoir when full is about 1300 km$^2$.
- The upper course of the Benue River was impounded in 1982 for hydroelectric power generation, irrigation and fisheries. The surface of the reservoir covers 700 km$^2$.

All these structures have had an impact on the natural dynamics of the river downstream of the dams and on fish abundance and diversity (Laë et al 2003). According to Laë (1994) the effects of the dams is felt especially during highwater, when the filling up of especially the Selengue and Markala dams leads to a deterioration of the flooding through decreased expanse and duration of flooding. This in turn has lead to a decrease in recruitment and fish catches. The yearly production loss has been estimated at 5000 tons (10% of fished volume) of which 2000 are directly attributable to the Selengue dam.

A fairly well documented example of the impacts of dams on the Niger is the Kainji Dam. As a result of diminished downstream flows, the floodplain lake Ndakolowu, downstream of the dam, has been strongly reduced in area (Bernacsek 1984). The Kainji Dam has been reported to also have positive effects through changed fisheries opportunities in the reservoir of the dam, the Kainji Lake, second in size in West Africa to Lake Volta. A report on small-scale fishery studies done by a Nigerian-German project stated that “Although the lake’s primary function is for hydroelectric generation, an important small-scale fishery has developed that in 1999 supported some 9502 fisherfolks using a wide range of gears including gill nets, cast nets, beach seines, fishing traps and longlines” (Alamu et al. 2003). However, earlier studies in the area pointed to the opposite. Welcombe (1985) reports a fish loss of 6000 tons per year due to the Kainji Dam. Later studies showed a 30% decrease in fish catches, and a reduction in commercially important Mormyridae species from an average of 20% of the catches to just 5% (Jackson and Marmulla 2000). It is not a simple task to weigh the gains and losses of a
certain large project, even retrospectively. However, in the presence of floodplains downstream of a dam, losses in flooding will inevitably lead to major changes to the rich floodplain ecosystem, and the losses of these should be compared to the gains received from the artificial lacustrine environment created through the reservoir.

For many decades (especially between 1970 and 1985) the Sahelian drought has caused decreased annual inflows to many rivers in West Africa. EIA's prepared in connection with dam constructions in regions affected by this drought suggest that the dam, and possibilities for increased flows during at least part of the year, will counteract the impacts of the drought. For example, the EIA prepared for the proposed construction of the Kanjandji Dam in Niger suggests mostly positive impacts of the dam through rehabilitation of floodplains (that have decreased due to drought), including fish passes in the dam and creating new habitats (Kimba 2003, Lahmeyer Int 2002).

5.2.3. Chad River Basin

The Waza Logone floodplain in Cameroon is an exceptionally well-documented case, where promising experiences in the rehabilitation of the floodplain have been collected. The Waza Logone floodplain covers an area of about 8000 km² (5000 in dry season). It is located in the North Province of Cameroon (Figure 4), where the floodplain comprises about 10% of the total surface area of major riverine wetlands in the West African Sahel (Emerton 2005). It therefore represents a critical area of biodiversity and productivity in an otherwise arid area. Sixty percent of the inhabitants of the region rely on floodplain and wetland resources for their basic income and subsistence (Emerton 2005).

Figure 4. Map of the Chad rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: www.iucn.org/themes/wan/eatlas/index.html
The high productivity of the Waza Logone region depends to a large extent on the overbank flooding of the Logone River (tributary of the Benue and Niger) and three seasonal rivers. Since 1979 the inundated area has been reduced by 964 km² representing almost 30% of the original flooded area, due in large part to the construction of a rice irrigation scheme (SEMRY) including a 30 km long dam creating a 400 km² reservoir (Maga Lake), as well as extensive embankments along the Logone River (Loth 2004). The construction works resulted in a 70% reduction of water supply to the floodplain from the Mandara Mountains, and an almost complete curtailment of the water supply from the Logone.

According to Loth (2004), the reduction in inundated area had a number of negative impacts on the ecology, biodiversity and socio-economy of the Waza Logone floodplain, including:

- Reduction in crop agriculture, mainly floating rice and floating sorghum, and flood recession sorghum.
- Loss of fisheries, including an estimated 90% decline in fish yields within flood-fed wetlands, and reduction of the capacity of the area to provide nursery for fish stocks in the wider river systems of the Logone and Chari. Decrease in dry season pasture: floodplain pastures (especially bourgou (*Echinochloa stagnina*)), a high-quality floodplain grazing area in the dry-season, which has been replaced by expanding rice cultivation. However, rice crop residues are a poor substitute for the loss of bourgou pasture (Wagenaar *et al.* 1986).
- Loss of plant resources, including grasses, shrubs and trees that were used for house construction, beekeeping, handicraft production, wood-fuel, wild foods and medicines. Grasses from the flooded areas were harvested and used for thatching houses and constructing fishing baskets.
- Decrease in wildlife populations, which has indirectly decreased economic activities within the tourism, sport and subsistence hunting sectors.
- Reduction in surface water availability, affecting water holes and water courses that are used for domestic and livestock water supplies and for water transport.

In response to the droughts which affected the Sahel in the 1960s and 1970s, many countries opted for large-scale, intensive irrigation schemes to meet their food security needs and to provide export opportunities. Unfortunately, until the early 1990s, these schemes were premised on overly optimistic economic forecasts and, even worse, implemented without any assessment of their impacts on downstream ecosystems and livelihoods. Today, a wealth of evidence demonstrates that, in many instances, these engineering projects … have not delivered the food increases anticipated during pre-commissioning phases. It has therefore become apparent that full floodplain conversion to irrigated agriculture is economically risky because the traditional farming, herding and fishing activities which such projects replace require no capital investments and often generate higher and more regular (and thus safer) returns per unit of water used.

Loth 2004: The Return of Water
Due to all these losses in the natural floodplain ecosystem services, it was decided to carry out restoration of the floodplains, which started in 1988 and continued until 2000. The restoration of the floodplain began with two pilot releases of water, which coincided with above average rainfall during the period 1994 to 1997. In these years a larger surface area was flooded than during the years immediately following the rice-irrigation interventions. The ecological monitoring programme initiated by the project showed that as a result of re-flooding, perennial grasses returned, and since grazers prefer perennial grasses, the number of wild herbivores increased. Socio-economic data showed improvements in fishing yields and livestock production as a result of increased flooding (Loth 2004). The restoration also led to a marked increase in the number of waterbirds, mammals, fish production, improvement and extension of pasture and changed agricultural opportunities (Emerton 2005). The return of the flood was of greatest value to pasture and fishing, while it also significantly benefited agriculture, the state of other natural resources (such as grass and bourgou) and surface water reserves (Loth 2004). The environmental, social and economic impact of the restoration project, as well as the methods used e.g. for the valuation of the re-inundation of the ecosystem, and the planning framework for managed flood releases etc. have been described in detail in Loth (2004).

5.2.4. Senegal River Basin
The Senegal River is accompanied by fringing floodplains along nearly its entire main course (Figure 5).

![Map of the Senegal river basin](www.iucn.org/themes/wani/eatlas/index.html)
The Senegal floodplain received, in a natural state, floods during the high-water period between June and October. During this high water period the river overflows its banks and floods the broad alluvial plain of the middle valley. This enables farmers to practice recession agriculture, growing crops during the dry season, after the waters have receded and the low-water period has started (Finger and Teodoru 2003).

In response to the droughts of the seventies, two major dams were built in the Senegal River, the Diama and Manantali dams. Water management policies were mainly dictated by the needs of new production systems, such as irrigated farming, hydropower and fluvial transport while traditional recession farming was considered old fashioned (Kloff and Pieterse, webcitation). The first dam to be completed (in 1986) was the Diama Dam, located 27 km upstream from St. Louis (Senegal). It was built to stop the dry-season intrusion of seawater. The impoundment reservoir became fully operational in 1992, after the completion of the embankment on the Mauritanian side. The second is the storage dam at Manantali in Mali (completed in 1990) on the Bafing, the main tributary of the Senegal River (delivering approximately 50% of the annual flow). The reservoir is theoretically capable of stocking 11 billion m³ of runoff from the strongly seasonal rainfall in the mountains of northern Guinea. The water can then be gradually released over a longer period than the natural flood (Hamerlynck et al.web citation).

Most of the environmental and social impacts [of the Diama and Manantali dams] have stemmed from the physical separation of the river bed from the floodplains by the building of longitudinal embankments. The original ecosystems now either have too much water (the reservoir and the lowest lying parts of the floodplains) or too little water (the higher parts). Special impacts have occurred in the former estuarine part downstream of the Diama dam which became hypersaline, a common problem with dams in tropical areas. The changed hydrology in the regions has led to salinisation and loss of top soil, hampering the agricultural sector. Areas previously affected by floods and droughts, have now a stable water level which has led to the invasion of Typha domingensis, a reed that has perfectly adapted to the new water management regime.

In the agricultural sector, on top of the salinisation and loss of soil fertility mentioned previously, production has been hampered by the increase in the populations of granivorous (grain eating) birds. It is thought that this population explosion is linked to the permanent availability of fresh water which has eliminated the important dry season mortality. Another factor may have been the creation of inaccessible breeding and resting areas in the tens of thousands of hectares of former floodplain invaded by Typha domingensis. Another major problem is that the land available for the previously largely practised recession agriculture, a sustainable type of agriculture, is now insufficient.

The fish species living in the main rivers of the Sahel have a life cycle that is adapted to the characteristic seasonal flooding, migrating into the floodplain to spawn and returning to the river bed with the new generation at the water’s retreat. Through history, the different communities of fishermen in the Sahel have learned to exploit this life cycle by allowing the spawning migration to go through virtually without intervention, and by concentrating their effort on the fish trying to regain the permanent waters of the river bed. Many techniques exist for the blocking of the return channels with different devices. There is a very clear relationship between flood extent and fish capture, estimated at around 50 kg per ha. Fish catches in the delta of the Senegal River were estimated to be around 30 000 tonnes in the pre-dam era and most of this production has been lost.
subsequently. This loss has been very extreme in the formerly estuarine part downstream of Diama and probably this has also impacted on marine fisheries through the loss of nursery functions for mullets (Mugilidae), shrimp (Penaeidae), shad (Ethmalosa fimbriata) and other species having an obligatory estuarine life history stage.

Though catches in the Manantali reservoir have increased this is certainly not a compensation for the losses in the rest of the valley. It is likely that a change in species composition has occurred in the Diama reservoir, with a decrease of the typical migratory species and a relative increase of the more sedentary, opportunistic species (Claridae, Cichlidae) but no joint surveys have been done in the international waters of the river and no data have been made available from surveys carried out by Senegal. Fishing in the Diama reservoir is seriously hampered by the dense stands of Typha, and by the floating invasives, Pistia stratiotes and (since 1999) Salvinia molesta that are blocking the channels.

The conversion of the floodplains of the Senegal valley for irrigated agriculture has considerably reduced the quality and quantity of dry season pasture. This loss is more extensive than the surface area actually converted to rice fields because of the hydraulic infrastructures used for the control of water supply to the paddy fields. The irrigation systems target paddy fields only, while the surrounding floodplains have dried out and been subjected to wind erosion removing the topsoil causing sedimentation problems in the tributaries, blocking water transport.

Floodplain forests, especially those of [the indigenous] Acacia nilotica and Borassus aethiopium, are of great value. Most of the natural floodplain forests of the valley had already suffered from the drought and overexploitation but after the dams losses have been compounded. The forests have died because of lack of water (on the higher grounds) or waterlogging (in the low-lying areas. The impact on Sporobolus robustus stands, a perennial grass used in mat weaving, which incidentally was the main source of income of the local women, was also devastating. Another important species that used to occupy the seasonal pools in the floodplains is the water lily Nymphaea lotus, which was used locally as a cereal substitute and for its pharmaceutical properties. Most of the original habitat is now covered with Typha.

Summarised from Hamerlynck et al. 2000

These impacts, summarised above as presented in Hamerlynck et al. (2000), finally led to restoration projects, including the Diawling National Park projects. The construction of the Diama Dam in 1986 affected also the floodplain and estuarine areas on the Mauritanian bank by the absence of floods. In 1994, managed flood releases were initiated in the Bell Basin (4000 ha) of the Diawling National Park, as part of a rehabilitation effort. The basin was designated as a joint management area between traditional users and the Park authority and a revised management plan was developed through a participatory approach based on topographical, hydro-climatic, ecological and socio-economic data. Hydraulic modelling was developed as a tool to support stakeholder negotiations on the desired characteristics of the managed flood releases. The volume of flood release required to restore the delta did not affect hydropower generation, navigation or intensive irrigation, for which the dams in the basin were constructed. This project provides an example of implementation of the recommendations of the World Commission on Dams through ecologically and
sociologically beneficial operation of a dam-based infrastructure within the basin, agreed through stakeholder participation (Duvail and Hamerlynck 2003).

5.2.5. Zambezi Basin

Compared to many other river basins in Africa, the Zambezi (Figure 6) is for much of its length relatively little affected by human activities.

Figure 6. Map of the Zambezi rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: www.iucn.org/themes/wani/eatlas/index.html

The major changes in land use affecting biodiversity in the Zambezi Basin over the last 100 years have been the construction of the two major dams at Kariba in 1958 to form the 5361 km² Lake Kariba and at Cabora Bassa in 1974 to form the 2665 km² Lake Cabora Bassa (Timberlake 1998). However, due to inadequate or non-existent baseline data, as well as the absence of EIAs on species composition and abundance, it is impossible to assess the change deriving from these major developments (Timberlake 2000). Prior to these impoundments a series of dikes was built to keep the Zambezi floodwaters out of the sugar plantations. This regulation of river flow and flooding events has almost certainly had a major impact on species abundance and distribution, but the extent of these changes, given a naturally variable and changing environment, is still not clear (Timberlake 2002). Lesser dams that have had major effects on biodiversity are
Itezhi-Tezhi and Kafue Gorge, both on the Kafue River in Zambia, situated at the upstream and downstream ends of the Kafue Flats floodplain, respectively (Timberlake 1998). These two dams have altered and now strongly regulate flooding patterns on the Kafue Flats. The area flooded during the rainy season is now smaller (4340 km$^2$) and more regular. Flood duration is longer and slightly delayed. During the dry season a larger area remains permanently flooded (about 1000 km$^2$). The amplitude of water level fluctuation has been reduced from a mean of 5.1 m to a new mean of 3.3 m (Bernacsek 1984). Other dams are much smaller and situated on the upper reaches of tributaries. Two further dams are planned for the Zambezi: at Batoka Gorge below Victoria Falls, and at Mepanda Uncua below Cabora Bassa (Timberlake 2002).

The construction of these dams has resulted in regulation of the previously-vast annual Zambezi floods below Victoria Falls. Kariba Dam reduced the flood magnitude of the Zambezi River by an average of 24% in eight out of ten years (1970–80 period), which in turn reduced flooding on the downstream Mana Pools floodplain (Bernacsek 1984). Cabora Bassa Dam prevents flooding of the Lower Zambezi floodplain, resulting in drying of floodplain lakes (Bernacsek 1984). The reduction in the flooding has caused radical changes in the fish fauna of the Middle and Lower Zambezi, e.g. a dramatic decline in two commercially important cyprinid fish species (*Labeo congoro* and *L. altivelis*), due to their spawning migration routes being blocked (Lévêque 1997). New fisheries opportunities were expected to be created in the reservoir of the dam, Lake Kariba, which however turned out to be unproductive. This caused the introduction of an endemic sardine-type fish from Lake Tanganyika, which now accounts for over 80% of the commercial catch of the lake (Revenga and Kura 2003 and references therein). The reduction in flooding has also led to the modification of riparian and wetland vegetation by encouraging woody growth at the expense of grassland and, obviously, the large-scale development of lacustrine environments and benthic fauna (Timberlake 1998). Unfortunately, owing to the lack of a good series of pre-impoundment data on biodiversity and ecology, it is difficult to reliably determine the magnitude and exact cause of these changes. However, already in 1970, Attwell reported that the Kariba Dam had both directly and indirectly a great influence on the ecological deterioration of the Mana floodplains, due to the alterations in the flood regime. He mentions effects of flood releases at abnormal seasons affecting the regeneration of vegetation due to the decrease in silt-load in the alluvium caused by the dam, as well as the reproduction of many animal species, such as frogs, crocodiles, water leguaans and terrapins that breed in backwaters and small pools, and several bird species nesting on the riverbanks, where the eggs and larvae are swept away. The lack of flooding during the wet season again has severely affected especially higher lying areas where the vegetation has changed markedly, and species adapted to standing water have become more common. Some of these species, such as water ferns and water lettuce, create considerable problems due to clogging of waterways, and consequent habitat alteration for several key species (e.g. hippopotamuses and crocodiles). In general, Attwell draws attention to the requirement of diversity rather than stability in environmental conditions to maintain a healthy floodplain ecosystem.

Further downstream along the Zambezi, Bento and Beilfuss (2004) have studied the environmental flows for the sustainable development of the Zambezi Delta and the Marromeu complex Ramsar site. They found that the construction of the Cabora Bassa Dam has led to a change in the magnitude of Zambezi flows, the timing of the annual peak to the discharges, and duration of the inundation of the Zambezi Delta, all of which has led to a marked change in vegetation cover in the pre- and post-dam conditions. The
area covered by typical savannah species, such as *Acacia* sp. and certain types of palms had increased by up to 24%, while typical wetland species, such as certain types of grass and shrubs adapted to seasonal inundation had declined markedly. The density and distribution of larger wildlife, such as water buffalo and antelopes, had changed clearly, with a concentration of animals on isolated patches of wetlands left, while the areas left dry after the building of the dam had been abandoned. This leads to heavy grazing pressure and probable land degradation in the limited wetland areas preserved.

A number of mitigation measures have been proposed to ameliorate the changes in the flooding regime, mainly prescribed flood releases from Cabora Bassa, opening up by means of culverts or bridges the major distributor channels coming off the main Zambezi River that feed important floodplains and swamp areas, and ensuring that the forested areas important for the maintenance of the watershed functions are not further deforested (Timberlake 2000).

### 5.3. Australia

In general, wetland habitats are decreasing in Australia mainly due to modified flood regimes, floodplain isolation and increasing salinisation (Ball 2001). Australia has at least 446 large dams (>10 m crest height), most of the stored water being diverted upstream of floodplain wetlands, while 50% of floodplain wetlands on developed rivers may no longer flood (Kingsford 2000). In the State of the Environment Report for Australia (Ball 2001), the following factors have been listed as key pressures on aquatic ecosystems:

- changes in natural flow regimes due to water extraction and supply
- direct modification or destruction of important habitats
- barriers to the movement of plants and animals upstream
- effects of poor water quality
- competition from introduced and exotic animal and plant species
While figures concerning the construction of major dams and water storages since 1990 are not readily available, it is clear that the growth in total water storage has declined significantly since the mid-1980s. This is partly because the most economically efficient sites for water storage have already been developed and because attitudes have changed towards major storages and their potential effects on river flows and floodplain habitats (Ball 2001). The Murray-Darling Basin in the temperate South-East of Australia is highly developed, and the most studied floodplain in Australia (Figure 7). The Murray-Darling Basin has most of its annual runoff diverted and the second highest number of dams with storage capacity exceeding mean annual runoff, as well as 87% of divertible resources extracted (Kingsford 2000). Irrigation is a major water demand sector in Australia, and has led to severe water shortages in many parts of the country. Development of the Murray-Darling Basin has resulted in 9 801 000 million l/yr of water being used for irrigation, therefore reducing flows that would have naturally inundated floodplain wetlands. Floodwaters, which used to reach the Chowilla floodplain about every 1.2 years, now reach the floodplain every 2.5 years. Moderate flooding now only occurs every three years and lasts half as long. Large floods that previously inundated the floodplain every three years and lasted for three months now occur every 10 years and last for two months (Ball 2001 and references therein). This reduction in flood frequency has had a considerable impact on native floodplain plant and animal species in the Murray-Darling Basin floodplains. In the Chowilla floodplain, populations of 18...
species of snails in the Lower Murray River have declined in the last 50 years. Snails are important foods for native fish species and waterbirds and therefore their decline in population may also affect these species. Reduced flows have allowed dense littoral plants, reeds (*Phragmites australis*) and cumbungi (*Typha spp.*) to become established in weir pools, displacing other naturally occurring species (Ball 2001 and references therein).

The Macquarie Marshes are located on the Lower Macquarie River, also in the Murray-Darling Basin, and represent an area of approximately 130 000-200 000 ha, part of which (18 000 ha) is listed under the Ramsar Convention. The marshes contain a number of wetland types and their important ecological features include waterbird habitat, inland reed swamps and floodplain woodlands. Since the 1960s there has been a loss of over 50% of the original marsh area, the primary cause being a 30% reduction in annual river flows since the construction of Burrendong Dam in the late 1960s. These losses correspond to a decrease over the same period of 40-50% in the area inundated by large floods and have resulted in a decline in the waterbird population. Grazing and irrigated agriculture are common activities in the wetland catchment, and some reclamation of the marshes for farming has also taken place. Prolonged inundation and alienation of floodplain areas from the river by levees and erosion of river channels have also had significant impacts. The reduction in wetland area in the marshes has had additional downstream impacts including increasing salinity and erosion. The management of the Macquarie Marshes is focused on achieving a sustainable balance between water supply for irrigation, erosion control and environmental values (Ball 2001).

Also other artificial in-stream barriers have proved to have a significant impact on native fish populations. Common built structures in Australia, apart from dams, include weirs, regulators, farm dams, floodgates, causeways, culverts, pipes, channelised streams, bridge footings, and erosion control works (Ball 2001 and references therein). Major barriers isolate fish communities, restrict passage and result in changes in fish community structures, as many native fish need to migrate up and down river systems to breed, disperse and travel to spawning grounds. Of the 55 species of native freshwater fish in New South Wales, 32 are known to be migratory and require free passage to sustain populations (Ball 2001 and references therein). In Victoria, 2438 existing barriers to fish movement and migration have been identified, while there are over 1700 barriers to fish movements in New South Wales rivers systems of the Murray-Darling Basin, with three rivers having over 300 separate barriers to fish movement. Also floodplain isolation, due to flood mitigation through the construction of e.g. levees along the riverbanks is common in most large Australian rivers.

The greatest impacts of dams and other built structures on floodplain wetlands in Australia are predicted to continue within the Murray-Darling Basin, while in the tropical areas of Australia, the impacts of built structures on floodplain environments are less well known (Kingsford 2000). Recently, a review by Douglas et al. (2005) examined ecological functions of wetlands and rivers of tropical Australia, which have received international and national recognition for their high ecological and cultural values. Unlike many tropical systems elsewhere in the world and their temperate Australian counterparts, they have largely unmodified flow regimes and are comparatively free from the impacts associated with intensive land use, while plans exist for high investments in new dams, weirs, channels and potential areas for irrigation on many river systems in the northeast coast basin (Kingsford 2000). Also, the growing demand for agricultural development and existing pressures, such as invasive plants and feral animals, threaten
their ecological integrity. According to Douglas et al. (2005), there are five general principles about food webs and related ecosystem processes that both characterise the tropical rivers of northern Australia and have important implications for their management. These are: (1) the seasonal hydrology is a strong driver of ecosystem processes and food-web structure; (2) hydrological connectivity is largely intact and underpins important terrestrial–aquatic food-web subsidies; (3) river and wetland food webs are strongly dependent on algal production; (4) a few common large species have a strong influence on benthic food webs; and (5) omnivory is widespread and food chains are short.

5.4. Asia
Intensive seasonal flooding occurs in many parts of Asia, and despite natural flooding events being recognised as an important mechanism essential to maintain natural resources, the devastating effects of extreme floods also cause concern. Frequent flood and drought events continue to dominate the mindset of water resource managers, and engineering solutions are easily used as the tool for flood control (Gopal 2002). Non-structural approaches, such as flood forecasting and protection and restoration of floodplains, in comparison to structural approaches in general, are a good alternative to flood control through the use of large constructions (Gopal 2002) such as dams and extensive embankments, unless the construction can be justified due to other purposes (irrigation, water storage, hydropower). However, numerous large dams as well as other flood control structures have been built, their impacts being a subject of intensive debate.

5.4.1. Bangladesh
Bangladesh is one of the lowest lying countries in the world, and has historically been hard hit by flooding, while at the same time being much dependent on normal seasonal flood levels to sustain the fisheries and other natural resources that a large part of the population depends on. Bangladesh has one of the richest and largest floodplain systems in the world, floodplains constituting about 80% of the country (BCAS 2004, referring to several sources). Because of the large damage to the human population caused by floods, many flood control programs have been built to mitigate the adverse impacts of the flooding. These constructions have affected the floodplain environment and fisheries, most strikingly through the drastic reduction in floodplain area of over 2 million hectares in the past 30 years (Parveen and Faisal, 2003), which has severely impacted floodplain dependent fish species (constituting 60% of the 251 fish species found in Bangladesh).
Numerous studies carried out in Bangladesh point to decreasing inland fish catches due to water resources development projects, as well as decreasing fish diversity (BCAS 2004). The Flood Action Plan was a collaborative international study comprising 26 components since 1990, developing long-term flood control policies and an action programme for Bangladesh (Figure 8). The results of these, as well as various other studies carried out on inland fish production in relation to the flood control, drainage, irrigation and compartmentalisation projects, indicate that fish catches and fish diversity are declining in inland water bodies of Bangladesh, while production has increased in culture fisheries (BCAS 2004). In general, whenever flood control projects reduce the area of flooded land, there will be a loss of habitat for fish production and a subsequent loss in annual fish yields or catch per unit area. Flood control programmes have been found to affect reproduction and larval fish drift (de Graaf et al. 1999, de Graaf 2003c), block fish migration and dispersal routes (Mirza and Ericksen 1996), reduce species diversity by up to 30%, most of which belong to the more valuable white fishes (BCAS 2004). Sluice gates have proven to be fatal for many fish species, e.g. carps (white fish) of which only small numbers can get through sluice gates (BCAS 2004) and fish larvae and hatchlings, of which 25% died when passing the sluice gates (Marttin and de Graaf 2002). The authors found that there was a difference between the mode of operation of the regulating sluice gate: when operating in an undershot mode (water passing
underneath the gate door) up to 44% of released hatchlings died, while only 11% died when passing the regulator when operated in overshot mode (water flowing on top of the gate door).

Mirza and Ericksen (1996) report the impacts of one of the embankment projects, the Chandpur project. The project is one of the major water resource development projects of Bangladesh, and covers an empoldered area of 56,655 ha, designed to provide flood protection, drainage and irrigation to the empoldered area. It was found that the open-water fishery in the project area has undergone great losses (83%) while the closed-water culture fish farming has benefited from the project, creating suitable stable conditions for fish culturing. However, the benefits for fish culturing opportunities have not compensated for the loss in natural open-water fisheries, and the total fish production has decreased by nearly 30% as a consequence of the Chandpur project. These developments have indirectly led to another impact: the fish consumption per capita in the area has dropped markedly (to half of the national average in 15 years) as a result of lower fish production and catches, higher population numbers and higher cost of buying farmed fish (the production of which has increased, and which is being exported out of the local area to a large extent), affecting especially the poorest people. Mirza and Ericksen (1996) note that water control projects have substantially reduced fisheries from floodplains, recommend that environmental considerations be taken into account and suggest that all new projects should collect baseline data on all fishery related issues for the benefit of future impact assessments. Annual losses of between 300 and 3000 metric tonnes of net fish production was estimated in connection with another FCDI project in the Southeast region of Bangladesh, the Meghna-Dhanagoda FCDI. The losses were mainly due to drainage and loss of floodplains and beels in the area, as well as the closure of internal canals inside the project (BCAS 2004).

In the Pabna Irrigation and Rural Development Project (PIRDP) site in northwestern Bangladesh, studies were carried out by Halls et al. (1998) concerning fish migration and movement through sluice gates in a flood control, drainage and irrigation (FCDI) scheme. It was found that *Catla catla, Channa striata* and *Wallago attu* migrated through the sluice gates, both with and against prevailing currents in different seasons, while the smaller *Anabas testudineus, Glossogobius giuris* and *Puntius sophore* did not. Species assemblages were significantly different inside and outside the FCDI schemes, with up to 25 species absent or less abundant inside compared to outside. The majority of these species were large predators or conspicuous members of the highly prized migratory 'whitefish' category, including the silurid catfish, Indian major carps, mullets and clupeids. In their absence, species inside FCDI schemes were dominated by much smaller resident 'blackfish' species. Assemblages inside FCDI schemes thus had both a reduced species richness, and a unit value reduced by up to 25%. It was concluded that FCDI schemes such as the PIRDP negatively affect fish species assemblages and stock values by reducing the accessibility of impounded floodplains to migratory fish. Though some fish are capable of penetrating existing sluice gates, management measures are required to encourage the passage of more species (Halls et al. 1998).

FAP 20 was a study developing a compartmentalisation approach to flood hazard mitigation. The concept includes an embanked area that would provide a comprehensive water control system to allow controlled flooding without causing damage to crops, fisheries, infrastructure or urban land. Built structures include main river embankments, existing road and railway embankments, inlet and outlet control structures and improved waterways for controlled flooding, drainage and navigation. De Graaf (2003b)
summarises the results of the Compartamentalisation Pilot Project (CPP), maintaining that no difference in fish catch before and after the CPP was noted, attributable to the project not significantly altering the average flooded area. De Graaf (2003c) concludes that this type of controlled flooding is a better option than complete flood control, from a fisheries perspective.

As a summary, evidence suggests that fish production from inland capture fisheries has been in decline in Bangladesh for some time. A major reason for this decline is the flood control projects, while pesticides and industrial pollution are also mentioned (BCAS 2004) as important factors impacting the fisheries. FCDI projects have been implemented partly to increase rice production, but it has turned out that they have been of little value for rice production, whereas their effects on fisheries have been devastating (reducing indigenous floodplain fisheries by over 70%), due to built structures such as embankments, sluice gates, and culverts preventing floodwater from entering the floodplains (BCAS 2004). The results of FAP-17, designed solely to address inland fisheries issues and the impact of different types of FCDI projects on fish resources, as well as mitigation measures to prevent harmful effects, listed the following impacts of flood control on fisheries in Bangladesh (Ali and Fisher 1997):

- Loss of fish catch through loss of habitat
- Reduction in catch per unit area
- Reduced fish density/abundance
- Increased fishing effort
- Reduced biodiversity
- Reduction in the numbers of migratory fish and the number of fish migrations
- Disruption of fish community structure
- Increased capture at regulators
- Reduced opportunity for mitigation measures and
- Reduced potential for stock enhancement.

The local people were found to be highly dependent on fisheries related activities, especially the small and landless farmers in agricultural communities. The flood season was especially important for the fisheries, and it was found that reduction in flooding and floodplain area led to significant losses in income, a cheap source of animal protein and employment opportunities.

5.4.2. India

The main rivers in India, Ganges, Brahmaputra and Indus, are extensively regulated for water diversion, flood control and hydropower by a series of dams, barrages and embankments. The Indo-Gangetic floodplain is the largest wetland regime in India, but up to 70-80% of individual fresh water marshes and lakes in the Gangetic floodplains have been lost to developments after the 1950s (Ramachandra 2001). According to Mathur et al. (web based reference) there are over 4000 big dams in India, submerging over 37 500 km² and having displaced at least 42 million people in India. High population density leading to high domestic and industrial pollution, and the numerous activities in the catchments, floodplains and within the river channels have seriously decreased the quality of water. Rehabilitation of the floodplains of India to remedy the grave pollution of the rivers has been suggested by Gopal (2003).
Development of the water resources of the Brahmaputra Basin has caused concern. Fazal (web based reference) points out that the raising of embankments in India without adequate measures for the restoration of ecological balance in the catchment areas has led to increased siltation of rivers and reservoirs. In several cases riverbeds are now higher than the ground level in their vicinity. Indiscriminate use of land along the river banks has also resulted in the formation of ravines and gullies. Ravine formations are estimated to have damaged about 3.67 million hectares in Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujrat, Maharashtra, Punjab, Tamil Nadu and West Bengal. Nearly 2.3 million hectares have been rendered almost useless on the banks of the Chmnbal, the Yamna, the Mahi and some other rivers. Boruah et al. (2000) draw attention to the importance of beel (deeper parts of the floodplains where water is trapped when the flood recedes) fisheries and the ecological degradation of the beels in the Brahmaputra River Basin in Assam. Problems have been encountered due to eutrophication caused by the construction of embankments along almost the entire length of the Brahmaputra River and many of its tributaries in the 1950s. The establishment of embankments considerably reduced the flooding and the flushing of the beels, and the impact has since been aggravated by human activities such as buffalo and cattle grazing, agriculture and over fishing. Boruah and Biswas (2002) summarise the impacts of the Brahmaputra embankment and dike constructions, escalating the problems caused by deforestation and subsequent erosion of the riverbanks. The embankments trap the sediment load, which is now deposited on the riverbed, making the level rise on a daily basis while the land has remained the same, except for losing the natural manure normally received during floods. Furthermore, the embankments are responsible for the shrinkage of the spawning and feeding grounds of many riverine fishes, leading to a decline in e.g. major carp species.

Kaziranga National Park in the Brahmaputra River floodplains in Assam is a small national park with important biodiversity related to the floodplain environment. Management plans for the national park draw attention to the impacts of planned developments for the area, including suggested construction of highways and expressways, harnessing of water resources for hydroelectric potential through a series of dams on Brahmaputra River (with no large dams so far, but extensive embankments constructed for flood control, Mathur et al. web based reference), and developments in the fields of agriculture, and oil and gas production. Main threats identified include changes in the river flow and barrier effects created by the construction of roads through or along ecological corridors connecting other areas with the floodplains (Mathur et al. web based reference).

5.4.3. Mekong region

The impacts of dams have been debated for a long time in the Mekong region. The Mekong has been subject to intensive dam building, the effects of which in many cases have been little studied. Despite the impacts of dams being better known now, tens of new dams are either currently under construction or planned on the Mekong and its tributaries (MacLean et al. 2004). According to MacLean et al. (2004) nearly one-third of the river’s total sediment load originates in the Chinese sections of the Lancang/Mekong (Figure 9). Numerous dams in the Upper Mekong are reported to have severe impacts on downstream environments, including floodplains. These include (according to IRN 2002)
• Agriculture: Greater regulation of the flood cycle means that there will be less frequent floods, which will decrease sediment and nutrient deposition and hence reduce soil fertility. Without a massive program of artificial fertilizer use, long-term agricultural yields will decline.

• Fish and fisheries: Spawning sites may be drastically reduced in the dry season and in the rainy season lower water levels in the flooded forests of southern Laos and Cambodia will affect important fish feeding, spawning and nursery grounds. This may result in a major decline in fisheries in the Mekong Basin, including possible extinction of some species.

• Erosion: Water released from the lowest dam in the scheme will have less sediment than before and will therefore scour and erode the bed of the river downstream. This erosion could alter the Mekong’s course and width, weaken supports for buildings, piers and bridges, and cause financial loss to downstream areas.

Amornsakchai et al. (2000) prepared a case study on the impacts of the Pak Mun Dam. The dam is built on the Mun River, 5.5 km upstream from its confluence with the Mekong, in Northeast Thailand. The dam has a maximum height of 17 m and total length of 300 m. The reservoir has a surface area of 60 square km at normal high water level of 108 meters above the mean sea level and a capacity of 225 million cubic meters. None of the EIA studies performed predicted that fisheries issues would become problematic during construction or implementation. After the completion of Pak Mun Dam, however, the Lower Mun River experienced a decline in fishing yields with an estimated value of US$1.4 million per annum at 20 Baht/kg. In the post-dam period fishing communities located upstream and downstream of the dam reported a 50-100% decline in fish catch and the disappearance of many fish species. The dam has especially affected several migrating and rapid-dependent fish species. A fish pass was built but this has apparently not been functioning as anticipated. Assessment of project impacts, like the assessment practices in past dam projects, remained focused on inundated areas and resettlement issues. The Pak Mun project happened to be the first run-of-river type dam, with no reservoir and thus impacts due to flood and resettlement were not assumed to be as serious as those of other big dam projects in the region. Thus, fisheries impacts were overlooked.
In order to demonstrate the impacts of blocking the flow of the Mun River caused by the Pak Mun Dam, the local villagers requested the government to open the sluice gates for a year in order to assess the impacts on fisheries and their livelihoods from the dam. The Thai government agreed to open the dam gates on June 14, 2001 for four months to conduct studies on fisheries, social impacts and the impact of the dam on electricity supply. A participatory research project was carried out as a collaboration between Pak Mun villagers and researchers from South East Asia Rivers Network (“Thai Baan research”). Selected results from the report are presented below.

When the Dam was built, villagers found that only 45 out of 265 fish species indigenous to the Mun and Mekong rivers remain in the Mun river in Pak Mun area. The reservoir submerged perennial plants that typically grew in the rapids, riverbanks and islands (Don) and allowed the invasive alien weed, giant mimosa, to thrive and dominate the riverbanks. The still water also created an environment where new types of aquatic weeds and microorganisms proliferated, such as hyacinth, “itchy snails” and the fish parasite Mae Pla.

Villagers found that opening the dam gates for one year had dramatic impacts, bringing much of the fishery and associated ecosystem back to life. When the dam gates were opened, a large number of fish once again migrated from the Mekong to the Mun River,
laying eggs from the mouth of the river upstream to the river’s tributaries. Village researchers found that 129 species of fish returned to the Mun River during the period between June 2001 to May 2002.

The opening of the Pak Mun Dam gates restored the diversity of fish species in the Mun River. Among the native species of fish, village researchers documented that 104 species migrate from the Mekong River to the Mun River, and 25 species live and migrate within short distances within the Mun River. The migratory fish from Mekong to the Mun River include some endangered species, such as the Mekong giant catfish, or Pla Buek, Pla Dtong Grai Pla Kae Hin and Pla Eian Hu or Too Na Hoo Khao.

The opening of the dam gates has restored the fertile ecosystem near to its state before the dam was built. When sluice gates were open, the still body of water began running again, cleaning the river and sweeping away water hyacinth plants within the first month. Gradually, rapids began to reappear in the river, however, they were covered with sediment, or Aon. After three months, the river washed away the Aon from the rapids. After five months, the populations of the Mae Pla fish parasite decreased and then disappeared. Eventually, the Mun River's fisheries, ecosystem, and vegetation returned to near to the normal state before the dam was built.

SEARIN 2004

Riverbank vegetable gardens are a form of highly productive and important seasonal farming practised by tens of thousands of families from Yunnan down to the Mekong Delta region in Vietnam. It is an agro-ecosystem which has traditionally relied on the rich sediments carried down by the Mekong and its major tributaries, and deposited each year on the floodplain and banks to maintain soil fertility (Blake 2004). The growing of the numerous crops in riverbank vegetable gardens requires almost no fertilizers (Roberts 2001). In the northeast of Thailand large-scale dams, water extraction schemes and deforestation have radically altered the hydrology and geomorphology of the rivers draining the Khorat Plateau, resulting in mass abandonment of this sustainable farming system on a massive scale. According to Blake (2004), riverbank vegetable gardens are still relatively common in Laos and Cambodia, both along the mainstream Mekong and its many tributaries, providing vital nutrition and livelihood income to villagers and communities. Here too it is threatened by massive irrigation, flood management and hydroelectric schemes, like along the Sesan river in Northeast Cambodia and the Xe Bang Fai River, which would be impacted by the planned trans-basin diversion Nam Theun 2 Dam in central Laos (Blake 2004).

The planned Nam Theun 2 Hydropower Project is the largest infrastructure developments project in Lao Peoples Democratic Republic, including a 48 m high dam creating a reservoir covering an area of 450 km² in the wet season (Norplan and EcoLao 2004). A cumulative impact assessment was carried out regarding added and induced impacts. Regarding environmental impacts, the CIA pointed to possible indirect impacts regarding increased pressure on wildlife, migration of fish by the establishment of the reservoir, better protection, but also threats to biodiversity from extractive activities, hunting and general population increases, leading also to increased untreated wastewater possibly causing oxygen depletion, increased logging activities causing increased threats to biodiversity, agricultural activities causing eutrophication and higher levels of pesticides in the water (and consequently fewer fish), lowered biodiversity and fish production due to changes in flow regime, while an increase in back swamps may also increase floodplain area, reduced discharge in the flood season, negative impacts
on fisheries in the Great Lake of the Tonle Sap, and positive impacts through dampening damaging flood incidents and reduced salt intrusion in the Mekong Delta.

Schouten (1998) has studied the downstream impacts of Nam Ngum 1 Dam in Laos. The dam has had positive impacts through increased fisheries in the reservoir; however, water quality downstream of the dam has deteriorated due to low levels of oxygen in the deeper layers of the stratified dam. The dam also blocks fish from upstream spawning areas and has hence impacted especially migratory fish.

A report by the Stockholm Environment Institute (SEI 2002) analyses five case studies in the Greater Mekong Sub-region dealing with various infrastructure projects (roads and dams). Out of five projects involving large-scale built structures, one had a cumulative assessment carried out (Theun-Hinboun hydropower project in Laos), while none had an economic evaluation of environmental impacts done. One of the analysed projects had no EIA process carried out whatsoever (Kinda Dam in Myanmar). The integration of social and environmental issues on a regional scale was found to be weakly carried out. The Theun-Hinboun hydropower project has been considered an environmentally friendly project due to its run-of-the-river design, absence of reservoir and hence absence of resettlement issues involved. However, the EIA process (which started too late to be able to change the design of the project) pointed to impacts on fish migration, but little consideration was given to downstream losses and potential mitigation measures to avoid these. Loss of fish biodiversity due to hydropower dams was found to be the single most important ecological issue in connection with the Theun-Hinboun hydropower project (SEI 2002), and loss in fish catch the single most important socio-economic issue. The cumulative assessment, which considered further ongoing and planned hydropower projects, indicated that these impacts would be exacerbated through further decreased flows downstream of the developments.

The SEI (2002) study also pointed to the Ho Chi Minh City – Phnom Penh highway, which in Cambodia separates the Mekong River from the Bassac Marshes, as a habitat for a diverse and abundant population of water birds. The road currently disrupts the flow of flood waters from the Mekong River to the Bassac Marshes due to the poor design of drainage structures. By improving the drainage structures, such as culverts, along this section of the road, the project will contribute to restoration of ecosystem functioning and productivity in adjacent areas (SEI 2002).

6. REVIEW OF GUIDELINES AND RECOMMENDATIONS FOR MANAGEMENT OF FLOODPLAINS

While this review did not specifically concentrate on EIA procedures in connection with the case studies, it was noted that guidelines for EIAs do not generally include instructions for how to consider specific floodplain variables and the interconnections between different environmental sectors. Therefore, few recommendations are available for how to assess the environmental impacts of a project on these integrated features of floodplain ecosystems, or how to include economic valuation of lost ecosystem services. The nature of various floodplain systems differs from river to river, and therefore the results of detailed studies done on one floodplain cannot be directly applied in another. This underscores the need for baseline information collection, even if this would be done
immediately prior to project design while the site is still undisturbed. It is, however, important to make sure that the time available for data collection spans at least two years and analysis of data is given proper attention (SEI 2002). Similarly, the importance of designing and implementing environmental and social management plans and the regular monitoring of impacts and results of mitigation measures are emphasised.

Despite a general lack of guidelines with regard to floodplain environments, specific guidelines with regard to dam construction, design, and management of fisheries impacted by dams have been prepared. McCartney et al. (2000) and Ledec and Quintero (2003) propose a set of key indicators of likely environmental impacts of dams (see Table 1) in different situations. This should be noted as a guideline in connection with EIAs and could be developed to apply also when considering other built structures than dams.

Table 1. Indicators of likely environmental impacts in connection with the construction of dams and other impoundments (according to McCartney and references therein, 2000)

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<th>Indicator</th>
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<tr>
<td>Reservoir surface area</td>
<td>The area flooded by the reservoir is a strong proxy for many environmental and social impacts. A large reservoir area implies the loss of much natural habitat and wildlife, or the displacement of many people or both. Very large reservoirs are typically in the lowlands and often impound large rivers. Large rivers tend to be characterised by a greater range of habitats and food sources associated with greater fish diversity and a wide range of trophic adaptations.</td>
</tr>
<tr>
<td>Water retention time in reservoir</td>
<td>Mean water retention time (calculated as a function of reservoir volume and mean river flow) during normal operation is very useful in estimating the extent to which a reservoir will have long-term water quality problems.</td>
</tr>
<tr>
<td>Biomass flooded</td>
<td>The greater the amount of biomass flooded the greater the implications for reservoir water quality. Flooding native forests also harms biodiversity conservation and releases greenhouse gases (carbon-dioxide and methane) into the atmosphere.</td>
</tr>
<tr>
<td>Length of river impounded</td>
<td>To conserve aquatic and riparian biodiversity (including riverine forests), dam sites should minimise the length (kilometres) of river (main stem plus tributaries) impounded by the reservoir (measured during high flow periods).</td>
</tr>
<tr>
<td>Number of downstream tributaries</td>
<td>The greater the number of tributaries of the dam site, the better, in terms of maintaining a) accessible habitat for migratory fish, b) the natural flooding regime for river ecosystems and c) nutrients of sediment inputs needed for the high biological productivity of estuaries.</td>
</tr>
<tr>
<td>Access roads through forests</td>
<td>Where the risks of induced deforestation are high, project siting should minimise the kilometres of required new or upgraded access roads passing through or near natural forests.</td>
</tr>
</tbody>
</table>

Bernacsek (2000) specified a series of management procedures to facilitate sound management of fish biodiversity, fish stocks and fisheries in connection with all stages of dam construction (Table 2). The adoption of these procedures in the identification, design, appraisal, construction and operation phases of dams would facilitate a systematic approach to mitigation measures for fisheries management.
Table 2. Capacity and information base requirements for effective management of fish biodiversity, fish stocks and fisheries threatened or affected by dams during different phases of the project cycle, modified from Bernacsek (2000.)

<table>
<thead>
<tr>
<th>Phase of project cycle</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam identification</td>
<td>Community-based or user group fisheries management systems should be put into place in the impacted area for commercial and recreational fisheries. An Initial Environmental Examination should be carried out. A data base should be assembled, providing detail on the aquatic environment, fish biodiversity, fish migration, existing fisheries upstream and downstream, likely impacts of the dams and possible mitigation measures.</td>
</tr>
<tr>
<td>Dam design</td>
<td>Community-based fisheries management should be continued. An Environmental Impact Assessment should be carried out. The information base should be made more comprehensive. An assessment of the level of impacts on, and the risks for, fish and fisheries, and a statement with regard to the degree of suitability and acceptability or need for rejection, of the project from a fisheries point of view should be prepared. A set of mitigation measures and an environmental management plan should be prepared.</td>
</tr>
<tr>
<td>Dam project appraisal</td>
<td>CBM should be continued. The worth of the project should be examined. A set of questions and criteria concerning the fisheries impacts and mitigations should be satisfied before approval for dam construction is given.</td>
</tr>
<tr>
<td>Dam construction</td>
<td>Fisheries management activities need to be carried out which aim at preventing damage to fish biodiversity and fish stocks arising from construction activities, such as soil erosion and silt runoff, siltation of key fish habitats downstream, blast damage from explosives and blockage of fish migration. Real time data required. Management activities need to be rapidly responsive to the construction schedule. Special attention needs to be given to reservoir preparation with regard to clearing forests in a manner which will reduce problems of snagged nets and ghost fishing yet still allow sufficient surface area for periphyton growth for fish forage. Information needs focus on suspended solids, sediment transport, fish mortality, fish migration and fish biodiversity.</td>
</tr>
<tr>
<td>Dam operation</td>
<td>Needs for fisheries management in four impact areas must be addressed: 1) the reservoir and its affluent streams, 2) the fauna passage facilities, 3) the downstream river channel and floodplain and 4) the delta, estuary and adjacent sea. The downstream river fisheries management concerns focus on aeration of anoxic discharge water from the dam, provision of effective fish passes to allow broodstock and juveniles to migrate across the dam, reduction of turbulence in the stilling pool, and mitigation of fish losses on the floodplain. The release of artificial mini-floods and the provision of adequate dry season flow is crucial to maintaining a suitable environment for migratory fish species, especially endangered species.</td>
</tr>
<tr>
<td>Dam decommissioning</td>
<td>Fisheries management should focus on rapid recovery of fish stocks that have suffered impacts during dam operation. Measures should be implemented to prevent damage to fish stocks during dam demolition as well as enhancement measures, e.g. river rehabilitation, for the aquatic and related terrestrial environments. Fish biodiversity and migrations, as well as sediment loads, should be carefully monitored. CBM should be continued.</td>
</tr>
</tbody>
</table>

Some recommendations have been presented in the literature, based on lessons learnt in various tropical floodplains/wetlands. Lessons learnt in Senegal have shown that the combined use of modelling and thorough participatory methods involving local communities and stakeholders to explore various mitigation scenarios and options in a
specific floodplain environment has led to successful results. In connection with the Waza Logone restoration project, the ecosystem approach was used extensively and throughout the project. The project provided an example of the sound practice of integrating ecosystem conservation and sustainable development, and the results from the project have been adopted by many international organisations including the World Bank and IUCN, as well as Multilateral Environmental Agreements such as the CBD.

Based on experiences from dams in Laos, Schouten (1998) recommends that feasibility and design studies for hydropower projects consider variable-level reservoir intakes that allow water to be taken continuously from the reservoir (better quality) surface water layer. Variable-level intakes avoid release of water from the (anoxic) hypolimnion and associated negative downstream effects. He also points to the importance of paying attention to downstream effects and the cumulative impacts of dams in the Mekong region. Schouten (1998) recommends hydrological and water quality monitoring and modelling, as well as fish surveys and fisheries monitoring, as a necessary baseline for hydropower development that should also lead to the formulation of mitigation measures and appropriate watershed management planning.

Lessons learnt in Australia (Douglas et al. 2005) have given rise to recommendations regarding management of tropical wetlands. According to these principles, one should avoid developments that would:

- Disrupt the flood pulse
- Reduce hydrological connectivity
- Impact factors influencing the production or composition of algae, such as turbidity and increased runoff of nutrients, herbicides, pesticides or metals into the water
- Disrupt the species composition and especially the occurrence of key species of the food webs.

As management options for Indian rivers and floodplains, Boruah and Biswas (2002) recommend the use of an integrated ecohydrological approach through e.g. modelling the impacts of anthropogenic activities on fish stocks (commercial and endangered species especially), emphasising mitigation measures such as control of riverbank erosion through phytoremediation, identifying the main factors impacting fish migration, and interaction between stakeholders.

The growing awareness of the cumulative negative impact on inland capture fisheries of the progression of flood control embankment and polder type projects throughout Bangladesh has led to management plans being developed (Hoggarth et al. 1999, Nishat 1997), suggesting e.g. the further study of the potential of closed water fisheries (resident black fish especially), as well as adapting hydraulic structures used in FCDI projects to fish-friendly models (overspill of sluice gates, fish passes, etc.) to enhance natural migration (Nishat 1997). Ali and Fisher (1997) recommend stock enhancement schemes, increased future research activities, as well as the following mitigation measures:

- Production of deep water aman (rice fields)
- Habitat rehabilitation and protection
- Increased fish migration across flood control structures
Based on lessons learnt in Bangladesh (Ali and Fisher 1997, Hoggarth et al. 1999) especially in connection with flood protection schemes on floodplains, the following recommendations have been extracted:

- Ensure fish migration routes through structures
- Protect fisheries and habitats through protected areas/times
- Minimize loss and degradation of flooded areas
- Strengthen management institutions, and develop monitoring, forecasting and information dissemination.

Hoggarth et al. (1999) recommend the following management implications for floodplain river environments:

- Managers of fisheries and other resources must discuss their impacts on each other
- The impacts of floodplain modifications must be investigated and managed at both catchments and local levels
- Variability in habitats between localities necessitates local involvement in management
- Uncertainty in hydrological regimes necessitates local involvement in management
- Quantity and quality of flood water must be maintained for high fish productivity
- Diversity of floodplain habitats must be maintained for high fish biodiversity
- River channels must be maintained for fish migrations and access to spawning grounds.

Increasingly, CIAs and SEAs are called for with regard to developments involving large structures. There are few environments where a built structure will be an isolated structure impacting the environment, and the final consequences for the environment rarely add up to the simple additional value of each structure. To study the synergistic effect of many built structures, the cumulative impact, is naturally a complicated task. According to the Council on Environmental Quality regulations, cumulative effects are defined as “the impact on the environment which results from the incremental impact of
the action when added to other past, present and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions (40 CFR § 1508.7)" (NEPA 1997). A selection of studies including or referring to the cumulative impacts of dams has been listed on the WCD web pages ([http://www.dams.org/kbase/submissions/showsub.php?rec=ENV130](http://www.dams.org/kbase/submissions/showsub.php?rec=ENV130)) some of which report promising approaches to the assessment of cumulative impacts in connection with e.g. impacts of dam tailings on dissolved oxygen levels downstream of dams. Modelling has been utilised in some of these studies and has shown encouraging results for assessing impacts as well as mapping potential mitigation measures.

SEI (2002) recommends that the need for Strategic Environmental Assessments be considered and developed for certain sectors, as stated in the Paris Declaration on Aid Effectiveness (OECD-DAC 2005) and recommended in the Strategic Environmental Framework for the Greater Mekong Sub-region, and a set of guidelines developed based on the results of these.

7. CONCLUSIONS AND LESSONS LEARNT

Information on floodplain ecology and functions in general is abundant, detailed studies on ecosystem functions having been conducted in the Amazon floodplains as well as the West African floodplains. However, studies concerning impacts of built structures are not as abundant, with the exception of large dams. A general conclusion is that there has been a marked increase in the awareness of the value of floodplains in past decades, as well as the impacts of constructions in these environments, but there is clearly a gap between this general awareness and the amount of research done on the type, magnitude and consequences of the impacts.

Tropical floodplains are diverse, complex and productive environments where hydrology and the flood pulse determine the seasonal succession. They support high numbers of endemic species. The high fisheries potential in these productive ecosystems is recognised in all tropical floodplains. Recently, other ecosystem services supplied by floodplains have been increasingly appreciated, with the decreasing state of remaining floodplains ones. Floodplains are now ranked amongst the highest valued landscapes in the world.

Increasing human impacts on floodplain areas, including various built structures, has led to flow modification, floodplain habitat alteration or destruction and water pollution, factors also defined as the three main causes for loss of freshwater biodiversity. A built structure rarely occurs in isolation, but rather attracts and induces developments beyond the control of the project developer, potentially causing additional impacts on the environment.

Most studies reviewed, regardless of location, emphasised the importance of the floodpulse and the protection of both lateral and longitudinal connectivity of floodplains. Isolation of the floodplain through e.g. embankments leads to a complete loss of floodplain ecosystem services.
In connection with pre- and post-valuation of tropical floodplain ecosystems, it has been shown that when a floodplain has been “reclaimed” for other uses, such as agriculture, the economic benefits gained rarely reach the same level as the ecosystem services provided by the floodplain when it was intact. Compensating for lost floodplain ecosystem services, such as recession and dry-season agriculture and natural pasture for livestock, is hard, if not impossible, to do through alternative land-uses.

Large dams have caused much discussion concerning their impacts on the environment, both upstream and downstream of the dam. However, any structure causing large-scale hydrological alteration will have many of the same impacts as dams, such as habitat fragmentation, change, deterioration and loss, as well as genetic isolation, changes in biogeochemical processes, impacts on biodiversity and pollution. The water quality changes caused by dams can strongly affect downstream floodplain environments, especially if acting in concert with other structures causing similar, or synergistic, effects. The construction of large dams or other large infrastructure usually attracts further developments, leading to higher pollution loads. The combination of the effect of the dam and the reservoir on the water quality being released downstream, and increased runoff from industry, agriculture and settlements possibly aggravated by erosion caused by these developments, can lead to severe cumulative impacts. These effects will be further exacerbated if the volume of released water is reduced.

Smaller, but numerous, built structures such as the various types of embankments, channels and dikes that are an integral part of most floodplain related livelihoods in tropical floodplains have similar, although more localised effects. The large number of this type of localised flood control construction, as well as canals, small dams and weirs built for irrigation purposes, most probably lead to significant cumulative impacts, which have not been studied to any large extent. Canalization (for e.g. improved navigation) of floodplain rivers is of concern due to the probability of cutting off the lateral connectivity to the adjacent floodplains, causing isolation and subsequent deterioration thereof. Pollution of the water caused by mines, industrial or urban structures can have long-term effects, as illustrated by the mercury pollution of Amazonian floodplains caused by mining activities.

In the Amazon floodplains built structures are still scarce, with the exception of large dams, road and gas pipe constructions. The major impacts of human activities on the várzea floodplain forests are classified, with decreasing destructive effects, as: 1. modification of the hydrological regime (e.g. by hydropower dams and navigation channels), 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species and 4. pollution. Decreases in fish catch and species richness, as well as significant changes in the species composition due to the disturbance of floodplains were often reported. Most of the documented cases concern very large size projects. The documentation is coloured by the strong opinions of different stakeholders and often refer to mere “enormous impacts” without specifying the type or magnitude of these said impacts. Much attention has been focussed on social impacts since these have, historically as well as presently, been significant and difficult in the case of Latin America.

In Africa less baseline information is available and much of the continent’s water resources have been little studied until the last few decades of the previous century. In most parts of Africa, water availability is sufficient only in the moist equatorial belt. Therefore, water needs for irrigation, domestic and industrial uses have caused the
construction of numerous reservoirs affecting the downstream flow and floodplains. Changed hydrological regimes of rivers has adversely affected floodplain agriculture, fisheries, pasture, forests and plant resources that constituted the organising element of community livelihoods and culture. Deterioration of floodplains has in many cases also had a devastating impact on wildlife, which in turn has severely impacted the important tourism industry in Africa. Drought has often exacerbated the negative impacts of built structures affecting floodplains, and much attention has thus been directed toward rehabilitation of the impacted floodplains. Therefore, most of the limited number of projects dealing with the rehabilitation of floodplains to restore former floodplain ecosystem services stem from the African continent.

Positive results in efforts to rehabilitate floodplains through managed flood releases have also been achieved in Africa (e.g. Senegal, Waza Logone and Zambezi floodplains). These rehabilitation efforts have shown that through (artificially) reintroducing floods to a former floodplain environment, it is possible to partly recover ecosystem services lost, while the complete variety of floodplain ecosystem services may be hard to restore.

In Australia five principles concerning the ecosystem processes of tropical wetlands have been recommended to improve the management of floodplains and large river systems. These include avoiding developments that would 1. disrupt the flood pulse, 2. reduce hydrological connectivity, 3. increase the input of nutrients into the water, or 4. disrupt the species composition and 5. disrupt the occurrence of key species of the food webs. Increased use of hydrological models to include connectivity to floodplains, and generally increased collaboration between scientists and management to improve the integration of river, river basin and floodplain management is also recommended.

In Asia severe floods have created much damage to human populations living in very low lying areas, such as Bangladesh, which has prompted applied research into ways of mitigating the hazards of flooding, while simultaneously preserving the beneficial functions of flooding. In this respect there is a pool of experiences from e.g. the Flood Action Plan studies. Different types of flood control structures have repeatedly been proven to impact fish, both in terms of acting as barriers for normal fish movement and migration, as well as decreasing fish diversity. To remedy this situation, a number of specific management and mitigation measures have been formulated and proposed, as well as structural approaches allowing controlled flooding (see chapter 5.4.1.). In India, extensive embankments and dikes along major river channels have caused problems with sedimentation and elevation of river channels, erosion of the riverbanks, and deterioration of the water quality in the beels, affecting the important beel fisheries.

Guidelines and recommendations for management practices in floodplain environments have been collected from the literature reviewed and presented in chapter 6. Based on these, and on the general knowledge base collected through the literature reviewed, a set of recommendations has been prepared and is presented in Chapter 8.
8. RECOMMENDATIONS FOR ENVIRONMENTAL ASSESSMENT AND MANAGEMENT OF FLOODPLAIN ENVIRONMENTS

Modification of the hydrological regime has been found the first and foremost threat to floodplain ecosystems, based on numerous experiences in tropical floodplains worldwide. Therefore, any structure affecting the all-important hydrology of a floodplain should be assumed to influence the environment, and treated with consequent caution. Most impacts are directly or indirectly combined with aspects of changing hydrological regimes, and cannot be separated from this. Any assessment must take into account impacts on integrative processes such as the flood pulse and alterations to any aspect of it, including the magnitude, timing, amplitude, duration, modality, smoothness and rapidity of change. In general, the loss of flooded areas and hydrological connectivity should be minimized.

Another general recommendation concerns the importance of a systematic, professional and serious EIA processes. This entails, amongst other things, accommodating adequate baseline collection (to be extended over at least two years) and presenting a comprehensive collection of proposed mitigation measures to ensure that these be taken into account in the design phase of the project, rather than later at a significantly greater expense. The incorporation of an Environmental Management System (EMS) is a central part of the EIA process and the resulting EMS must be adhered to throughout the project cycle, including the setting of milestones, response plans to detected changes and an evaluation of the functioning of the EMS. Also, Strategic Environmental Assessments should be developed for relevant sectors.

The following recommendations have been drawn from the case studies considered in this review:

1. Indirect impacts of large-scale construction sites may be enormous in comparison to the actual structure. Land-use change, potentially induced by project activities in the area surrounding the project site, and their impact on the environment should be considered in EIAs.

2. Small-scale canals and natural water channel modifications are possibly the most common type of built structure, and therefore lead to many cumulative impacts. Taking these into account in connection with new built structure assessments is of importance.

3. The main causes of freshwater aquatic biodiversity loss have been identified as flow modification, habitat alteration, water pollution, introduction of exotic species and over-exploitation of certain species. All these issues are, directly or indirectly, linked to built structures, and therefore EIAs relating to built structures should include a component considering biodiversity issues at as many levels of the ecosystem as possible.

4. In connection with river regulation such as dams, as well as other large structures blocking migration routes and causing fragmentation of habitats, fish biodiversity has decreased in most reported cases. In connection with new built structures it is therefore of importance to consider this probable impact at an early stage and prepare mitigation measures during the entire project cycle. Planning of structures should take into account the movement of fish, as well as securing the presence of sanctuaries/protection times. The design of sluice
gates and other modified passages, should take into account that for many fish an overshot mode regulator is less destructive than an undershot one, while e.g. various designs of turbines for hydropower differ with regard to mortality of passing fish.

5. Lessons learnt have shown that the destruction of floodplains affects specialized artisanal-type fisheries, often operating on a small-scale. This type of small-scale fisheries livelihood is very hard to replace and it is therefore of importance to assess and value in the course of the EIA process. The spread of invasive plant and animal species (often occurring as a result of changed hydrology or intended introductions of e.g. fish to reservoirs) can lead to surprising and dramatic losses/changes and also affect local livelihoods that depend on other ecosystem goods than fish.

6. When assessing the impact of built structures on e.g. fish catches, it is of importance to evaluate the distribution of the catches between subsistence fisheries and professional fisheries. In many cases, it has been shown that e.g. flood control structures have benefited groups of people that have the ability to invest in fish farming, while the opportunities for natural open water fisheries have diminished, either through changes in species composition or fish production in the affected area. Unlike land, floodwater usually belongs to all. Therefore, the risks connected to reduced floodwater availability are significant especially for non-land owners, the poorest section of the rural population.

7. The value of other ecosystem goods, such as forest and plant resources, pasture, wildlife etc. are often underestimated until these are lost with degenerating floodplain conditions. Even though fisheries are indisputably the most significant resource of the floodplains, other natural resources are of great importance in view of diversification of food resources and livelihoods, and often play an important part especially for the poorest people. Also e.g. the value of wetlands as natural purification filters for water is surprisingly high. The use of integrative approaches, such as the ecosystem approach, is highly recommended in complex environments such as floodplains.

8. Valuation of ecosystem services should be developed and integrated into project planning and EIA procedures. This type of valuation yields figures and a numerical measure that can be integrated into more conventional economic cost benefit analyses of the proposed investment, and allows a more thorough economic analysis of the predicted returns for different investment options.

9. Lessons learnt have demonstrated the sensitivity of tropical floodplain environments to increased nutrient runoff. Recent research has illustrated the importance of phytoplankton to tropical floodplains in Australia and South America. This has important implications for the management of floodplains. Attention should be directed to the control of water quality changes (nutrients, but also turbulence, herbicides, metals etc.) influencing phytoplankton productivity and species composition of the floodplains, which could have a profound impact on the entire food chain including the species composition of fish.

10. In connection with road construction, it is of importance to assess how to reach a compromise between construction costs and the need for including e.g. culverts and other means to facilitate floodwater flows and the passage of flora and fauna. In many cases where the needs of the ecosystem functions have not been taken into account during the planning phase of the construction, fitting of culverts has been done at a later stage (and at a significantly higher cost) to e.g. enable fish passage.
11. In connection with any built structure in floodplain areas, the effects of increased access to the wetlands should also be assessed. It has been shown that improved access due to lessened flooding, improved road network and consequent increased human habitation in the floodplain areas will inevitably lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road accessibility. Increased access has also had drastic effects on wildlife due to intensified poaching in areas previously less accessible. Similarly, the newly accessible areas will be subject to new agricultural activities or improved agricultural methods (including irrigation, flood control works, and other infrastructure as well as new crops or varieties), which in turn will cause changes in the hydrology and increased runoff of pesticides and herbicides.
ANNEX 1. LIST OF REFERENCES


Bayley, P. 1998. Fisheries and aquatic biodiversity management in the Amazon. FAO Report No 98/055 CP-RLC.


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Petrere, M. (1996) Fisheries in large tropical reservoirs in south America. Lakes and Reservoirs: research and management. 2; 111-133


Schouten, R. 1998. Effects of dams on downstream reservoir fisheries, case of Nam Ngum. Fish Catch and Culture Vol 4; no 2.

Southeast Asia Rivers Network (SEARIN) Assembly of the Poor, Pak Mun Dam Affected People, Thailand. 2004. The Return of Fish, River Ecology and Local Livelihoods of the Mun River: A Thai Baan (Villagers’) Research. SEARIN publication. 


ANNEX 2: STRUCTURES ANALYSED IN DETAIL

Structure type is classified roughly according to size:

1 = dams and reservoirs
2 = irrigation related smaller structures, weirs, regulators, dykes, levees
3 = roads, railways, gaspipes, canals, flood control, polders
4 = mines and other structures impacting water quality
5 = fishing gear

<table>
<thead>
<tr>
<th>Structure type</th>
<th>Size</th>
<th>Built</th>
<th>Location</th>
<th>Continent</th>
<th>Type of Impact</th>
<th>Main findings</th>
<th>Social Impact</th>
<th>Economic impact</th>
<th>Recommendation</th>
<th>Time of study</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 5 Hydropower reservoirs; Kindaruma, Kamburu, Gitaru, Masinga, Kiambere</td>
<td>Kamburu: Area: At upper storage level 15 km$^2$, cumulative surface area 40,215 km$^2$.</td>
<td>1968, 75, 78, 81, 88</td>
<td>Kenya, Tana River</td>
<td>Africa</td>
<td>Downstream flow and physical characteristics, decreased frequency and magnitude of flooding.</td>
<td>Changes include reduction in area and composition of floodplain grasslands, currently much used for pasture, increasing grazing pressure. Lowering of surface and groundwater, loss of fertile riverbank sediment depositions, reduction in swamps and ox-bow lakes.</td>
<td>Increasing grazing pressure has lead to conflict between pastoralist and floodplain agriculturalists over land and resource use.</td>
<td>The total costs of the existing dams estimated at nearly 27 mill US$, additional (proposed Mutonga Grand Falls) dam construction 19 mill US$ in flood loss related costs. Over 1 million people have been affected.</td>
<td>Further reservoir construction would lead to a cessation of biannual flooding, increasing the net cost of the dam building with 19 mill US$. Dam design options including e.g. constriction of the reservoir and dam to allow for biannual flood simulation would lead to a higher economic net value and rate or return.</td>
<td>1994</td>
<td>23</td>
</tr>
<tr>
<td>1. Aswan Dam</td>
<td>111 m high, 3600 m long, 43 million m$^3$, reservoir area 6000 km$^2$, volume 150-165 km$^3$.</td>
<td>1902</td>
<td>Nile River, Egypt</td>
<td>Africa</td>
<td>Change in hydrology</td>
<td>Prior to impoundment by the Aswan High Dam tilapia constituted 35% of the fish catch but rose to 75% afterwards, probably due to decrease in current velocity and increased macrophyte growth. Loss of floodplain habitat depresses recruitment of migratory taxa such as moromyids, cyprinids, characoids, catfish and Nile perch. The number of fish species recorded from the lower Nile has decreased from more than 70 species to between 20 and 30.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Bakolori Dam</td>
<td>1970's</td>
<td>Nigeria</td>
<td>Africa</td>
<td>Reduction in extent, depth and duration of flooding</td>
<td>Reduction in the area of rice cultivation from 60 to 14% of plots in study area. Corresponding rise in amount of early millet and sorghum. Dryseason cultivation was reduced with up to 73%. Substantial decline in fishing in both dry and wet seasons.</td>
<td>In many villages fishing was stopped altogether in the floodplain, and in others there was a shift to fishing in the main river channel. Five villages (24%) reported no fish catches at all, eleven reported fish to be of smaller size and twelve the absence of certain species, e.g. Nile Perch. The number of fishermen leaving the villages increased from 33% to 67% after dam closure.</td>
<td>Estimated loss of cropping in the Sokoto Valley in total for wet season - 0.74 and dry season - 3.06 million Naira. (Ref 18) or 7 million US$ (ref 86)</td>
<td>Since dam construction can have important effects on the viability of traditional floodplain livelihoods and bring considerable losses of agricultural and fishery production downstream, effort should be put into predicting them in advance of dam construction. It is one problem to recognize adverse environmental and socio-economic effects, but another to get them taken into account in decision over the future of proposed projects.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 1. Cahora Bassa Dam | 1975 | Mozambiqu e | Africa | Elimination of flood cycles in the Zambezi River downstream of the dam | After the construction of the dam, the previous floodplains of the Marromeu have ceased nearly completely, and the complex is much drier at the end of the dry season than under natural conditions. The stagnant waterways are infested with exotic vegetation, and intrusion of saltwater. The dessiccation of the floodplain has opened the area to aggressive poaching of wildlife species and widespread grassland fires. | | | |
| 1. Construction of dams in northern Cameroon; also Sahelian drought | In past 30 years (1970 onward) | Lake Chad Basin, Nigeria | Africa | Reduction of riverine discharge and floodplain; major reduction in size of Lake Chad, but creation of fringing floodplain; change in species diversity; change in fish migrations & distribution; catch rates stable; increased demand/ prices from nonlocal markets; | The impact of environmental change has been widely characterized in the literature as a drastic decline of the fishery. In this study it is hypothesised that while the nature of the fishery has changed, the total economic value may have remained relatively stable. | No change | 44 |

<p>| 1. Construction of dams on headwaters; (ii) smaller irrigation dams elsewhere; (iii) Sahel drought (70s/80s) | In past 30 years (1970 onward) | Nguru-Gashua Wetlands, Nigeria | Africa | Reduction of riverine discharge and floodplain; reduction of fish stock size abundance and diversity; falling catch rates; increased regional demand and prices. | The study assumes that the relatively low reduction in economic value of the fishery (11%), in the face of drastic reduction in the aquatic environment, is only a temporary phase. It is anticipated that the fishery in the Nguru-Gashua Wetlands will not be able to sustain the present level of activity, and that it will become overexploited (biologically and economically) in the near future. The situation will be exacerbated by the inability of local authorities to manage water releases from the major headwater dams. | Estimated change in value of fishery -11% | 44 |</p>
<table>
<thead>
<tr>
<th>1. Construction of Lagdo and Gongola River dam; also Sahelian drought</th>
<th>In past 30 years (1970 onward)</th>
<th>Upper River Benua, Nigeria</th>
<th>Africa</th>
<th>Reduction of riverine discharge, size of annual flood, less inundation of floodplains, reduction of fish biodiversity and stock size; falling catch rates; prices stable; stable local demand</th>
<th>The reduction in the size of the River Benue and its floodplain over 20 years since the construction of the Lagdo Dam upstream in Cameroon, coupled with low and only local demand for the available fish, has produced a fishery of low value to the local economy overall.</th>
<th>Estimated change in value of fishery -96%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dam and irrigation constructions in Nigeria</td>
<td>In past 30 years (1970 onward)</td>
<td>Nigeria</td>
<td>Africa</td>
<td>Altered hydrological patterns and drying up of floodplains</td>
<td>Fisheries have been impacted by environmental change, mainly as a result of natural (e.g. Sahel drought) and manmade (e.g. dam construction) disturbance. The impact of change has in all cases led to a reduction in the aquatic environment – rivers and floodplains have been reduced in size, Lake Chad has shrunk and been replaced by a large swamp – and by and large, as a consequence, fish stocks have been reduced in size, diversity and distribution.</td>
<td>44</td>
</tr>
<tr>
<td>1. Dam construction for large-scale irrigation</td>
<td>Hadejia Jama-are River basin, Nigeria</td>
<td>Africa</td>
<td>Losses of benefits from intact floodplain system</td>
<td>Agricultural, fishing and fuelwood benefits lost through reduced flooding downstream against the gains from increased irrigation production upstream.</td>
<td>Irrigation benefits can only partially replace the lost benefits from reduced floodplain inundation</td>
<td>Regulated flood releases is the best hope of minimizing further losses of floodplain benefits. Further expansion of large-scale irrigation within the river basin should also be avoided.</td>
</tr>
<tr>
<td>Dam, Brokopondo Reservoir</td>
<td>Surinam</td>
<td>America</td>
<td>During dam building, vegetation was not cleared which led to deoxygenation of water, affecting the levels of oxygen 110 km downstream of the dam, causing massive fish kills. In tropical areas it may take many decades of even centuries for the organic matter to decay within impounded reservoirs due to the high amount of plant biomass (while in temperate areas this may take just one decade).</td>
<td>Clearing of vegetation in reservoir site is of importance in tropical areas.</td>
<td>1964-1970</td>
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<tr>
<td>Sokoto and Rima floodplains, Niger</td>
<td>Africa</td>
<td>Decrease in floodplain area from 100 000 ha in 1960 to 50 000 ha in 2020</td>
<td>Expected loss of production in fish, pasture and agriculture 50%</td>
<td></td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Hadejia Komadugu, Nigeria</td>
<td>Africa</td>
<td>Decrease in floodplain area from 380 000 ha in 1960 to 38 000 ha in 2020</td>
<td>Expected loss of production in fish, pasture and agriculture 90%</td>
<td></td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Kainji Dam</td>
<td>1968</td>
<td>Niger River</td>
<td>The flooding of the “fadamas” on either side of the Niger River has been reduced since the construction of the dam. The fadamas are no longer suitable for fish-season cultivation because soil moisture is insufficient. 50-70% of the surface area of each fadama has been lost for agriculture. Natural soil fertilisation has been significantly reduced, leading to a 20% drop in the rice yields.</td>
<td></td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Kainji Dam</td>
<td>1968</td>
<td>Niger River</td>
<td>Decrease in fish catches after filling of dam</td>
<td>Fish catches from the system were reduced by 30%, and the commercially important Mormyridae were reduced from about 20% of the catch to around 5%.</td>
<td>1970s</td>
<td>107</td>
</tr>
<tr>
<td>1. Kainji, Bakolori and Tiga Dams</td>
<td>Kainji Dam: Area: At upper storage level 1 260 km², cumulative surface area 32 035 km².</td>
<td>1968</td>
<td>Niger River</td>
<td>Africa</td>
<td>Altered flow regime, stabilisation of flow in downstream area of dams, eliminating much of the seasonal inundation of the floodplains.</td>
<td>Fish catches declined to between 39 and 75% of their original values. Changes occurred in species composition, decline of swamp dwelling and herbivorous fish and increase in predators, finally reducing stock as a whole since not sustainable. (4) Productive pools and swamps, previously flooded in the downstream area, became dry (73). Dramatic change in species composition (78).</td>
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</tr>
<tr>
<td>1. Kariba Dam</td>
<td>Area: At upper storage level 5550 km², cumulative surface area 20 670 km².</td>
<td>1958</td>
<td>Zimbabwe/Zambia</td>
<td>Africa</td>
<td>Reduced flood magnitude of the Zambezi River by an average of 24 percent in eight out of ten years (1970–80 period)</td>
<td>Labea congoro and Labeo altivelis were important commercial fishes in the Zambezi and abundant in the Kariba area before the closure of the dam. They used to have well marked annual spawning migrations up the tributary rivers. The decline in the Labea stocks after closure of the dam was expected.</td>
</tr>
<tr>
<td>1. Kariba dam</td>
<td>Area: At upper storage level 5550 km², cumulative surface area 20 670 km².</td>
<td>1958</td>
<td>Zimbabwe/Zambia</td>
<td>Africa</td>
<td>Flooding of preferred habitat</td>
<td>The effects of human activities on wetland and aquatic biodiversity across the Zambezi Basin are still rather speculative when it comes to detailed assessments. The major reason for this is the shamefully inadequate or non-existent baseline data on species composition and abundance; thus an assessment of change deriving from a major (a) prescribed flood release from Cabora Bassa, (b) opening up by means of culverts or bridges the major channels coming off the main Zambezi River that feed the swamp areas, and (c) ensuring that the forested Cheringoma Plateau which is an</td>
</tr>
<tr>
<td>1. Kariba dam and Cabora Bassa dam</td>
<td>At upper storage level 5550 km², cumulative surface area 20 670 km². Cahora Bassa: At upper storage level 2</td>
<td>1958 and 1974</td>
<td>Zimbabwe/Mozambique</td>
<td>Africa</td>
<td>Changes in hydrology</td>
<td>(a) prescribed flood release from Cabora Bassa, (b) opening up by means of culverts or bridges the major channels coming off the main Zambezi River that feed the swamp areas, and (c) ensuring that the forested Cheringoma Plateau which is an</td>
</tr>
</tbody>
</table>
| S. No. | Dam Name | Location | Year | Description | Economic Impact | Cost Estimate
<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Maga dam</td>
<td>Logone River, Cameroon</td>
<td>1979</td>
<td>These schemes seriously modified the floodplain regime leading to an acceleration of the degradation of the environment caused by drought. These modifications are also thought to have eliminated the flooding of some 59,000 ha of floodplain and seriously reduced another 150,000 ha which were important breeding and nursery areas for fishes.</td>
<td>IUCN Waza Logone restauration project started in 1993. The economic impact of pilot flood releases in 1994 and 1997 was an added value of over 800,000$ a year through restoring floodplain goods and services. Relating these changes to further recovery of floodplain ecology and biology showed an incremental economic benefit of between 1.1 million and 23 million US$.</td>
<td>Total catch reduction would be an estimated 6,700 t/yr, total direct lost of 120 US$ million over the 21 years during which the flooding pattern has been significantly affected (1979-2000) (ref 44). Economic costs of flood loss in the Waza Logone region estimated as 1.31 mill US$/year in pasture losses, 0.47 mill US$/year in fisheries losses, 0.32 mill US$/year in agriculture losses, 0.29 mill US$/year in grass losses and 0.02 mill US$/year in surface supply losses (ref 71).</td>
</tr>
</tbody>
</table>

67 km², cumulative surface area 27,675 km².
| 1. Pak Mun Dam | Max height 17 m, total length 300 m. | post 1981 Mekong River, Laos | Asia | Number of fish species declined from 121 fish species in 1967 to 66 species in 1981 and 31 in 1990. EIA done in 1981 predicted that fish production from the reservoir would increase considerably, while the opposite has happened. Livelihoods of fish dependent households affected. The number of households dependent on fisheries in the upstream regions declined from 95.6% to 66.7%, but no alternative viable means of livelihood has been identified, requiring financial compensation by the government. Decline in fishing yields downstream estimated to USD 1,4 million per annum. Upstream losses due to closure of Tum Pla Yon traps estimated USD 212000 per annum. 2005 119 | 72, 74, 107 |
| 1. Manantali and Diama dams | Senegal valley floodplains, Senegal | Africa | Decrease in floodplain area from 550,000 ha in 1960 to 55,000 ha in 2020. Expected loss of production in fish, pasture and acgriculture 90%. Filling of the reservoir behind the Manantali Dam has reduced the volume and duration of the annual floods, which in turn has diminished the inundation of the flood plain and resulted in weakened ecosystems depending on prolonged seasonal submersion, a reduced area suitable for flood-recession cropping and curtailed groundwater recharge. Diama Dam has been invaded by dense growth of aquatic plants which hamper fishing efforts and access to the water. Reference 107: There was a net loss of 11250 tons (representing approximately 50%) of fish from the system due to intrusion of salt waters and changes in hydrological regime. The increase in aquatic plant species offer habitat for vectors of water-borne diseases. An explosion of mosquito and snail populations has brought malaria and bilharzial to epidemic proportions. | 72, 74, 107 |
| 1. Reservoirs in the Amazon | Amazon floodplains | America | Migratory patterns of fish | Building of reservoir affected species differently: some seem to be negatively affected by habitat change, while others respond positively. However, a common trend is the decrease in species diversity and abundance of frugivorous species. The impact on the fish community in Tucurui was more severe for migratory species. Five years later the fisheries situation had improved and catches had increased to pre-filling levels, but downriver the fisheries did not show the same recovery probably due to recruitment failure in the absence of floodplain habitat. |

| 1. Selenge and Markala Dams, Niger River | Selenge Dam: Area: At upper storage level 409 km², cumulative surface area 34,900 km². | 1943 and 1980 | Niger River, Mali | Africa | Decrease in highwater level, decrease in flow and duration of flooding, leading to a decrease in recruitment and fish catches | Loss in catches between 1600 to 4000 tons annually due to Markala, 5000 tons (10% of fished volume) since Selenge was built. However, only 2000 tons can be attributed to the dam, while 3000 ton losses are due to drought. | Fishermen have had to pursue complementary livelihood activities such as agriculture, and part of the family may have moved to other parts of Mali or to other countries |

| 1. Several dams on the Niger and tributaries | Niger valley floodplains, Niger | Africa | Decrease in floodplain area from 300,000 ha in 1960 to 150,000 ha in 2020 | Expected loss of production in fish, pasture and agriculture 50% | 25 |

| References therein | 40 and references therein | 72 |
1. Tucurui Dam

| Brazil | America | Decrease in fish biodiversity in the reservoir, upstream and downstream of the dam | Fish diversity decreased between 30-50 species following impoundment. 11 species have disappeared in total. Piscivorous species have increased instead of detritivorous species in the reservoir and to a lesser extent upstream of the reservoir. |

1. Tucurui Dam

| Brazil | America | Changes in fish catches | Increase in fish catch in reservoir (from 400 to 3200 tons annually) and upstream (from 400 to 1000 tons) of dam, decrease downstream (with half, from 1000 to 500 tons annually) |

1. Tucurui Dam

| 1984 | Brazil | America | Blockage of fish migration, creation of anoxic environments due to decaying vegetation left in the reservoir. | Because of decomposing vegetation in the impoundment, both from remains of the forest left uncut when the lake was filled and from aquatic weeds that proliferated on the surface, the water became acid and anoxic, which rendered the water unsuitable for many fish species. The diversity of fish species declined drastically, with the communities becoming dominated by a few species. While primary consumers had been most abundant, the population of predators exploded immediately after closing: in the first |

11

11

41 and references therein
Year piranhas (Serrasalmus spp.) made up 40%–70% of fish caught. The dominance of predators was maintained during the three first years, although some primary and secondary consumers were able to make a partial recovery. The biomass of fish present fluctuated strongly in the first three years: by January 1986 fish biomass had increased to a level above that present prior to closing, followed by a crash in the third year. This is probably due to the predatory fish that made up much of the biomass starving for lack of prey.

1. Dams
Logone floodplains, Cameroon
Decrease in floodplain area from 1 100 000 ha in 1960 to 660 000 ha in 2020
Expected loss of production in fish, pasture and agriculture 60%

2. Dikes

Pantanal, Brazil
America
Attempts to enclose areas of the Pantanal in the Camargo de Correia Island with dikes led to a prolonged moisture period within the dikes (rather than keeping the water out as expected).

Growth of woody weeds made the area unusable for cattle ranching.

"Floodplain-friendly" philosophies recommended: utilising the unique adaptations and life strategies of organisms originating from floodplain environments.
<table>
<thead>
<tr>
<th>2. Flood control, drainage and irrigation schemes (FCDI)</th>
<th>Bangladesh, Asia</th>
<th>Control of water levels, avoiding rapid inundation and preventing extreme flood events</th>
<th>Benefits to agricultural sector can be significant, while fish production and species richness is lowered by the structures. Fish yields inside a flood control compartment can be 50% lower compared to outside, with up to 25 species of fish absent or less abundant. Biodiversity, measured in fish species richness, was 6-35% lower inside than outside of fully functional FCDI schemes. Lower rates of recruitment of migratory whitefish species whose lateral migrations are obstructed by the embankments is largely responsible for these changes.</th>
<th>Unit value of fish catches inside FCDI schemes dropped with 28% due to changes in stock species composition from white fish dominated to smaller, black fish dominated.</th>
<th>Mitigation measures for the combined impacts of FCDI and increasing dry season irrigation on fish production and biodiversity suggested: 1) improving passage of migratory species, 2) improving production of resident fish species based upon improved sluice gate management and alternative cropping strategies.</th>
<th>1996 onward</th>
<th>27, 28, 32</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Floodplain levees</td>
<td>River Murray, Australia</td>
<td>Reduced floodplain connection and area of floodplain inundated</td>
<td>An audit should be undertaken of all floodplain levees and other structures (block banks, roads) that alter the natural movement of water across the floodplain. Unnecessary and illegal levees should be removed as a matter of priority.</td>
<td></td>
<td></td>
<td>2002</td>
<td>31</td>
</tr>
<tr>
<td>2. Regulator</td>
<td>1992-1998? Lohajang River, Bangladesh, Asia</td>
<td>Mortality of hatchlings</td>
<td>Hatchling densities highest in surface layer and near the embankment. Spawning of major carp during first 8-10 weeks of the flood. 44% of fish larvae passing a regulator operated in undershoot mode die within 2 hours, while only 11.8% die if passing in overshot mode.</td>
<td>Fish gates should be overflow and close to shore. Fish passes should be open during spawning time.</td>
<td></td>
<td>1992-1998</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>No.</td>
<td>Action Description</td>
<td>Location</td>
<td>Year</td>
<td>Impact</td>
<td>Economic Costs</td>
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<tr>
<td>2.</td>
<td>Several, including rice irrigation scheme, establishment of embankments and the Maga Dam</td>
<td>Africa</td>
<td>1979 onwards</td>
<td>Waza Logone, Cameroon</td>
<td>Inundated area reduced by almost 30%</td>
<td>Reduction in crop agriculture (floating rice and sorghum, flood recession sorghum. Loss of fisheries, including an estimated 90% decline in fish yields. Reduction of capacity of the floodplains to provide nursery for fish stocks in the river systems of Logone and Chari. Decrease in dry-season pasture by sedentary farmers and nomadic pastoralist from northern Cameroon as well as neighbouring countries. Loss of plant resources used for construction, beekeeping, handicraft production, woodfuel, wild foods and medicines. Decrease in wildlife populations impacting tourism and subsistence hunting. Reduction in surface water availability.</td>
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<td>Many families have left the villages to settle in other areas where this influx of immigrants has lead to the over-exploitation of resources. (Ref 86)</td>
<td>Original value contributed by the flooding (area 3383 ha) was over 19 million US$, or 3000/km2 flooded area. Economic costs of flood loss of 30% was estimated at -2.4 million US$ per year, including losses in pasture (1.31), fisheries (0.47), agriculture (0.32), grass (9.29) and water supply (0.02). According to ref 86, the watering of wildlife of the Waza National Park amounted to 1.8 million US$ in 1983, fish catches in the surroundings of the park have fallen to less that 10% of former values, the loss of 900 km2 floodplain pasture represents a loss of 2.5 million US$, and increased migrations by</td>
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<td>Flood re-release was recommended and carried out in two pilot releases in 1994 and 1997, resulting in an annual increase in the flooded area of 200 km2 and led to recovery in the number of wildlife, increase in fish production, improvement and extension of pasture and changed agricultural opportunities.</td>
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**Note:** Dates before 1979 onwards are approximate.
elephants due to vegetational changes has lead to major damages caused by the elephants to hundreds of hectares of agricultural land, amounting up to 850 US$ per farmer.

| 2. sluice gates or pumps positioned along earth embankments or levees | Bangladesh | Asia | Annual inundation of approximately 2–3 million ha of floodplain in Bangladesh has been either prevented altogether, or controlled. | The reduction in floodplain area is one of the reasons for declining floodplain fisheries in Bangladesh but over-exploitation of inland fish stocks has also been reported |
| 2. Small dams for irrigation | Khammouane, Savannakhet and Champassak provinces, Laos | Asia | Reduced water flow in wet season, increased dry season flows | Significant reduction in riverine habitat area, increased lacustrine and dry-season rice-field areas. Redistribution of catch and fishing effort from riverine to reservoir fisheries. No significant impact on species richness or relative abundance of functional feeding groups. Synthesis: Small to medium scale irrigation schemes in rain-fed rice-farming landscapes have only moderate impacts in fisheries. Changes in agricultural practices in the wet season are likely to have greater effects on fisheries than dry-season irrigation. |

37

1999-2001

53
<p>| 2. Weirs | Murray Darling River, Australia | Australia | Mortality of fish larvae | The percentage of fish larvae dying while passing the weir was significantly higher in the undershot weir than in overshot. Both species were affected but golden perch had greater mortality rate while passing. | Based on this and other studies on the impact of different types of weirs it seems that overshot weirs have less damaging effects on fish larvae and hatchlings, compared to undershot weirs creating much turbulence and water velocities. | 2004-2005 | 26 |
| 2. Weirs | River Murray, Australia | Australia | Unseasonal flooding, wetlands permanently drowned by weir-pools | In cases where it is not possible in the short to medium term to modify weir heights or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wetting and drying regimes. | 2002 | 31 |
| 2. Weirs for irrigation | Irrigated land area average 155 ha, associated paddy area average 93 ha between 1965 and 1997 | Khammouane, Savannakhet and Champassak provinces, Laos | Asia | Diversion of water flow | Weir schemes had no significant impact on aquatic habitat, but caused significant decline (-36%) in fish catches that was partly explained by fishing effort. Weirs had no effect on species richness, but were associated with a significant increase (+17%) in the relative abundance of omnivores. Synthesis: Small to medium scale irrigation schemes in rain-fed rice-farming landscapes have only moderate impacts in fisheries. Changes in agricultural practices | 1999-2001 | 53 |</p>
<table>
<thead>
<tr>
<th>Category</th>
<th>Date</th>
<th>Location</th>
<th>Country</th>
<th>Description</th>
<th>Year</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Constructed canals to bypass the convoluted river channels to facilitate navigation</td>
<td></td>
<td>Barotse floodplain, Zambia</td>
<td>Africa</td>
<td>Vegetation changes, increase of throughflow of flood water reducing the extent of flooding Reduced flooding significantly reduces breeding grounds for fish, since these are located in the shallowest areas.</td>
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<td>14</td>
</tr>
<tr>
<td>3. Cuiaba-Porto Velho Highway</td>
<td>1970s</td>
<td>Rondonia, Brazil</td>
<td>America</td>
<td>Increased turbidity, milky color of water Turbidity was mainly caused by erosion from agricultural activity along the new highway and its feeder roads in the watershed.</td>
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<td>6</td>
</tr>
<tr>
<td>3. Dredging and excavation of river channel</td>
<td>?</td>
<td>Boro River, Okavango Delta, Botswana</td>
<td>Africa</td>
<td>Increased surface outflow to meet human needs The dredging led to significant encroachment of terrestrial plant species onto the floodplain</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>3. Empolderments for water control programs to mitigate flood hazard</td>
<td>after 1980</td>
<td>Chalan Beel Polder D project, NW Bangladesh</td>
<td>Asia</td>
<td>not known Open water fisheries dropped in the project area from a pre-project 3300 tonnes/year (1980) to a post-project 786 tonnes/year (1992) (-76% in 12 years).</td>
<td></td>
<td>1992</td>
</tr>
<tr>
<td>3. Empolderments for water control programs to provide flood protection, drainage and irrigation</td>
<td>1978</td>
<td>Chandpur Irrigation Project between Meghna and Dakatia rivers</td>
<td>Asia</td>
<td>Restriction of floodplains, modification of timing and amplitude of flooding. Inhibits movement and migration of fish and prawns. Limits the availability of the floodplain area for grazing, feeding and growth of juveniles of riverine and Production of floodplain fish was substantially reduced. Prawn species were affected variously, some benefiting form the regulated freshwater environment inside the project, others failed to disperse from inside of project area to outside through the regulator, possibly due to greater velocity of water during the period of operation. Some species received little adverse Fish consumption has decreased from 36 g/person/day pre-project (1972) to 19g/person/day post-project (1992), and the increase in exported fish from closed water culturing has decreased the intake per capita even more. Especially the</td>
<td></td>
<td>1991</td>
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</table>
estuarine breeding fish, reduction of the size and quantity of stocks. Destruction of riverine character inside embankments, restricting the passage of fry, juveniles and adults of migratory species. Blocked connection and passage to the Dakatia River.

effects while some riverine species have almost disappeared inside the project area. Also the sex rations of some prawn species have been affected with the ratio of male to female increased. Tidal and estuarine fish have been seriously impacted by blockage of migratory routes. Coastal plain species are favoured by the stable freshwater environment inside the project area. Carp species have decreased inside the project area and the number of carp fingerlings has decreased and become extremely rare in the Dakatia River. *Hilsa ilisha* was found to be able to migrate into the project area through the regulator during the early monsoon season. Closed water fisheries have been impacted favorably by the project, significantly decreasing the number of exodus of fish during high water. 9 out of 47 resident shallow water fish species were beneficially affected while the rest showed no effect. 9 out of 38 jag fish species were benefited. Open water fisheries experienced a net loss in the project area 5343 tonnes/year (-83%).

poorest people in the area have suffered from the decreased open-water fish population and fish catch. Access to flooded lands have been lost due to shrinkage of the floodplains, and much of the open waters have been leased by the government to influential fish farmers. The price of the fish has gone up and cannot be afforded by the poorer people. Decrease in number of fishers was also shown over a 13-year period after the constructions. Catch per fisher within and outside the project areas was 2.55 kg/day and 4.8 kg per day, respectively.
<table>
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<tr>
<th>Region</th>
<th>Impact</th>
<th>Description</th>
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<tbody>
<tr>
<td>Amazon to Lima</td>
<td>Degradation of pristine, high-biodiversity Amazon jungle area; resettlement and destruction of food and water supplies of indigenous peoples (some voluntarily isolated)</td>
<td>The gas pipe through very remote areas of the Amazon rainforest, including floodplains, has had severe impacts on local people and their livelihoods. The main problem has been the erosion that the clearing of vegetation has had, which has in turn polluted the water and decreased fishing possibilities. Impact mitigation measures are recommended.</td>
</tr>
<tr>
<td>Pantanal, Brazil</td>
<td>Building of the canal will require cutting off natural meanders, deepening of the river channel, buildings to be constructed along the shores and rocky outcrops to be removed.</td>
<td>Changes in the hydrology will be irreversible. Lowering of the river channel depth by 10 or 25 cm could reduce the flooded area by 12 or 32%. In Northern Pantanal there are areas of high fish species diversity which would be affected by this and 40-60% of the species could be eliminated. Natural capital of the Pantanal should be weighed against the economic benefits derived from the hidrovia construction. The predicted modifications of the flooding regime caused by the construction would not fit within the concept of sustainable development.</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>Control of water levels</td>
<td>Catch per unit area was 65-104% higher outside flood control area than inside. Integrated floodplain management options to be introduced to benefit both farmers and fishermen.</td>
</tr>
<tr>
<td>Amazon floodplains</td>
<td>Mercury pollution of water</td>
<td>Landings of fish show a decrease in production from 87000 metric tons in 1969-79 to 37000 metric tons in 1984-85. Mostly caused by a natural drought, while increased fishing effort did not have an effect on the total of the catches. Decline in individual catches from 1900kg in 1966 to 740 kg per year in 1989.</td>
</tr>
<tr>
<td>Niger</td>
<td>Decrease in inundated surface of floodplain, lost water volumes</td>
<td>Landings of fish show a decrease in production from 87000 metric tons in 1969-79 to 37000 metric tons in 1984-85. Mostly caused by a natural drought, while increased fishing effort did not have an effect on the total of the catches. Decline in individual catches from 1900kg in 1966 to 740 kg per year in 1989.</td>
</tr>
<tr>
<td>No Structure, DROUGHT</td>
<td>Sahel</td>
<td>Africa</td>
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### Results Summary

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**Status**: Enabled  
**Reports**: Summary and Detail

### 2. Details

1. Name, contact details (email preferred) and position

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### 3. Geographic

2. Which floodplain areas are you working or living in/familiar with?

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3. In which country (countries) is the floodplain situated?

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<tr>
<th>Response Percent</th>
<th>Response Total</th>
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<td>Country</td>
<td>Response Percentage</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Australia</td>
<td>19%</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>14.3%</td>
</tr>
<tr>
<td>Botswana</td>
<td>4.8%</td>
</tr>
<tr>
<td>Brazil</td>
<td>28.6%</td>
</tr>
<tr>
<td>Cambodia</td>
<td>14.3%</td>
</tr>
<tr>
<td>Cameroon</td>
<td>0%</td>
</tr>
<tr>
<td>China (PRC)</td>
<td>0%</td>
</tr>
<tr>
<td>Dem. Rep. Congo</td>
<td>0%</td>
</tr>
<tr>
<td>India</td>
<td>9.5%</td>
</tr>
<tr>
<td>Laos</td>
<td>4.8%</td>
</tr>
<tr>
<td>Mali</td>
<td>0%</td>
</tr>
<tr>
<td>Mozambique</td>
<td>0%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>0%</td>
</tr>
<tr>
<td>Peru</td>
<td>0%</td>
</tr>
<tr>
<td>Thailand</td>
<td>4.8%</td>
</tr>
<tr>
<td>Vietnam</td>
<td>9.5%</td>
</tr>
<tr>
<td>Zambia</td>
<td>4.8%</td>
</tr>
<tr>
<td>Other Country</td>
<td>28.6%</td>
</tr>
<tr>
<td>Total Respondents</td>
<td>21</td>
</tr>
<tr>
<td>(skipped this question)</td>
<td>3</td>
</tr>
</tbody>
</table>
4. Description of floodplain

4. Which of the below illustrates the floodplain environment you are describing? Tick off as many as are appropriate.

<table>
<thead>
<tr>
<th>Environmental Type</th>
<th>Response Percent</th>
<th>Response Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal flooding</td>
<td>68.4%</td>
<td>13</td>
</tr>
<tr>
<td>Monomodal flooding (one time per year)</td>
<td>36.8%</td>
<td>7</td>
</tr>
<tr>
<td>Non-Seasonal, unpredictable flooding</td>
<td>5.3%</td>
<td>1</td>
</tr>
<tr>
<td>Flush floods of high amplitude</td>
<td>10.5%</td>
<td>2</td>
</tr>
<tr>
<td>Large river floodplains with slow, ample and predictable floods</td>
<td>52.6%</td>
<td>10</td>
</tr>
<tr>
<td>Várzea</td>
<td>31.6%</td>
<td>6</td>
</tr>
<tr>
<td>Igapó</td>
<td>36.8%</td>
<td>7</td>
</tr>
<tr>
<td>Flooded forest</td>
<td>52.6%</td>
<td>10</td>
</tr>
<tr>
<td>Flooded shrubland</td>
<td>26.3%</td>
<td>5</td>
</tr>
<tr>
<td>Flooded savannah (grassland)</td>
<td>15.8%</td>
<td>3</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>21.1%</td>
<td>4</td>
</tr>
</tbody>
</table>

Total Respondents: 19

(skipped this question) 5
5. What are the most significant goods and services provided by the floodplain?

<table>
<thead>
<tr>
<th>Goods and Services</th>
<th>Very significant</th>
<th>Significant</th>
<th>Not very significant</th>
<th>Not significant at all</th>
<th>N/A</th>
<th>Response Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural resources in general</td>
<td>47% (7)</td>
<td>53% (8)</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>0%</td>
<td>1.53</td>
</tr>
<tr>
<td>Fish</td>
<td><strong>78% (14)</strong></td>
<td>22% (4)</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>0%</td>
<td>1.22</td>
</tr>
<tr>
<td>Wild vegetables</td>
<td>7% (1)</td>
<td>20% (3)</td>
<td><strong>40% (6)</strong></td>
<td>27% (4)</td>
<td>7%</td>
<td>2.93</td>
</tr>
<tr>
<td>Fruit</td>
<td>13% (2)</td>
<td>13% (2)</td>
<td><strong>53% (8)</strong></td>
<td>20% (3)</td>
<td>0%</td>
<td>2.80</td>
</tr>
<tr>
<td>Game</td>
<td>0% (0)</td>
<td>15% (2)</td>
<td>31% (4)</td>
<td><strong>46% (6)</strong></td>
<td>8%</td>
<td>3.33</td>
</tr>
<tr>
<td>Rubber</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>15% (2)</td>
<td><strong>54% (7)</strong></td>
<td>31%</td>
<td>3.78</td>
</tr>
<tr>
<td>Wood</td>
<td>19% (3)</td>
<td><strong>31% (5)</strong></td>
<td>19% (3)</td>
<td>25% (4)</td>
<td>6%</td>
<td>2.53</td>
</tr>
<tr>
<td>Medicinal plants</td>
<td>0% (0)</td>
<td>23% (3)</td>
<td>23% (3)</td>
<td><strong>31% (4)</strong></td>
<td>23%</td>
<td>3.10</td>
</tr>
<tr>
<td>Other ecosystem services such as</td>
<td>17% (1)</td>
<td><strong>50% (3)</strong></td>
<td>33% (2)</td>
<td>0% (0)</td>
<td>0%</td>
<td>2.17</td>
</tr>
<tr>
<td>Nutrients and fertile soils for agriculture</td>
<td>40% (6)</td>
<td><strong>47% (7)</strong></td>
<td>7% (1)</td>
<td>7% (1)</td>
<td>0%</td>
<td>1.80</td>
</tr>
<tr>
<td>Food for domestic animals</td>
<td>13% (2)</td>
<td><strong>47% (7)</strong></td>
<td>13% (2)</td>
<td>20% (3)</td>
<td>7%</td>
<td>2.43</td>
</tr>
<tr>
<td>Food for wild animals</td>
<td>7% (1)</td>
<td><strong>43% (6)</strong></td>
<td>29% (4)</td>
<td>14% (2)</td>
<td>7%</td>
<td>2.54</td>
</tr>
<tr>
<td>Transportation/navigation</td>
<td>25% (4)</td>
<td><strong>31% (5)</strong></td>
<td>19% (3)</td>
<td>25% (4)</td>
<td>0%</td>
<td>2.44</td>
</tr>
<tr>
<td>Recreational and aesthetic value</td>
<td>20% (3)</td>
<td><strong>40% (6)</strong></td>
<td><strong>40% (6)</strong></td>
<td>0% (0)</td>
<td>0%</td>
<td>2.20</td>
</tr>
<tr>
<td>Ecotourism potential</td>
<td>29% (4)</td>
<td><strong>50% (7)</strong></td>
<td>21% (3)</td>
<td>0% (0)</td>
<td>0%</td>
<td>1.93</td>
</tr>
<tr>
<td>Flood control</td>
<td>21% (3)</td>
<td><strong>57% (8)</strong></td>
<td>14% (2)</td>
<td>7% (1)</td>
<td>0%</td>
<td>2.07</td>
</tr>
<tr>
<td>Groundwater replenishment</td>
<td>15% (2)</td>
<td><strong>54% (7)</strong></td>
<td>15% (2)</td>
<td>0% (0)</td>
<td>15%</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Total Respondents: 19

(Skipped this question)
5. Built Structures

6. Have any structures been built in the floodplains? Which ones and when, and for what purpose?

<table>
<thead>
<tr>
<th>View</th>
<th>Total Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td>(skipped this question)</td>
<td>9</td>
</tr>
</tbody>
</table>

7. Has an Environmental and/or Social Impact Assessment been done before building? If so, do you think it has adequately addressed the potential or actual effects of the built structures on fisheries and floodplain ecosystems? If not, why? What improvement(s) would you suggest?

<table>
<thead>
<tr>
<th>View</th>
<th>Total Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
<tr>
<td>(skipped this question)</td>
<td>10</td>
</tr>
</tbody>
</table>
8. Have you recorded or heard of any positive or negative impacts of these structures that have affected the environment (e.g. flow of water, changes in water quality, silting or turbidity, changes in animal and plant species occurring)?

<table>
<thead>
<tr>
<th>Impact</th>
<th>Response Percent</th>
<th>Response Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>environment (e.g. flow of water, changes in water quality, silting or turbidity, changes in animal and plant species occurring)</td>
<td>91.7%</td>
<td>11</td>
</tr>
<tr>
<td>fish (species, numbers or areas of occurrence) and the fisheries (number or composition of catch, fishing areas) in the floodplain area</td>
<td>100%</td>
<td>12</td>
</tr>
<tr>
<td>livelihoods of local people in the floodplain area</td>
<td>83.3%</td>
<td>10</td>
</tr>
<tr>
<td>socio-economy of the area</td>
<td>58.3%</td>
<td>7</td>
</tr>
<tr>
<td>management of the fisheries</td>
<td>66.7%</td>
<td>8</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>16.7%</td>
<td>2</td>
</tr>
</tbody>
</table>

Total Respondents

(skipped this question)
9. Please describe and, if possible, quantify the impact(s).

<table>
<thead>
<tr>
<th>View</th>
<th>Total Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
</tr>
</tbody>
</table>

(skipped this question) 13

10. Can you recommend a way or alternatives for the built structure mentioned, that would have less environmental or social impacts, but would still serve its purpose considering the special challenges of a floodplain environment? Please describe here. You can also point to documents recording these impacts, and recommendations, here.

<table>
<thead>
<tr>
<th>View</th>
<th>Total Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
</tr>
</tbody>
</table>

(skipped this question) 13
### ANNEX 4 PERSONS CONTACTED FOR INFORMATION ON FLOODPLAIN RESEARCH

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>Study area</th>
<th>Affiliation</th>
<th>Reply</th>
<th>Notes</th>
<th>Questionnaire link sent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gertjan De Graaf</td>
<td>26.4</td>
<td>Bangladesh</td>
<td>Nefisco</td>
<td></td>
<td>X</td>
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</tr>
<tr>
<td>Felix Martin</td>
<td>26.4</td>
<td>Bangladesh</td>
<td>FAO</td>
<td>X</td>
<td>Sent articles</td>
<td>X</td>
</tr>
<tr>
<td>Professor Shinji Tsukawaki</td>
<td>2.5</td>
<td>Cambodia</td>
<td>Uni Kanazawa</td>
<td>X</td>
<td>Sent articles</td>
<td>X</td>
</tr>
<tr>
<td>Dr Klement Tockner</td>
<td>2.5</td>
<td>Global</td>
<td>EAWAG/ETH</td>
<td>X</td>
<td>Sent articles</td>
<td></td>
</tr>
<tr>
<td>Professor Robin Clarke</td>
<td>2.5</td>
<td>Brazil</td>
<td>Uni Rio Grande do Sul, Brazil</td>
<td>X</td>
<td>Sent articles</td>
<td></td>
</tr>
<tr>
<td>Terry Boyle</td>
<td>2.5</td>
<td>Brazil (Plata basin)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Robert Naiman</td>
<td>2.5</td>
<td>Uni Washington</td>
<td></td>
<td>X</td>
<td>No work on floodplains</td>
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<tr>
<td>Professor Bill Adams</td>
<td>2.5</td>
<td>Nigeria</td>
<td>Uni Cambridge</td>
<td>X</td>
<td>Sent articles</td>
<td></td>
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<tr>
<td>Dr Wolfgang Junk</td>
<td>3.5</td>
<td>Amazon</td>
<td>Max-Planck Institute for Limnology</td>
<td>X</td>
<td>Sent articles</td>
<td></td>
</tr>
<tr>
<td>David Dudgeon</td>
<td>3.5</td>
<td>Asia</td>
<td>Uni Hong Kong</td>
<td>X</td>
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<td></td>
</tr>
<tr>
<td>Mauro Ruffino</td>
<td>3.5</td>
<td>Amazon</td>
<td>Coordinator of &quot;ProVárzea&quot;</td>
<td>X</td>
<td>Sent articles</td>
<td></td>
</tr>
<tr>
<td>Virginia Dale</td>
<td>3.5</td>
<td>Americas</td>
<td>Oak Ridge National Laboratorium, USA</td>
<td>X</td>
<td>Sent articles</td>
<td></td>
</tr>
<tr>
<td>Jukka Käyhkö</td>
<td>5.5</td>
<td>Amazon, Africa</td>
<td>Uni Turku</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Risto Kalliola</td>
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<td>Amazon</td>
<td>Uni Turku</td>
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<tr>
<td>Petteri Alho</td>
<td>5.5</td>
<td>Global</td>
<td>Uni Turku</td>
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<tr>
<td>Roberta Lossio</td>
<td>8.5</td>
<td>Latin America</td>
<td>Independent consultant</td>
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<tr>
<td>Aarnyak project</td>
<td>9.5</td>
<td>India, Brahmaputra</td>
<td></td>
<td></td>
<td>Reply from Partha Yoti Das, busy but will contact later</td>
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<tr>
<td>Kaziranga Protected Forests</td>
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<td>India</td>
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<tr>
<td>Dr Paul Loth</td>
<td>12.5</td>
<td>Nigeria</td>
<td>Uni Leiden</td>
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<td>Acquired elsewhere</td>
<td>X</td>
</tr>
<tr>
<td>Dr Lee Baumgartner</td>
<td>12.5</td>
<td>Australia</td>
<td>Dep of primary industried, Australia</td>
<td>X</td>
<td>Sent articles, would like to see report when finished</td>
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</tr>
<tr>
<td>Professor Isaacman</td>
<td>15.5</td>
<td>Cahora Bassa, Mozambique</td>
<td>Uni Minnesota</td>
<td></td>
<td>Acquired elsewhere</td>
<td>X</td>
</tr>
<tr>
<td>Brian Marshall</td>
<td>15.5</td>
<td>Zambezi Basin</td>
<td></td>
<td></td>
<td>X</td>
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</tr>
<tr>
<td>R. Cunliffe</td>
<td>15.5</td>
<td>Zambezi</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Name</td>
<td>Basin</td>
<td>Institution</td>
<td>X</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------</td>
<td>------------------------</td>
<td>--------------------------------------------------</td>
<td>--------</td>
<td>-------</td>
<td></td>
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<tr>
<td>25</td>
<td>Olivier Hamerlynck</td>
<td>15.5 Senegal, Africa</td>
<td>IUCN</td>
<td>X</td>
<td>Sent links to articles</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Madiodio Niasse</td>
<td>16.5 Senegal, Africa</td>
<td>Independent consultant</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>&quot;Rafael Herrera Fernández&quot;</td>
<td>16.5 Brazil, Venezuela</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Atossa Soltani</td>
<td>17.5 Camisea, Peru</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Robert Montgomery Head</td>
<td>17.5 Americas</td>
<td>Environment and Social Unit, IADB, USA</td>
<td>X</td>
<td>Busy but will reply later</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Mr Holt-Giménez</td>
<td>17.5 Amazon</td>
<td>BIC</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Mr George Lukacs</td>
<td>17.5 Australia</td>
<td>Australian Centre for Tropical Freshwater Research</td>
<td>X</td>
<td>student Vern Veitch replied</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Tonje Folkestad</td>
<td>17.5 Global dams</td>
<td>WWF</td>
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<tr>
<td>33</td>
<td>Mr Welcomme</td>
<td>19.5</td>
<td></td>
<td></td>
<td>Email not working</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Dr Ashley S. Halls</td>
<td>22.5 Bangladesh</td>
<td>Aquae Sulis Ltd</td>
<td>X</td>
<td>Sent articles</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Dr Sandra Kloff</td>
<td>24.5 Senegal, Mauritania</td>
<td>IUCN</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Dr Shumway</td>
<td>5.6 Africa</td>
<td>Edgerton Research Laboratory New England</td>
<td>X</td>
<td>Will send publication</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Dr Frank Farqharson</td>
<td>15.6 global</td>
<td>Water Resources, CEH, UK</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Judith Rosales</td>
<td>15.6 Orinoco, Venezuela</td>
<td>Uni Guyana</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Dr Maria Piedade</td>
<td>15.6 Amazon</td>
<td>INPA</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Karl Wantzen</td>
<td>16.6 Amazon, Pantanal</td>
<td>Uni Konstanz</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Dr Kai Lorenzen</td>
<td>18.6 Amazon, Mekong</td>
<td>Imperial College London</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Ulrich Saint-Paul</td>
<td>18.6 Amazon, Vietnam</td>
<td>Center for Tropical Marine Ecology Bremen</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Dr. Michael Douglas</td>
<td>18.6 Australia</td>
<td>Charles Darwin University</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Additional information especially concerning the Mekong received from Matti Kummu (selected articles by Lamberts etc), Marko Keskinen (CD ROM with literature, plus fisheries database), Eric Baran, Sophie Nguyen Khoa and Yumiko Kura (World Fish Centre/Phnom Penh)
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Environment Component

REVIEW OF TONLE SAP BUILT STRUCTURES ENVIRONMENTAL IMPACT ASSESSMENTS (EIAs) WITH REGARD TO FISHERIES

Prepared by

Sophie NGUYEN-KHOA¹ & Puthy CHET²

¹ WorldFish Center
² Ministry of Environment

December 2006
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ACRONYMS AND ABBREVIATIONS

ADB   Asian Development Bank
CDC   Council Development of Cambodia
CDRI  Cambodia Development Research Institute
CEA   Cumulative Effect Assessment
CNMC  Cambodia National Mekong Committee
EIA   Environmental Impact Assessment
EMP   Environmental Management Plan
FACT  Fisheries Action Coalition Team
IEE   Initial Environmental Examination
IEIA  Initial Environmental Impact Assessment
JICA  Japan International Cooperation Agency
LEPNRM Law on Environmental Protection and Natural Resources Management
MAFF  Ministry of Agriculture, Forestry and Fisheries
MOE   Ministry of Environment
MOP   Ministry of Planning
MOT   Ministry of Tourism
MIME  Ministry of Industry, Mines and Energy
MPWT  Ministry of Public, Wage and Transportation
MOWRAM Ministry of Water Resources and Meteorology
MRC   Mekong River Commission
NGO   Non-Governmental Organization
SEA   Strategic Environmental Assessment
TA    Technical Assistance
WCS   Wildlife Conservation Society
1. INTRODUCTION

This study is part of the Environment Component of the ADB Technical Assistance (TA) 4669 “Study of the Influence of Built Structures on the Fisheries of the Tonle Sap”. The objective of the 10-month study is to improve the awareness and understanding of government agencies and policy-makers of the influence of built structures on the hydrological regime of the lake and on the fisheries of the Tonle Sap (Project Proposal Report). The Technical Assistance is led by the WorldFish Center and the Cambodian National Mekong Committee (CNMC). It is composed of several components identified across disciplines: hydrology, environment, fisheries ecology, livelihoods and socioeconomics, and communication to the public and policy-makers.

The Environment Component aims to assess the state of global and local knowledge on the impacts of built structures on aquatic ecosystems and fisheries. It builds on reviews of scientific literature on the impacts of built structures on tropical floodplains worldwide, and of scientific and grey literature on built structure environmental impact assessments (EIA) in relation to the fisheries of the Tonle Sap. Results will inform and support policy-and decision-making related to built structure development.

The report presents the review of local environmental impact assessments of built structures on the fisheries of the Tonle Sap. The study focuses on EIA - including their initial forms such as Initial Environmental Examination (IEE) and Initial Environmental Impact Assessment (IEIA) - of existing and planned built structure projects implemented in the Tonle Sap area. It highlights the strengths and weaknesses of EIA processes and outputs in order to identify how best to implement adequate and effective EIAs to assess the impacts of built structures on the Tonle Sap fisheries.

The report presents the review method and activities, the evaluation of EIA reports, discussion of results and recommendations for enhanced built structure EIAs with regard to fisheries. The review was conducted mainly in Phnom Penh by an international researcher (2 months) with the assistance of a local research support officer from the Ministry of Environment (4 months), based at the regional office of WorldFish Center, Cambodia.

2. METHODS AND ACTIVITIES

The review of environmental assessments is primarily based on the collection of secondary information but it also includes informal consultation of stakeholders in relevant government institutions, NGOs and other civil society groups. Methods and activities cover the identification of the review scope, consultation of stakeholders, collection of secondary data and identification of indicators for evaluation of EIA reports.

2.1 DEFINITION OF THE SCOPE OF THE REVIEW

The boundaries of the review are defined here in terms of environmental assessment type and geographical scope, and the range of built structures.
2.1.1 Environmental assessment categories and geographical scope

EIA can be broadly defined as a process for evaluating the impact of a project on the functioning of ecosystems and the well-being of humans. Various forms of environmental impact assessments exist and are derived from EIA: initial (such as IEIA, IEE), social (Social Impact Assessment, SIA), cumulative (Cumulative Effects Assessment, CEA) and strategic (Strategic Environmental Assessment, SEA).

While EIA usually includes the assessment of socioeconomic and livelihood impacts, independent Social Impact Assessments (SIA) may be conducted to increase the depth of social studies. Some countries in the Greater Mekong Sub-region refer to SIA as a complementary but separate process to EIA; others such as the MRC assume that EIA includes adequate analysis of social impacts (MRC 200X). The review will thus evaluate coverage of socioeconomic impacts in EIA while searching for SIA reports where available.

Initial and shorter forms of environmental assessments exist in order to screen significant impacts and determine whether a more comprehensive assessment through EIA is required. They are variously referred to as ‘initial EIA’ (IEIA) in local official documents, and ‘Initial Environmental Examination’ (IEE) in donor agency (e.g. the ADB) documents. In this report, therefore, the generic term ‘EIA’ is used to cover available IEIA and IEE.

In order to address all potential significant effects on the Tonle Sap fisheries, the spatial scope of the review must cover all projects affecting the Lake directly and indirectly, including the tributaries flowing into the Lake. Three relevant scales have thus been identified: 1) the Tonle Sap Great Lake (TSGL), 2) the sub-catchment draining into the Lake including the Lake’s associated floodplain, and 3) upstream areas up to the boundaries of the Tonle Sap Basin (TA 4669 Inception Report 2006). While built structure projects far from the Tonle Sap catchment could have an indirect effect on the Tonle Sap fisheries, a comprehensive review of the whole basin is not feasible within this review. Main issues on larger scales will be addressed in relation to built structure EIA through a general review of Strategic Environmental Assessment (SEA) and Cumulative Effects Assessments (CEA).

2.1.2 Types of built structures

The Technical Assistance study (TA 4669 Proposal 2006) defines built structures as follows: "Built structures consist of constructions that: i) oppose water outflow (e.g. dams, weirs, irrigation schemes, dykes, levees); ii) prevent water inflow (e.g. embankments, polders, flood control works); iii) alter water inflow or outflow (e.g. roads, railways, drainage canals, agricultural works, bank modifications); iv) degrade water quality (e.g. plants with aqueous effluents, mining and mineral processing facilities, sewerage systems, and dredges)."

The Law on Environmental Protection and Natural Resources Management (12 December 1996) states that all projects and activities should be subject to an EIA. Because this would not be practical and cost-effective, a list of built structure projects requiring an Initial EIA (IEIA) and/or EIA was included in the Sub-decree on the EIA Process (see also Section 3.1). All activities included in the list are potential threats to the environment and are divided into separate categories. The following categories
require an IEIA or EIA: (a) hydropower; (b) irrigation systems; (c) port construction; and (d) dredging. Built structure projects that should require an EIA on the basis of the criteria defined in the Environmental Law (August 1999) and for which EIA is compulsory have been identified.

In principle most built structure projects can have an impact on fisheries, through changes to the biophysical (e.g. erosion, pollution) and social (e.g. livelihood changes, etc.) characteristics of the fishery system and the aquatic productivity of the ecosystem. Due to the short duration of the study and the difficult access to information (see Section 4.1), the review had to focus on built structures of key concern regarding the fisheries of the Tonle Sap. While structures such as airports and railways are covered by the study, they are not reviewed comprehensively. The structures identified as most relevant to this study are listed in the table below (Table 1).

Table 1: Main built structures under review

<table>
<thead>
<tr>
<th>Sector or category</th>
<th>Built structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>• Bridge and road construction (above 30 tons weight)</td>
</tr>
<tr>
<td></td>
<td>• National road construction (longer than 100 km)</td>
</tr>
<tr>
<td></td>
<td>• Railway construction (all sizes)</td>
</tr>
<tr>
<td></td>
<td>• Port construction (all sizes)</td>
</tr>
<tr>
<td></td>
<td>• Airport construction (all sizes)</td>
</tr>
<tr>
<td>Agricultural sector</td>
<td>• Irrigation systems (greater than or equal to 5,000 ha)</td>
</tr>
<tr>
<td></td>
<td>• Drainage systems (greater than or equal to 5,000 ha)</td>
</tr>
<tr>
<td></td>
<td>• Fishing ports (all sizes)</td>
</tr>
<tr>
<td>Structure degrading water quality</td>
<td>• Port construction (all sizes)</td>
</tr>
<tr>
<td></td>
<td>• Irrigation systems (greater than or equal to 5,000 ha)</td>
</tr>
<tr>
<td></td>
<td>• Drainage systems (greater than or equal to 5,000 ha)</td>
</tr>
<tr>
<td></td>
<td>• Fishing ports (all sizes)</td>
</tr>
<tr>
<td></td>
<td>• Industrial, waste water treatment plant</td>
</tr>
</tbody>
</table>

It must be noted that EIAs are not required for a range of structures likely to influence the fisheries of the Tonle Sap Basin such as small-scale irrigation and drainage systems, fishing gears, dikes and bunds in agricultural fields. These small structures contribute to the cumulative impacts on the ecosystem and thus on the Tonle Sap fisheries, which are considered in Sections 5.3 and 5.4. Large fishing gears are also included in the built structures studied by other components of the study (hydrology, fisheries and socioeconomic-livelihoods).

2.2 CONSULTATION OF KEY STAKEHOLDER INFORMANTS

The purpose of the stakeholder consultation is threefold: i) to enhance the collection of information and knowledge through key informants, ii) to increase awareness of this study, and iii) to learn the perceptions of stakeholders on the actual implementation of environmental assessments in Cambodia and improve the understanding of stakeholder issues and concerns.

Key stakeholders were identified in government institutions, civil society including nongovernmental organisations (NGOs), donor agencies and to a lesser extent for such a review, local communities (see Table 2 below). The majority (but not all) of key
representatives are based in Phnom Penh where most meetings were organised. Informal discussions were carried out with a few villagers and provincial and district officers during a preliminary visit of the project team in Pursat province (25 May 2006).

A brief stakeholder analysis estimated the importance of stakeholders in the project and his/her influence in decision-making for built structure projects. The Ministry of Environment has been identified as the main actor, with support or involvement of the CNMC and all respective agencies implied in a built structure project. However, in practice the MOE and CNMC do not have much influence in enforcing and monitoring the implementation of EIAs (e.g. SEI and ADB 2002) (see further details in Section 3.1).

Table 2: List of key stakeholders met during the review

<table>
<thead>
<tr>
<th>Stakeholder Category</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government institutions</td>
<td>• Ministry of Environment (MOE)</td>
</tr>
<tr>
<td></td>
<td>- EIA Unit</td>
</tr>
<tr>
<td></td>
<td>- Biosphere Reserve Unit</td>
</tr>
<tr>
<td></td>
<td>• Ministry of Agriculture, Forestry and Fisheries (MAFF)</td>
</tr>
<tr>
<td></td>
<td>- EIA Unit, Department of Fisheries</td>
</tr>
<tr>
<td></td>
<td>• MIME</td>
</tr>
<tr>
<td></td>
<td>• Ministry of Water Resources and Meteorology (MOWRAM)</td>
</tr>
<tr>
<td></td>
<td>• Provincial and District officials</td>
</tr>
<tr>
<td>Donor agencies</td>
<td>• ADB</td>
</tr>
<tr>
<td>NGOs</td>
<td>• FACT</td>
</tr>
<tr>
<td></td>
<td>• OXFAM Australia</td>
</tr>
<tr>
<td></td>
<td>• Nature Conservation Society</td>
</tr>
<tr>
<td>Local communities</td>
<td>• A few villagers (informal interviews during field visit)</td>
</tr>
</tbody>
</table>

2.3 COLLECTION AND REVIEW OF SECONDARY DATA

Collection of secondary information was carried out through various mechanisms:

- Internet-based search engines and use of specific websites belonging to local organisations and donor agencies (esp. the ADB) and local websites (NGOs, etc.)
- Library searches at the JICA, CDRI, ADB, and other libraries in line ministries
- Meetings with stakeholders (information and reports provided by stakeholders and/or their organizations).

The variety of ways adopted for collecting information from different sources (Internet, libraries and local knowledge) increased knowledge and enlarged its breadth. In particular, this ensured consideration of the different perspectives and perceptions of stakeholders, and integration of various types of knowledge (e.g., local documents in Khmer language, grey and international literature). Where possible this also allowed cross-checking of information; for example the facts, views and option issues from grey literature and stakeholder knowledge, respectively.
2.4 INDICATORS FOR EVALUATION

A comprehensive evaluation of built structure EIAs would compare the predictions or evaluations of impacts derived from EIAs with actual impacts. However, since monitoring of the actual effects of built structures during and after project implementation is not recorded or has not been implemented, the present review cannot evaluate EIAs on this basis. The review evaluates the actual implementation of the EIA process and impact assessment methods, analyses and recommendations with regard to fisheries.

Indicators for evaluation have been selected through an iterative process that allowed their refinement and adequacy to Cambodia built structure EIA through increased knowledge of Tonle Sap fisheries and built structure development in the Mekong Basin. The evaluation focuses on the quality of the EIA process and the impact assessment and management recorded in collected EIA reports. Selected questions and indicators are indicated in the table below (Table 3). Indicators broadly relate to the process of EIA implementation, impact assessment methods and results, and management recommendations. Justification for the selection of key indicators is briefly explained below.

Table 3: Questions and indicators for evaluation

<table>
<thead>
<tr>
<th>Category</th>
<th>Question or Indicator</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EIA Process</strong></td>
<td><strong>Scope of the EIA</strong></td>
<td>Fisheries have often been neglected in EIA built structure projects.</td>
</tr>
<tr>
<td></td>
<td>• Are fisheries issues addressed?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Temporal and spatial boundaries of the EIA</td>
<td></td>
</tr>
<tr>
<td><strong>Participation of stakeholders</strong></td>
<td>• Degree of participation if any</td>
<td>Public participation is generally a requirement in EIA guidelines produced by donor agencies, notably by the ADB in Cambodia. However, literature shows that the practice of EIA in Cambodia differs and operational procedures make no mention of how or when these consultations should take place (McKenney 1999).</td>
</tr>
<tr>
<td></td>
<td>• Forms of participation</td>
<td></td>
</tr>
<tr>
<td><strong>Transparency of process</strong></td>
<td>• Communication of EIA process</td>
<td>Communication and dissemination of process information and outputs is a prerequisite for the participation of different stakeholders and sufficient consideration of their concerns.</td>
</tr>
<tr>
<td></td>
<td>• Dissemination of EIA outputs</td>
<td></td>
</tr>
</tbody>
</table>
### Impact Assessment

| Scope of fisheries assessment | • Aspects of fisheries and disciplinary fields covered  
| | • Time and spatial boundaries of fisheries assessment  
| | Disciplinary coverage (hydrology, ecology, socioeconomy, livelihoods, management and governance) and spatial and time boundaries. |

| Method for impact assessment | • Type of method selected  
| | • Adequacy to fisheries issues and local resources  
| | • Collection and use of secondary data and other sources of information  
| | • Collection and use of primary data  
| | • Baseline situation  
| | Type of method selected among existing ones (e.g. most commonly: ad-hoc, checklist, matrix, network, simulation modelling, expert system) or innovative methods.  
| | Selected methods will be evaluated on the basis of their adequacy with respect to fisheries issues and local resources, collection of data and information and assessment of the baseline situation such as, for example, the consideration of counterfactual effects. |

| Level of integration | • Across disciplines  
| | • Across sectors and scales  
| | Mainly across disciplines and possibly across sectors and scales. |

| Participation of stakeholders | • Degree of participation if any  
| | • Forms of participation  
| | Level and form of participation especially who participates. |

| Impact assessment results | • Are results qualitative or quantitative or both?  
| | • If qualitative, what is the quality of results and degree of subjectivity and uncertainty?  
| | • If quantitative, what is the quality of results and degree of uncertainty?  
| | Quality of impact assessment results. |

### Management Recommendations

| Identification of measures | • Mitigation measures  
| | • Enhancement measures  
| | Optimising the benefits of built structure projects includes mitigating negative effects and enhancing positive effects on fisheries |

| Adequacy and feasibility | • Adequacy to local resources and constraints  
| | • Cost-effectiveness  
| | • Monitoring of implementation  
| | Management measures exist and the main constraint is the suitability to local characteristics and resources. Sustainability of measures. |

| Support for decision-making | • Evaluation of trade-offs  
| | • Implications for policy-making  
| | Positive and negative impacts, various costs and benefits for the different options. |
3. STAKEHOLDER CONSULTATION AND SECONDARY INFORMATION

This section first presents the background of EIA procedures in Cambodia and the results of the stakeholders’ consultation. It then considers the evaluation of EIA reports.

3.1 EIA PROCESS IN CAMBODIA

Until recently, EIA in Cambodia was an *ad-hoc* activity with the Council for the Development of Cambodia (CDC) providing environmental (as well as overall) clearance for major investment projects. EIA was largely limited to public sector projects normally financed by organisations whose internal approval procedures mandated an environmental assessment (the ADB, World Bank, EU, bilateral agencies, etc.). A process was implemented for: i) transferring the responsibility for EIA from the CDC to the MOE; ii) transferring the initiative for conducting EIA from outside development agencies to Cambodian authorities; and iii) ensuring EIAs apply across all new and old activities in a systematic manner. The first step has virtually been accomplished while the other two require further substantial efforts (Urwin and Wrigley 2001).

The authority for EIA is currently vested in the Ministry of Environment as provided for by the Law on Environmental Protection and Natural Resources Management (LEPNRM). The scope of EIA has been extended to all investment projects, planned or existing. For existing projects approved at the Central Level of government, a screening application to determine whether EIA is necessary followed by the preparation and submission (if warranted) of an Initial EIA (IEIA) and an Environmental Management Plan (EMP) is required.

The preliminary screening criteria are qualitative and exempt a project from EIA if:

- project activities can be expected to have non-measurable or insignificant environmental impacts,
- the project appears to be in conformity with the objectives of the LEPNRM, the National Environmental Action Plan, regional environmental development plans (if adopted) and other laws relative to NRM, and
- the risk of environmental impacts during project construction, operation and closure are considered to be small (MOE 2000, Urwin and Wrigley 2001).

The Sub-decree on the EIA Process (11 August 1999) has delegated responsibility to the Ministry of Environment for establishing the EIA Guidelines but these have not yet been produced.

There are a number of obstacles to managing and enforcing EIA requirements in Cambodia. First, environmental assessment requirements are not well known and various sector ministries and project owners do not yet apply them. The authority of the Ministry of Environment to enforce the requirements appears to be limited by these circumstances. Another constraint is the limited capacity to conduct EIAs. There are few in-country specialists with experience in EIA reporting, and international consulting firms often have to be contracted, which is expensive and does not automatically increase local capacity to do this work.
The EIA principles of the donor agency (e.g. the ADB, World Bank, EU) and the host country should also be observed. The project proponent pays for the EIA, and a consultant is hired by the project proponent to conduct the EIA. The MOE reviews the documents with contribution of CDC and respective line ministries. As an example, ADB documentation (e.g. Lohani et al. 1997) describes EIA as a multi-step process by which a range of issues are taken into account to determine whether, or under what terms and conditions, a project should be undertaken. The screening process for the ADB categorizes loan projects into three groups, each of which requires a different level of environmental review (SEI and ADB, 2002):

- Category A: potentially serious environmental impacts, which require an EIA;
- Category B: potentially significant environmental impacts, which require an IEE but not an EIA;
- Category C: unlikely to have significant environmental impacts, which do not require an IEE or EIA.
ADB guidelines cover the environmental assessment requirements and environmental review procedures of the ADB (1993), environmental guidelines for selected infrastructure projects (1993), guidelines for incorporation of social dimensions into ADB operations (1993) and a handbook for incorporation of social dimensions into projects (1994).

3.2 STAKEHOLDER PERCEPTIONS AND ISSUES

The local review was somewhat limited and the results of the informal stakeholder consultations were not designed to be comprehensive. Instead they provide indications of key issues and concerns raised by relevant individuals and agencies involved in the EIA process at the implementation or institutional level. Results are derived from both direct communication with key stakeholder informants and the review of local and regional documents including the reports of the civil society.

Most stakeholders expressed a particular interest in the study topic, especially for improving the understanding of the impacts of built structures on the Tonle Sap in order to balance the social and economic development of Cambodia with the preservation of goods and services provided by the Tonle Sap ecosystem. Through numerous studies, awareness has increased of the potential negative impacts of built structures (especially large scale hydropower development) on the fisheries of the Tonle Sap, in particular by changing the river flow and its timing (e.g., Lamberts and Bonheur 2006). It is generally perceived that damaging the Tonle Sap ecosystem will in turn have negative social and economic impacts on communities dependent on the resources provided by this ecosystem.

Perception of impacts, issues and concerns may vary widely with the type of stakeholders (local stakeholders, civil society and government officials) interviewed. Key issues and concerns raised by stakeholders are summarised in the table below (Table 4).

Despite the increased emphasis on fisheries in development projects implemented in the Tonle Sap area, supported by the fisheries policy and EIA requirements set by donor agencies (especially the ADB and World Bank in Cambodia), the implementation and practice of built structure EIA shows insufficient consideration of fisheries issues, and no assessment has been carried out in accordance with the fisheries policy. The former ADB policy on fisheries states that the impacts of ADB projects on fisheries (notably the potential impacts of large-scale structures, especially dams) must be thoroughly assessed and eliminated or mitigated (ADB 1997).

Donor agencies and civil society call for increasing the scope of EIAs in order to address broader issues and the potential implications of project impacts at larger scales (esp. cumulative impacts). This contrasts with the general lack of financial and human resources in developing countries such as Cambodia. Beyond the issue of funding (by project proponent) and capacity building of local agencies, this review will show that there are also scientific issues in the definition of the scope (esp. boundaries) and priorities of EIAs (see also Section 4.3).
Table 4: Key issues and concerns per category of stakeholders

<table>
<thead>
<tr>
<th>Stakeholder category</th>
<th>Issues and concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local stakeholders, Civil society</td>
<td>• Negative impacts of built structures on fisheries tend to be underestimated</td>
</tr>
<tr>
<td></td>
<td>• The scope of EIAs is too narrowly defined or applied; in particular social impacts,</td>
</tr>
<tr>
<td></td>
<td>health and risk factors, and cumulative effects are generally not considered or</td>
</tr>
<tr>
<td></td>
<td>inadequately addressed</td>
</tr>
<tr>
<td></td>
<td>• Lack of scientific evidence, especially quantitative assessments of impacts on</td>
</tr>
<tr>
<td></td>
<td>fisheries</td>
</tr>
<tr>
<td></td>
<td>• Lack of participation of stakeholders in the EIA process; when stakeholders are</td>
</tr>
<tr>
<td></td>
<td>involved, there are concerns with regard to representativeness (referring to the</td>
</tr>
<tr>
<td></td>
<td>selection of stakeholders)</td>
</tr>
<tr>
<td>EIA implementers</td>
<td>• Scope of EIA is too broad</td>
</tr>
<tr>
<td></td>
<td>• Quantitative assessments cannot be achieved</td>
</tr>
<tr>
<td>Government agencies</td>
<td>• Scope of EIA is too broad (esp. perceived by MOE and MAFF officers) making</td>
</tr>
<tr>
<td></td>
<td>assessment of impacts difficult</td>
</tr>
<tr>
<td></td>
<td>• Lack of capacity to monitor and evaluate EIA implementation, analysis and results</td>
</tr>
<tr>
<td></td>
<td>• Inadequate guidance and consistent enforcement of the EIA process</td>
</tr>
<tr>
<td></td>
<td>• Inefficient, time-consuming, and costly EIAs relative to the benefits delivered</td>
</tr>
<tr>
<td></td>
<td>• MOE lacks resources to conduct EIA</td>
</tr>
<tr>
<td>Donor agencies</td>
<td>• Lack of institutional coordination</td>
</tr>
<tr>
<td></td>
<td>• Lack of political commitment</td>
</tr>
</tbody>
</table>

The various perspectives of key stakeholders highlight the need to balance the competing needs for socioeconomic development and especially the development of built structures, while preserving the Tonle Sap ecosystem goods and services, especially the benefits issued from its fisheries. This shows that positive and negative effects of built structure development urgently need to be clarified, assessed and valued.

However, the significance of EIAs is not fully recognised by many of the government ministries responsible for infrastructure or industrial and agricultural development, and environmental and social concerns are not always adequately considered in built structure project decision-making. The patron-client relationships often appear to be a more dominant force than the rule of law (SEI and ADB 2002). EIA is not sufficiently integrated with decision-making notably at the project preparation phase or with other supporting policy, planning and regulatory processes. At present there is a significant gap between public policy targets and laws and their implementation.
4. EVALUATION OF EIA REPORTS

This section first introduces the nature of the information collected and then provides the results of the evaluation in terms of the scope of EIAs, methods for impact assessment, results and management recommendations.

4.1 NATURE OF THE INFORMATION

EIA reports are scattered across various ministries, provincial and district government agencies, and with the project proponents. Access is generally difficult and very few reports are available within the MOE and other relevant ministries. EIAs are not systematically recorded and classified. As a result, a relatively small number of built structure EIA reports have been collected. Most EIA reports that are available refer to projects funded by international donors (grant or loan). No built structure Social Impact Assessments (SIAs) have been identified. The list of reviewed reports is indicated at the end of this report.

As a result of the small sample under review, the study had to broaden its initial emphasis on the evaluation of collected EIA reports in order to clarify why access to information was difficult. Possible reasons are that most EIA reports are not accessible and/or only few EIA projects have been carried out. Further stakeholder consultation showed that both were relevant for the following reasons:

• The Ministry of Environment does not access and record all EIA reports received by the various ministries and government agencies.
• Many projects are conducted with decision at the provincial level, sometimes without informing the head ministries, and local implementation of EIA is not fully controlled.
• The collection of reports from project proponents would require more time and resources to carry out field visits and further stakeholder consultations at the local level.
• A significant (but non-quantifiable) number of built structure projects do not provide EIAs. This is supported by MOE documentation (MOE 2000).
• The significance of EIA is not fully recognized by many government ministries responsible for infrastructure or industrial and agricultural development. The need for environmental assessment is still widely considered as secondary to the need for development.

In such a context, the study could not estimate the total number of existing EIAs and thus the representativeness of the study sample.

The scarcity of available EIA reports contrasts with the profusion of EIA guidelines and procedures disseminated worldwide, including specific guidelines for the Mekong River Basin and the Asia region. This reflects the discrepancy between the promotion of EIA by donor agencies and actual implementation of assessments.
4.2 PARTICIPATION OF STAKEHOLDERS IN THE PROCESS

Participation of stakeholders can occur during the EIA process and/or during the impact assessment (see Section 4.4). This section focuses on participation of stakeholders during the EIA process commonly called ‘Public participation’.

Participation of stakeholders is generally very limited and there is no systematic mechanism for the involvement of stakeholders, including communities, provincial authorities, local or international NGOs. This raises issues of transparency throughout the process, of communication and dissemination of information (in both Khmer and English) at local and national levels, and of allocation of resources to these activities.

The general conclusion drawn by stakeholders is that while the requirement for participation and consultation in EIAs is clearly stipulated it does not occur in practice in Cambodia. Again the practice of EIAs in Cambodia shows significant discrepancies with guideline requirements.

4.3 SCOPE OF EIA

Most built structure projects implemented in the Tonle Sap area that may have a significant direct effect on water resources have considered potential or actual effects on fisheries in their EIAs. This reflects the awareness and well-known importance of this sector in the economy of the country, in the livelihoods of at least 2 million people and in the environment, notably its aquatic resource diversity and productivity.

The appreciation of capture fisheries has increased with the increased awareness that the threats to Tonle Sap fisheries are not only coming from the sector itself but also and possibly mainly from the development of built structures (especially large-scale irrigation, hydropower and road construction) within the catchment and Mekong River Basin, in particular upstream of the Tonle Sap. For example, the planned proliferation of dams in the Upper Mekong presents high levels of risk of irreversible negative impacts on endemic and commercially valuable fish biodiversity. In the very short-term, it is likely that the effect of proposed irrigation projects in the Tonle Sap ecosystem will be more severe than the effect of expected changes in seasonal fluctuations in lake levels from the impact of hydropower projects on the Mekong River and its tributaries (SEI and ADB 2002).

Regarding temporal and spatial scales, the scope of EIA is initially project-specific and it is assumed that the project needs to assess and manage its immediate (e.g. during construction) or short-term impacts within the immediate area (e.g. the command area of an irrigation scheme). While longer and larger scales are recommended - for example, the ADB (2004) indicates that long-term impacts should be considered prior to expanding irrigation and hydroelectric projects - they have not been considered by local EIAs. Strategic Environmental Assessments (SEA) and Cumulative Effects Assessments (CEA) would address these issues as they are conducted at catchment and river basin levels, and often have a longer-term perspective. A major SEA has been identified and recently conducted for the Mekong (SEI and ADB 2002).
4.4 METHODOLOGY FOR IMPACT ASSESSMENT

4.4.1 Coverage of fisheries aspects and scope of fisheries assessments

Coverage of fisheries aspects in EIA reports under study has been evaluated on the basis of the criteria (or ‘situational variables’ in the baseline situation) indicated in the table below (Table 5).

Table 5. Coverage of fisheries impact assessments

<table>
<thead>
<tr>
<th>Fisheries aspect and scale of assessment</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Physical habitat</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>In most EIA reports</td>
</tr>
<tr>
<td>• Ecology of fisheries production</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>In most EIA reports</td>
</tr>
<tr>
<td>• Biodiversity</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Focus on fish species diversity</td>
</tr>
<tr>
<td>• Ecological integrity</td>
<td>Very Low</td>
</tr>
<tr>
<td></td>
<td>Only a few components of the ecosystem considered</td>
</tr>
<tr>
<td>• Exploitation of fisheries</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Focus on fishing effort</td>
</tr>
<tr>
<td>• Livelihood of fishers and fishing communities</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Focus on a few livelihood assets and functions</td>
</tr>
<tr>
<td>• Institutional arrangements</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Not much considered</td>
</tr>
<tr>
<td>• Management of fisheries</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Not much considered</td>
</tr>
<tr>
<td>• Consideration of other key relevant sectors</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Most EIA are sectoral</td>
</tr>
<tr>
<td>• Spatial scales</td>
<td>Very Low</td>
</tr>
<tr>
<td></td>
<td>Focus on project boundaries</td>
</tr>
<tr>
<td>• Temporal scales</td>
<td>Very Low</td>
</tr>
<tr>
<td></td>
<td>Focus on short-term impacts</td>
</tr>
</tbody>
</table>

The coverage of fisheries impact assessments tends to be sectoral and within project boundaries, and it tends to have a general focus on biophysical changes in the short-term: species diversity, hydrology, ecology and aquatic resource production. It must be noted that only a few EIAs mention aquatic resources other than fish, e.g. crab, shrimps, snails, aquatic plants, etc. despite their potential importance as a source of food for livelihoods, particularly for the poorer.

Socioeconomic and livelihood aspects are not systematically addressed and there are wide variations in EIA coverage. Overall, despite increased awareness and knowledge of the connection between biophysical and socioeconomic systems, socioeconomic effects are insufficiently considered and analysed in most EIA reports. Consideration of other sectors related to built structure development (esp. irrigation, hydropower, road construction) is limited or absent.

In terms of spatial scale, fisheries assessments are often limited to specific water bodies, essentially the main river(s) or stream(s), the Great Lake and the reservoirs for dam irrigation schemes. This provides a partial estimation of fisheries (esp. production and
productivity) in the project area. Consideration of all major water bodies in the catchment, upstream and downstream of the built structure would provide a more accurate estimation of fisheries production and its significance in livelihoods at the various locations.

Assessments focus on short-term impacts and neglect longer-term effects of built structures on the ecosystem and fisheries dependent livelihoods. As a result, potential trade-offs between immediate and long-term costs and benefits are not made explicit.

4.4.2 Method for impact assessment

Checklists of impacts, with or without their estimated significance per sector or per impact category, are most commonly used. The comparison of the situation before and after the project, prediction of impacts or ex-post impact assessment, is also frequently invoked. However, since most reports do not describe the methodological steps leading to results it has generally been difficult to identify the methodological rationale underlying impact assessments.

The description of the baseline (or pre-project) situation is often a major part of the assessment. A comprehensive evaluation of project impacts requires a thorough understanding of the situational variables for the pre-project situation and how these have evolved over time. However, in most cases, there is very little collection of primary data – and none in many cases - and recycling old data and information is common. Collection of primary data is usually carried out to larger extent in donor funded project EIAs, such as Stung Chinit and Northwest Irrigation projects.

The lack of scientific data and of baseline information in particular are often mentioned as major constraints to assessment, especially where the impact assessment method is based on a comparison of the situation before (baseline) and after the project (predicted scenario). Apart from physical changes that can be directly observed in the field, the main source of information may need to be the recall of individual or group interview respondents (see also Lorenzen et al. 2005). Participation of stakeholders in the assessment, e.g. in rapid and participatory appraisals, is generally limited yet higher than in EIA processes (see Section 4.2).

It may also be possible to compare the characteristics of the project and the impacted area with other similar projects for which fisheries impacts have been considered, or with comparable areas without irrigation development.

4.5 Assessment Results

Evaluation of assessment results has been based on the description and analysis of the baseline situation (before implementation of the project), and the identification and prediction of possible changes or evaluation of actual changes.

4.5.1 Baseline situation

The description and assessment of the baseline situation should provide sufficient and adequate information to understand the potential impacts of built structures and causation pathways. This should support later assessment and discrimination of built structure impacts from other changes. The baseline situation is essentially descriptive.
and based on secondary information. Some EIAs have carried out collection of primary data for specific information in the project area. Notably due to a lack of adequate monitoring of the state of these floodplain systems, estimation of fisheries production and indicators of productivity are “incomplete at best and very problematic in most instances” (Lamberts and Bonheur 2006).

Baseline situations usually refer to the hydrological importance of the Tonle Sap system, its uniqueness and exceptional fisheries productivity. The Tonle Sap is among the most productive fishery resources in the world, and is important in terms of biodiversity, productivity and its role in livelihoods. Because this high fisheries productivity is strongly related to the specific hydrological patterns (timing of the flow, specific seasonal and daily fluctuations, flow reversal, etc.) of the Tonle Sap, these fisheries are sensitive to changes not only within the catchment but also in the Mekong Basin. The Mekong mainstream, tributaries and associated lakes are characterized by high fish biodiversity, including a substantial number of endemic species.

Increasing human impacts in floodplain areas, including various built structures (especially hydropower dams upstream on the Mekong), has led to flow modification, floodplain habitat alteration or destruction and water pollution. These factors have been defined as the three main causes for loss of freshwater biodiversity worldwide (e.g. Kruskopf in press).

The socioeconomic situation and human well-being in the Tonle Sap area are strongly connected to natural resources and other ecosystem services due to the majority of livelihoods directly and largely dependent on natural resources. Rice cultivation and fishing are the most important occupations in the Tonle Sap area (Keskinen 2003). They are supplemented by a variety of other livelihood activities of which many are directly dependent on natural resources, such as firewood collection and hunting. Therefore, a high number of poor people remain vulnerable to environmental change because of their dependence on natural resources and the lack of livelihood alternatives.

Most EIA reports do not refer to indicators of sensitivity, vulnerability and resilience of the ecosystem and livelihoods in respective areas - simply stated, a resilient ecosystem is likely to be more resistant (and thus less vulnerable) to natural or human disturbances. Notably, while the significance and importance of fisheries and the Tonle Sap ecosystem are largely recognised and documented it is not always possible to assess the degree of sensitivity of specific locations in the ecosystem (e.g. built structure projects), apart from general knowledge of sensitivity to changes in environmental flows and biodiversity.

**4.5.2 Identification of impacts of built structures on fisheries**

Impacts of built structures on fisheries can be direct or indirect; they may affect the ecological characteristics of the Tonle Sap fisheries, and/or the livelihoods and socioeconomic and institutional baseline situation.
Table 6: List of direct and indirect impacts mentioned in EIA reports

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Impacts indicated in EIA reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct impacts</td>
<td>• Blockage or impedance of fish migration</td>
</tr>
<tr>
<td></td>
<td>• Changes in river flow</td>
</tr>
<tr>
<td></td>
<td>• Changes in aquatic habitats</td>
</tr>
<tr>
<td></td>
<td>• Disruption of connectivity between aquatic habitats</td>
</tr>
<tr>
<td></td>
<td>• Changes in water quality (nutrients, agrochemicals, metals, etc.) affecting the primary productivity, fish production and species composition</td>
</tr>
<tr>
<td></td>
<td>• Distribution and transportation of sediment</td>
</tr>
<tr>
<td></td>
<td>• Distribution and transportation of nutrients</td>
</tr>
<tr>
<td>Indirect impacts</td>
<td>• Degradation of water quality</td>
</tr>
<tr>
<td></td>
<td>• Land use changes</td>
</tr>
<tr>
<td></td>
<td>• Distribution and transportation of sediment</td>
</tr>
<tr>
<td></td>
<td>• Distribution and transportation of nutrient inputs, especially through changes in the flood pulse</td>
</tr>
<tr>
<td></td>
<td>• Changes in access to wetlands and water bodies</td>
</tr>
</tbody>
</table>

Blockage and impedance of fish migration are the most commonly identified impacts of built structures on fisheries. However, the migratory characteristics of fish species in the impacted area are rarely identified, with the notable exception of the Stung Chinit irrigation project. The Stung Chinit EIA indicates that fish populations in the project area are both migratory and non-migratory and that estimated impacts will likely be positive on non-migratory fish (due to increased availability of water) and possibly negative on migratory fish (due to impedance of migration).

The availability and quality of aquatic habitats and the connectivity between them may result from changes in river and stream flows and from land use changes. Disrupted connectivity affects the ability of aquatic organisms to move between riverine areas. The transfer of terrestrial organic matter to the aquatic phase through the flood pulse involves a variety of pathways, including ingestion and digestion by aquatic organisms, bacterial decomposition, biofilm formation and metabolism, and leaching of photosynthesis products (Lambert and Bonheur 2006).

In Stung Chinit, two major environmental concerns associated with the project are the impacts of restored weirs on migratory fish and the impacts of pesticides and fertilizers in the project area. Pesticides are of concern not only because of their impacts on the health of farmers in the project area who work in the fields and consume the rice but also because of the impact on downstream rice-fish paddies and on livestock and waterfowl. Another threat is increased use of fertilizers and the resultant runoff into the lake and its tributaries, poisoning the fish and the people who live on them.

Impacts on livelihoods are usually deduced from changes in fisheries productivity. However, even where productivity is maintained, built structures (esp. roads, dams) may change the pattern of access to water bodies and although rarely considered, consequences on livelihoods may be more negative than productivity changes. In turn, improved access due, for example, to reduced incidence of flooding, improved road networks and subsequent increased human habitation caused by new infrastructure in floodplain areas, will lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road construction. If negative, both
types of change may act to worsen the absolute position of poor people in terms of poverty, vulnerability and equity.

4.5.3 Predictive and analytical capabilities

The quality and accuracy of impact assessments are highly variable and most results on the impacts of built structures on fisheries are essentially descriptive. Most assessments focus on discrete factors or a few components of fisheries, especially fish migration and fish species diversity. Changes in connectivity between aquatic habitats and water quality and other characteristics (composition, temperature, etc.) are more difficult to assess.

Table 7: Identification of predicted or evaluated variables

<table>
<thead>
<tr>
<th>Category of variable</th>
<th>Predicted or evaluated variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrological regime</td>
<td>Extent of water withdrawal and depletion</td>
</tr>
<tr>
<td></td>
<td>Total flow changes</td>
</tr>
<tr>
<td>Aquatic habitats</td>
<td>Extent of flooded area</td>
</tr>
<tr>
<td>Connectivity between aquatic habitats</td>
<td>Some qualitative but no quantitative estimation</td>
</tr>
<tr>
<td>Fisheries production and productivity</td>
<td>For a few water bodies:</td>
</tr>
<tr>
<td></td>
<td>- Reservoir: potential production through stock enhancement or aquaculture</td>
</tr>
<tr>
<td></td>
<td>- Floodplain: no quantification</td>
</tr>
<tr>
<td></td>
<td>- Lake: no quantification</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Fish species diversity: identification of species before and after the project</td>
</tr>
<tr>
<td>Water quality changes</td>
<td>Composition</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
</tr>
<tr>
<td>Socioeconomic</td>
<td>Economic contribution of fisheries sector</td>
</tr>
<tr>
<td>Livelihoods</td>
<td>Loss of livelihood functions</td>
</tr>
<tr>
<td></td>
<td>Income changes</td>
</tr>
<tr>
<td>Institutions</td>
<td>Changes in institutional arrangements</td>
</tr>
</tbody>
</table>

Assessments of the influence of built structures on fisheries tend to focus on the impacts as outcomes, with limited information on why they may arise as predicted, and causal explanations of impact pathways is usually lacking. When considering social and economic outcomes, the number of possible pathways that could be the root cause is even greater (see also Lorenzen, Smith et al. 2005). The lack of causal explanations also has implications for the identification of mitigation measures (see Section 4.6.1).

Most assessments of built structure impacts on fisheries are essentially descriptive and lack analytical and predictive capabilities. This leads to weak interpretations, and conclusions tend to be made quickly, with a high degree of subjectivity and strong reliance on expert judgement. While using expert judgement is often required at various degrees in data-scarce contexts, built structure impact assessments are not sufficiently transparent and/or detailed to allow evaluation of the degree of expert judgement. This leads to excessive use of vague qualitative statements such as ‘slight eventuality’, ‘no major impact’ without indication of their rationale and justification for such results.
Local literature indicates that EIA results are difficult to translate and weigh against the quantified net benefit of the built structure project, essentially provided by cost-benefit analysis (CBA) of built structure projects. The EIAs considered do no attempt to value environmental, social, health and other factors, and results cannot feed into CBA methodology and practice. This is critical given the central role that CBA plays in decisions about whether or not to implement a proposed built structure project (e.g. McKenney 1999 on dam projects).

4.5.4 Degree of integration across disciplines and across sectors
The degree of integration has been evaluated across disciplines (hydrology, ecology, socioeconomics, livelihoods, governance) and across sectors (fisheries and key relevant sectors, e.g. agriculture in case the of irrigation projects). Fisheries are strongly dependent on interactions with other sectors especially agriculture and all water related activities. This is especially evident in the Tonle Sap where the majority of livelihoods rely on water-related natural resources (e.g. Keskinen 2003, Nikula 2005).

Built structure EIAs mostly assess impacts on discriminate characteristics and variables of fisheries and they tend to neglect subsequent or simultaneous changes that originate from interaction between variables. This is an issue for all EIAs since the environment is traditionally divided into manageable components or categories (e.g. water quality, biodiversity, soil fertility, air quality) and such clustering underlies common checklist frameworks.

However, such EIA frameworks cannot encompass ecological processes such as floodplain processes as these can be affected by changes occurring in different components of an EIA (e.g. soil fertility, surface water quality and level, and groundwater dynamics). As a result, effects of built structures on the Tonle Sap floodplain are partially or inadequately assessed except in rare cases where potential cumulative effects between EIA sectors have been considered (Lamberts and Bonheur 2006). The authors conclude that this leads to incomplete and inaccurate assessments of the impact of man-made flow changes.

In particular, Lambert and Bonheur (2006) demonstrate that EIA methodological frameworks have been superseded by cross-cutting patterns such as the flood pulse. They propose a framework to show the variety of environmental effects on fisheries across EIA components in contrast to the important aspects of the aquatic ecosystem and fisheries omitted by other EIA frameworks. Another potential bias is that the effects of a project on each component may be small, but the overall cross-cutting damage to the flood pulse may be significant.

While the importance of the biodiversity and productivity of the Tonle Sap ecosystem has been recognised and demonstrated, the development and application of such integrative processes is a prerequisite for effective built structure EIA with regard to the Tonle Sap fisheries. Ecologists suggest developing ecosystem impact assessments (see also Section 5.3) especially where floodplains are concerned.
4.6 MANAGEMENT RECOMMENDATIONS

The evaluation of management recommendations involves analysis of the mitigation and enhancement measures identified and their utility and adequacy.

4.6.1 Identification of mitigation and enhancement measures

To compensate for the effects of built structures on fisheries, mitigation and enhancement measures have been proposed by EIA studies. A relatively wide range of mitigation and enhancement measures are proposed for the large variety of built structures, and it is likely that the review of the EIA sample does not provide a comprehensive list of existing measures. These have been grouped in relation to the mechanisms or principles of change they propose to act upon (Table 8).

Table 8: Identification of mitigation and enhancement measures

<table>
<thead>
<tr>
<th>Category of measure</th>
<th>Measures identified in EIA reports</th>
</tr>
</thead>
</table>
| Mitigation measures | • Technical and engineering measures to ensure fish migration routes through structures such as fish passes and culverts (Lim and Lek 2005)  
• Minimise loss and degradation of flooded areas  
• Establish minimum dry season flow  
• Protect fisheries and habitats by establishing protected areas  
• Convert borrow pits (during road construction) into fishponds or ponds with water for gardening  
• Strengthen management institutions, and develop monitoring, forecasting and information dissemination |
| Enhancement measures | • Stock-enhancement  
• Aquaculture  
• Rice-fish farming |

However, despite their potential variety, most management recommendations target two main means for action: the mitigation of river fish migration and the enhancement of fisheries production in reservoirs (for dam irrigation and hydropower schemes) and fish ponds, and to a lesser extent the establishment of minimum river flows.

To mitigate the impact on migratory fish, a fish pass structure will be constructed at the Stung Chinit weir with a minimum slope allowing fish to migrate upstream. The Stung Chinit project has also proposed establishing a minimum flow. In the absence of quantitative studies, minimum environmental flow releases of at least 10% of the mean monthly flow have been recommended to maintain healthy aquatic habitats in temperate countries. Given the diverse nature of tropical fish faunas and the generally higher temperatures, this may not be sufficient for the Stung Chinit. However, much of the water diverted from the river channel will be distributed throughout the same area through paddies, secondary and tertiary canals and drains, and some will return to the river course through this system (Lim and Lek 2005).
4.6.2 Utility and adequacy of management measures

Utility and adequacy of mitigation measures is highly variable and can only be evaluated at a general level. There is not much consideration of the location of projects and their design at the planning stage since late remedial action (at the implementation stage) is generally not feasible. Cost efficiency of management measures cannot be evaluated in this study. EIA estimates should be incorporated into the overall CBA of the project. The costs of mitigation measures, in particular, should be included in overall project costs.

In general, management measures are recommended without much consideration of the whole project and potential trade-offs between different management and development options, notably the difficult balance and complex understanding of both positive and negative impacts of built structure development. “The lack of awareness of the presence and significance of a floodplain and the inextricable unity between floodplains and their main water bodies, combined with flawed impact assessment practices, lead decision makers to believe that mitigation of negative impacts on floodplain ecosystems is possible.” (Lambert and Bonheur 2006).

While standard practice in ADB activities, individual projects must be considered in the larger context within which the intervention is undertaken. Future planning should examine the cumulative impacts of individual interventions in view of overall resource management. For example, the individual and cumulative impacts of projects involving irrigation, water resource use, and rural development can be accounted for through integrated basin planning (SEI and ADB 2002) (see also Section 5.3 and 5.4).

5. DISCUSSION

The discussion aims to provide insights and recommendations for enhancing local EIAs in light of existing knowledge available locally and worldwide. Comments are made within the scope of the review, with consideration of its limitations due to both the difficulty of accessing information and the short duration of the study.

5.1 LACK OF DATA AND INFORMATION

As in many developing countries, the lack of data and information is strongly felt and it is a common constraint for research studies, especially for integrated fisheries assessments and quantitative assessment results, since these are generally resource and time consuming. While it is not feasible and practical to establish a comprehensive collection of baseline information for every project, improved data collection systems are needed, in particular the recording of all built structure projects (date, type, location, etc.) and key fisheries characteristics (gears used, main livelihood characteristics of fishers) at district, provincial and national levels.

Most EIAs do not provide any alternative to the scarcity of information such as, for example, the search for other sources of information, i.e. comparative studies, strategic analyses, and stakeholders’ perceptions and knowledge (including local ecological knowledge, e.g. Baird, 2003 and Poulsen, 2003). In addition, the use of knowledge, especially local/traditional knowledge and scientific knowledge, are not optimised. While knowledge needs to increase worldwide, especially in the quantification of the magnitude
of impacts (see Kruskopf, in press), significant literature now exists on the influence of certain built structures on aquatic ecosystems and fisheries, especially for large-scale dam irrigation schemes. Generic knowledge such as the ecology of fisheries, ecosystem functioning, and fisheries functions in livelihoods can be transferred and extrapolated for use in specific built structure EIAs (see further development in Section 5.3).

Therefore, the lack of data and information tends to be overemphasised as a reason for partial impact assessments that target official agreement for project implementation. Various ways for improving the accuracy and predictive capability of results have been identified. Essentially, beyond improvement of data collection systems, EIAs should enhance the use of, or identify the need to develop, methodologies and processes that are able to adapt to local conditions and optimise the use of existing knowledge and available data.

5.2 SCOPE OF ENVIRONMENTAL ASSESSMENTS

Despite the recognition of the need for inter-sectoral and inter-institutional coordination and partnership, most EIAs are essentially sectoral and project-focused. Scientific literature on the impact of human development on fisheries in Cambodia (e.g. Lambert and Bonheur 2006) shows that EIAs insufficiently cover adequate spatial scales, especially the necessary trade-offs and potential conflicts between the upstream and downstream effects of built structures on fisheries.

However, in practice, EIA studies often face difficulties in defining the boundaries of the study area. The critical need to cover upstream and downstream areas requires a catchment perspective. At the river basin level identification of the geographical scope (Upper and Lower Mekong River Basin) would be even more complex due to potential regional effects, especially trans-boundary effects between countries, such as effects on fish migration, sediment transportation and hydrological changes. The planned proliferation of dams in this sub-region presents a high level of risk of irreversible negative impacts on endemic and commercially valuable fish biodiversity. Environmental assessments conducted in the Lower Mekong Basin have mainly focused on pollution problems but they have not been used for assessment of macro-level issues such as land use conversion, soil erosion, catchment area treatment, illegal resettlement, conflicting uses of natural resources, etc. (SEI and ADB 2002).

There is an urgent need to develop and use frameworks that can exploit the results of project environmental assessments in sectoral and regional approaches such as SEA and CEA. This is even more critical in the case of the Tonle Sap Basin (including the river, lake and associated floodplain) where extensive studies show the connections between river flow patterns and fisheries production.
5.3 ASSESSMENT OF THE IMPACTS OF BUILT STRUCTURES ON FISHERIES

The complex and dynamic ecosystem of the Tonle Sap and its fisheries (and respective livelihoods) may not be understood and adequately evaluated by existing impact assessment. Beyond the lack of information and knowledge developed in Section 5.2, the review has highlighted the potential for improvement in increased exploitation of available knowledge (locally and worldwide) and use of adequate impact assessment methods, especially those that integrate multiple disciplines and consider interactions and linkages with key relevant sectors and scales.

As introduced in Section 5.1, the potential for increased use of local and worldwide knowledge is generally neglected. Enhanced use of local knowledge including traditional knowledge involves choosing the appropriate form and degree of stakeholder participation in impact assessments. Participation may also support the resolution of conflicting issues and a commitment to solving these issues (see also Section 5.4.2). In turn, insufficient participation and use of local knowledge could have strong implications for the quality of impact assessments (especially where affected people have not been adequately consulted) and the sustainability of management measures derived from assessment results.

While key gaps have been identified in relation to built structure impacts on fisheries (see also Kruskopf in press), the worldwide knowledge base of riverine and floodplain ecosystems has significantly increased and improved the understanding of complex ecological processes. Beyond increased knowledge of aquatic ecosystems, this knowledge provides the basis for comparative analysis, e.g. cross-check comparisons between local estimates and average productions in comparable ecosystems or water bodies. It also allows the use of appropriate assessment methods and tools, such as: i) modelling tools that may support quantification of some processes and identification of impact scenarios, and ii) methods and approaches that are able to generate information in contexts of data scarcity and uncertainty such as precautionary approaches.

Traditionally, EIAs have considered air quality, water resources, wildlife and human communities as separate entities for analysis. This separation of resources and sectors has neglected linkages with key relevant sectors, e.g. agriculture for dam irrigation schemes, transport and tourism for harbour construction, and has omitted or obscured many cumulative effects (e.g. Lambert and Bonheur 2006). EIA methodologies predominantly draw from checklist frameworks, and this review has highlighted the need for more integrative frameworks. While checklists of potential effects of built structures may enhance coverage of fisheries aspects (and usually the respective relative weight of the impact) they are likely to provide discrete evaluations that neglect cause-effect relationships and other interactions between factors of influence, e.g. feed-back effects.

The resulting description of impacts tends to be a multi-sectoral but static 'snapshot' that does not reflect longer-term impacts and undervalues the chain of impact causality. Thus, it may miss possible management actions that may significantly change the outcome of a built structure development (Nguyen-Khoa et al. 2005). Recognition of the interconnectedness of land, water and human resources has driven several developed countries to undertake ecosystem or watershed approaches to environmental protection. The ecosystem approach explicitly addresses the ecological interactions and processes necessary to sustain ecosystem composition, structure and function. Ecosystem
assessments address the full spectrum of indicators of ecological conditions ranging from the genetic to species to local ecosystem to regional ecosystem levels.

Better linkages with larger scales can be exploited through the use of natural and not just project boundaries. This leads to ecological regions, such as watersheds and eco-regions, that encompass ecosystem functioning and landscape-scale phenomena such as habitat fragmentation and that address resource or ecosystem sustainability. Increasingly, ecologists promote ecosystem approaches in order to provide the broad regional perspective needed in regional planning and the holistic thinking needed for impact assessment of fisheries and especially to address key principles of cumulative effects (SEI and ADB 2002).

5.4 MANAGEMENT MEASURES

5.4.1 Utility and adequacy of recommended measures

The management of built structures for the mitigation or enhancement of fisheries generally focuses on technical and engineering measures (esp. fish passes, fish ladders) and stock-enhancement in reservoirs for dam irrigation projects.

Often mitigation and enhancement measures are the end-product of built structure EIAs and neglect potentially effective interventions throughout the causality chain of impact, from its root causes to outcomes. As indicated in Section 5.3 on assessment, results do not provide sufficient information on cause-effect relationships and hence they do not support identification of management measures throughout key pathways of impacts. In addition, where quantifiable, the environmental, social, health and other impacts that cannot be mitigated should be added to total project costs.

Management measures are often afterthoughts, and changes in the design may not be possible. This constraint is particularly critical with technical and engineering measures. Also, proposed management measures omit or fail to adequately address local constraints to implementation, such as lack of resources or the need for institutional reforms (Nguyen-Khoa et al. 2005). For example, the implementation of built structures may offer a ‘window of opportunity’ to introduce institutional or other changes that can mitigate the problem.

5.4.2 Analysis of trade-offs and support for decision-making

Adequate design, location and management decisions with regard to built structures require appropriate analytical and decision-making processes. Competing demands are often raised by the needs for infrastructure development and the overall pressure for rapid socioeconomic development (short-term objectives) to the likely cost to the environment and natural resources (long-term objectives of sustainability). Within the fisheries sector, tensions may arise between the need for increased fisheries production and potential development of aquaculture and the conservation of aquatic resources requiring protected areas.

Present built structure EIAs in Cambodia would better support evaluation of these trade-offs if they made explicit the weight of the different environmental and socioeconomic factors and management options. This implies valuing environmental services and social
preferences for the present and future through identification of trends and possible scenarios of built structure development and consequent changes in fisheries. In addition, participation of stakeholders in the selection of the most desirable or acceptable options is likely to improve the sustainability of implementation of management measures.

The local capacity and coordination between relevant agencies, especially in the ministries and in particular the MOE, needs to be enhanced in order to improve the holistic understanding of the development of built structures and their potential effects on fisheries production, biodiversity and livelihoods. At present, due to lack of information, awareness and experience, the MOE may lack critical judgement and necessary authority in the evaluation of built structure EIA reports.

5.5 RECOMMENDATIONS FOR TONLE SAP BUILT STRUCTURES EIAs WITH REGARDS TO FISHERIES

In accordance with the results of the review, recommendations are made separately for the EIA process and for the assessment of built structure impacts on Tonle Sap fisheries.

5.5.1 Built structure EIA process

- Ensure knowledge of Strategic Environmental Assessments (SEA) and Cumulative Effect Assessments (CEA) conducted in respective catchments, sub-basins (Upper or Lower Mekong) and river basins.

- Adopt a holistic approach to defining EIA scope: define spatial and time scales and key linkages between built structures impacts on fisheries and other relevant main sectors.

- Increase participation of stakeholders: strengthen public consultation in particular.

- Learning and adaptation: iteratively improve the process and integrate lessons back into the EIA process during implementation and for further EIA.

- Increase transparency of the built structure EIA process.

- Increase coordination between relevant government agencies: need for a shared commitment throughout project planning and implementation.

- Enhance and support political commitment of the Government of Cambodia.

5.5.2 Assessment of impacts on fisheries

- Adopt a holistic approach to defining the scope of fisheries assessment: to identify key issues and key interactions with relevant sectors.
• Carry out an integrated impact assessment: to understand and assess the whole fishery system and interactions, e.g. the ecosystem approach, especially for complex ecosystems such as the Tonle Sap.

• Use and develop methods (and enhancement of their use) that can deal with lack of data and scientific uncertainty

• Increase and optimize the use of available knowledge, including stakeholder knowledge and international scientific knowledge. The significant knowledge of fisheries ecology and socioeconomy in floodplain ecosystems can be better exploited.

• Promote the production and exchange of data on built structures and fisheries: design and implement simple data collection systems.

• Enhance participation of stakeholders in fisheries impact assessments.

• Improve valuation of Tonle Sap fisheries and respective ecosystem services.

• Adopt a holistic and integrated approach to identifying management measures and provide measures that are both feasible and efficient.

• Assess trade-offs between costs (including social and environmental) and benefits of built structure projects. Ultimately, this aims to inform CBA to support decision-making related to built structure development.

• Produce assessment and management results that can feed into regional assessment frameworks such as Strategic Environmental Assessment (SEA) and Cumulative Effect Assessment (CEA).

• Develop specific guidelines on assessment and management of impacts of built structures on Mekong fisheries.

6. CONCLUSION

The review of local built structure project EIAs with regard to the Tonle Sap fisheries has highlighted key constraints and limitations to performing impact assessments and processes. Limitations have been identified at various levels: some are specific to the scope and assessment of built structure EIAs, while others relate more generally to the EIA process conducted in Cambodia. The relatively short duration of this review did not allow either in-depth analysis or broad coverage of built structures because of the poor availability of information and difficulty in accessing local EIA reports. Strengthened stakeholder consultation and increased searches in relevant government agencies are critically needed.

The review shows that built structures are likely to have negative impacts on the Tonle Sap fisheries but they may also have positive impacts. Effects may originate from the built structure itself but also from the operational system (e.g. irrigation) and – although
less considered in the EIAs under study - from the effects of subsequent economic development in the area (potential population increases, development of other smaller structures, etc.) triggered by the implementation of built structures, especially the construction of roads, dams and harbours. The principal negative effects arise from changes in river and tributary flows, the connectivity among aquatic habitats, and the degradation of water quality. Positive effects may result from increased production in irrigation reservoirs and decreased fishing efforts resulting from new livelihood alternatives brought by the built structure.

The review of EIA has highlighted the need for integrated assessment and management methods that can encompass the fishery system and key linkages with relevant sectors, especially farming for irrigation schemes. Management needs to assess and possibly quantify negative but also positive impacts in order to balance effects and analyse respective trade-offs. This would clarify the range of options available to stakeholders and support the decision- and policy-making relate to built structure development.

While increased integration and a holistic approach to the fishery system is required, EIA methods need to be feasible and appropriate to local resources, especially in balancing the accuracy of prediction that requires significant resources with achievable outputs and outcomes. This may be resolved in a two-speed process providing practical EIAs that assess key impacts on Tonle Sap fisheries while progressing towards more complex integrated assessments of fisheries impacts in the context of built structure development in the whole Tonle Sap ecosystem.

Increased transparency of EIA processes is urgently required, and making EIA reports widely available would be a useful first step. Public participation is needed to facilitate constructive debate, initiate resolution of difficult trade-offs and support stakeholder consensus on development choices. Increased local capacity in the EIA process should support improved monitoring of EIAs and exchange of information, as well as improved influence and authority of the MOE with the support of relevant ministries (esp. the MAFF, MOWRAM and MIME) to preserve the Tonle Sap aquatic ecosystem and fisheries.

In conclusion, improvements in EIA process and methods have a high potential for optimising the benefits of built structure projects while sustaining the aquatic ecosystem and fisheries of the Tonle Sap. This critically requires integrated impact assessment methods, enhanced participation of stakeholders, increased transparency of the process and political commitment for the institutional uptake of EIA procedures in a long-lasting way.
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ANNEX 1: List of projects that require IEE or EIA

Source: Annex of sub-decree No 72 ANRK.BK, 11 August 1999

Industry
I. Foods, Drinks, Tobacco
II. Leather tanning, Garments and Textiles
III. Wooden production
IV. Paper
V. Plastic, Rubber and Chemicals
VI. Mining production other than metal
VII. Metal industries
VIII. Metal processing industries
IX. Other industries
X. Agriculture
XI. Tourism
XII. Infrastructures

Foods, Drinks, Tobacco
- Food processing and canning > 500 tons/year
- All fruit drink manufacturing > 1,500 liters/day
- Fruit manufacturing > 500 tons/year
- Orange juice manufacturing All sizes
- Wine manufacturing All sizes
- Alcohol and beer breweries All sizes
- Water supply > 10,000 users
- Tobacco manufacturing > 10,000 boxes/day
- Tobacco leaf processing > 350 tons/year
- Sugar refineries > 3,000 tons/year
- Rice and cereal grains mills > 3,000 tons/year
- Fish, soy bean, chilli, tomato sources > 500,000 liters/year

Leather tanning, Garments and Textiles
- Textile and dyeing factories All sizes
- Garment, washing, printing, dyeing All sizes
- Leather tanning and glue All sizes
- Sponge rubber factories All sizes

Paper
- Paper factories All sizes
- Pulp and paper processing All sizes

Plastic, Rubber and Chemicals
- Plastic factories All sizes
- Tire factories > 500 tons/year
- Rubber factories > 1,000 tons/year
- Battery industries All sizes
- Chemical production industries All sizes
- Chemical fertiliser plants > 10,000 tons/year
- Pesticide industries All sizes
- Painting manufacturing All sizes
- Fuel chemicals All sizes
- Liquid powder, solid soaps manufacturing All sizes
### Mining production other than metal
- Cement industries: All sizes
- Oil refineries: All sizes
- Gas factories: All sizes
- Construction of oil and gas pipelines: > 2 km
- Oil and gas separation, storage facilities: > 1,000,000 liters
- Fuel stations: > 20,000 liters
- Mining: All sizes
- Glass and bottle factories: All sizes
- Bricks, roofing tile manufacturing: > 150,000 pieces/month
- Flooring tile manufacturing: > 90,000 pieces/month
- Calcium carbide plants: All sizes
- Producing of construction materials: > 900 tons/month
- Motor oil manufacturing: All sizes
- Petroleum study research: All sizes

### Metal industries
- Mechanical industries: All sizes
- Mechanical storage factories: All sizes
- Mechanical and shipyard enterprises: All sizes

### Metal processing industries
- Manufacturing of barbed wires, nets, etc: > 300 tons/month
- Steel, iron, aluminium mills: All sizes
- All kinds of smelting: All sizes

### Other industries
- Waste processing, burning: All sizes
- Waste water treatment plants: All sizes
- Power plants: > 5 MW
- Hydropower: > 1 MW
- Cotton manufacturing: > 15 tons/month
- Animal food processing: > 10,000 tons/year

### Agriculture
- Forest concessions: > 10,000 ha
- Logging: > 500 ha
- Land covered by forest: > 500 ha
- Agriculture and agro-industrial land: > 10,000 ha
- Flooded and coastal forests: All sizes
- Irrigation systems: > 5,000 ha
- Drainage systems: > 5,000 ha
- Fishing ports: All sizes

### Tourism
- Tourism areas: > 50 ha
- Golf courses: > 18 holes
Infrastructure

- Urbanization development
- Industrial zones
- Construction of bridge-roads
- Buildings
- Restaurants
- Hotels
- Hotels adjacent to coastal areas
- National road construction
- Railway construction
- Port construction
- Airport construction
- Dredging
- Dumping sites

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>All sizes</th>
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<tr>
<td>Urbanization development</td>
<td>All sizes</td>
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<tr>
<td>Industrial zones</td>
<td>All sizes</td>
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<tr>
<td>Construction of bridge-roads</td>
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<td>Buildings</td>
<td>Height &gt; 12 m or floor &gt; 8,000 m2</td>
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<td>&gt; 500 seats</td>
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<td>Hotels</td>
<td>&gt; 60 rooms</td>
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<td>Hotels adjacent to coastal areas</td>
<td>&gt; 40 rooms</td>
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<td>National road construction</td>
<td>&gt; 100 km</td>
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<tr>
<td>Railway construction</td>
<td>All sizes</td>
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<tr>
<td>Port construction</td>
<td>All sizes</td>
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<tr>
<td>Airport construction</td>
<td>All sizes</td>
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<tr>
<td>Dredging</td>
<td>&gt; 50,000 m3</td>
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<tr>
<td>Dumping sites</td>
<td>&gt; 200,000 people</td>
</tr>
</tbody>
</table>
ANNEX 2: List of EIA reports identified in the main relevant ministries

Ministry of Environment

Public projects (2 approvals and 4 monitoring)
1) EIA report on the Greater Mekong Sub-region (GMSR) project about communication in Kandal province, Takeo province, Kampot province and Sihanoukville of Ministry of Post and Telecommunications, which was approved on 12 January 2005.
2) EIA report on Water Supply project at Tbong Khmum village and Kangmeas village in Kampong Cham province of MIME, which was approved on 05 May 2005.
3) EIA report on the Built structure of Economic area project especially SEZ at autonomous port in Sihanoukville, which it is monitoring.
4) EIA report on Construction road 64 project from intersection of road number 6 in Kampong Thom through Preah Vihear province of MPWT, which it is monitoring.
5) EIA report on Electricity network of the Greater Mekong Sub-region (GMSR) Link from Vietnam to Phnom Penh Electricity of Cambodia, which it is monitoring.
6) IEIA report on master plan of water supply in Phnom Penh (2nd degree), which Phnom Penh Authority Supply is monitoring.

Private projects (9 approvals and 2 monitoring)
7) IEIA report on Golf course project for 18-hole golf playing at Poun village in Siem Reap for Royal report company and KANTRI Club Co. Ltd. which was approved on 13 September 2005.
8) Environmental and Social Impact Assessment report on Gem Commercial project in 3 villages are Lumphat and Ratanakiri province for Seoul Digem Cambodia Co., Ltd, which was approved on 22 September 2005.
9) Environmental and Social Impact Assessment report on Gem Commercial project at Patingthom area, Tinchak commune, Borkeo district in Ratanakiri for Ultra Marine Kiri (Cambodia Co., Ltd.) which was approved on 22 September 2005.
10) Environmental and Social Impact Assessment report at Sen Chao area in Samlot district in Battambang province for Ultra Marine Kiri (Cambodia Co., Ltd.) which was approved on 22 September 2005.
11) IEIA report on Development Eco-tourism project in Ream Park area in Sihanoukville for Yee Jia Development Company, which was approved on 23 September 2005.
12) IEIA report on Development of Eco-Tourism at Tetek Puf in Kampong Speu province for NewCosmos Development (Cambodia) Co., Ltd, which was approved on 23 September 2005.
13) Environmental and Social Impact Assessment report on alkali commercial project at Prak Mountain area, Oral district in Kampong Speu province for Future Environment Co., Ltd, which was approved on 23 September 2005.
14) IEIA report on Construction of Petroleum and Pump Petroleum project at Otre in Sihanoukville for Tela Petroleum Group Investment Co., Ltd, which was approved on 19 October 2005.
15) Environmental and Social Impact Assessment report on sand construction commercial project in Kuntheay Island, Lekdek district in Kandal province and Check Island, Peamchor district in Prey Veng province for Khmer Dynastic International Co., Ltd, which was approved on 20 October 2005.
16) EIA report on Granted Land Project at Botum Sakor Park in Koh Kong for Greenrek Co., Ltd, which it is monitoring.
17) IEIA report on project of restaurant construction of NEXUS NAGA HOTEC in Phnom Penh for NAGA Resorts and Casinos Limited, which it is monitoring.
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Livelihoods Component

INFLUENCE OF BUILT STRUCTURES ON LOCAL LIVELIHOODS

Case studies of road development, irrigation and fishing lots

Prepared by

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ANNEXES
KEY TERMS USED IN THIS REPORT

**Buffer zone.** A zone that usually surrounds or adjoins core areas and is used for cooperative activities compatible with sound ecological practices, including environmental education, recreation, ecotourism, and research. In the Tonle Sap Biosphere Reserve, a buffer zone of about 5,400 square kilometers (km²) surrounds the core areas up to the outer limit of the flooded forest.

**Commune council.** In Cambodia, an elected body that governs commune administration. In addition to fulfilling their administrative tasks, commune councils participate in informal dispute resolution, plan and implement development projects, do some agency functions for the central and provincial governments, and conduct advocacy. Development activities consist mainly of small-scale infrastructure and public goods projects.

**Community management.** The community-based management of local natural resources, including certain designated fishing areas, with support from relevant authorities, institutions and organizations. Examples relevant to this report include community fisheries committees, road committees as well as farmers’ water user groups.

**Core areas.** Securely protected sites for conserving biodiversity, monitoring minimally disturbed ecosystems, and undertaking research and other low-impact uses such as education. In the Tonle Sap Biosphere Reserve, core areas are in Prek Toal (213 km²), Battambang; Boeng Tonle Chhmar (Moat Kla) (145.6 km²), Kampong Thom; and Stung Sen (63.5 km²), Kampong Thom.

**Chronic poverty.** Describes the condition of households who remain poor over time. In this study, the “chronic poor” describes those households that remained poor between the period prior to the change in built structure studied and the current period, as defined by household surveys. Those “vulnerable to chronic poverty” were previously in the non-poor group but then fell below the poverty line; those who moved “out of poverty” were previously in the poor group but then managed to move above the poverty line. The “non-chronic poor” includes these two latter groups plus those who were above the poverty line during both time periods. See also ‘Poverty’.

**Flooded forest.** A descriptive term for the natural vegetation that originally covered most of the Tonle Sap’s floodplains. It is now characterised by low forest and shrubs that contribute to the fisheries productivity of the Tonle Sap.

**Gini coefficient.** A measure used to describe income inequality. In this study, it is used to describe income inequality among households within a village. The coefficient is provided as a fraction between 0 and 1, where a higher number indicates greater inequality. Here, 0 corresponds to perfect income equality (i.e. everyone has the same income) and 1 corresponds to perfect income inequality (i.e. one person has all the income, while everyone else has zero income).

**Livelihood.** The capabilities, assets, and activities required for a means of living. A livelihood is sustainable when it can cope with stresses and shocks and maintain or enhance itself in the present and in the future without undermining the natural resource base.

**Livelihood approach.** A way of thinking about the objectives, scope, and priorities for development. It reinforces positive aspects and militates against constraints or
negative influences. Its core principles are that poverty-focused development should be people centered, responsive, and participatory; multilevel; conducted in partnership; sustainable; and dynamic. It puts people at the center of development.

**Poverty.** The state of being deprived of the essentials of well-being such as adequate housing, food, sufficient income, employment, access to required social services and social status. Poverty is usually measured with reference to a poverty line; if a household earns an income lower than a set amount, that household and its members are deemed to be living in poverty. In this study, the measure of poverty includes cash income as well as a dollar-value equivalent for household production (such as rice or fish catch) consumed by the family. See also ‘Chronic poverty’.

**Social capital.** The networks of relationships among persons, firms, and institutions in a society, together with associated norms of behavior, trust, cooperation, etc., that enable a society to function effectively. It is measured by the degree to which a community collaborates and cooperates to achieve mutual benefits.

**Transition zone.** An area in which stakeholders work together in a variety of economic and other activities to manage and sustainably develop a biosphere reserve's natural resources. In the Tonle Sap Biosphere Reserve, a transition area of about 9,000 km² lies between the outer boundary of the buffer zone and Highways No. 5 and No. 6.

**VILLAGE NAMES AND DESCRIPTIVE NAMES USED IN THIS REPORT**

1. Road development case study, Pursat province:
   - Chong Khlong: Cham village near the road
   - Ou Ta Prok Main: Khmer village near the road
   - Ou Ta Prok Up: Khmer village far from the road

2. Irrigation case study, Kampong Thom province:
   - Snao: Head-user village
   - Sa’ang: End-user village

3. Fishing lot case study, Battambang province:
   - Thvang: Village far from Tonle Sap Lake
   - Prek Toal: Village near Tonle Sap Lake

**ACRONYMS USED IN THIS REPORT**

- **ADB** Asian Development Bank
- **CF** Community fishery
- **CFA** Community fishery area(s)
- **NGO** Non-governmental organization
- **TSL** Tonle Sap Lake
- **SLF** Sustainable Livelihoods Framework
EXECUTIVE SUMMARY

1. This report documents the results from an assessment of the influence of built structures on the livelihoods of Tonle Sap communities, as part of the livelihoods component of the “Study of the Influence of Built Structures on the Fisheries of the Tonle Sap”. The livelihoods component aims to identify the links between built structures and socioeconomic change with a specific emphasis on fisheries, and aims to ensure that the analysis and recommendations regarding the influence of built structures incorporate the knowledge, perspectives and insights of people living in the immediate surroundings of the built structures.

2. This study examines cases involving three different types of built structures: road development in Pursat province, irrigation development in Kampong Thom province, and fishing structures along with associated management systems, in Battambang province.

3. Two field research approaches were employed simultaneously, namely quantitative analysis using household surveys (using semi-structured questionnaires with open-ended questions as well as ranking and rating questions) and qualitative analysis using a combination of key-informant interviews and group discussions and exercises (participatory village survey methods). These two approaches were selected to enable direct assessment of key observable and perceived influences of the built structures as well as to gauge communities’ understanding of the interconnectivity between their livelihoods, environment, aquatic ecosystems and built structures.

4. The type of built structure clearly influences how direct benefits are distributed. The case studies illustrate that different types of built structures (roads, irrigation schemes, fishing gears) have different degrees of openness or exclusion in terms of the ability of poor households to access the livelihood opportunities enabled by the structures. Overall, roads are most open as they provide public access with no direct exclusion. Irrigation is meant to bring livelihood benefits by increasing the seasonal availability of water, but still to a limited group, i.e. for landholders within the irrigation scheme and possibly for laborers and marketers nearby. In addition, the irrigation reservoir creates a new open access resource for fishing, although the access to the reservoir may be limited by different kinds of regulation and management practices. Fishing structures of the lots are clearly most exclusive as they funnel benefits to a small group and exclude the majority from the fishing area.

5. Yet there is also much we can say that applies across different types of built structures in different social and ecological settings. Institutions matter quite significantly, in ways that enable positive livelihood strategies (for example, through effective participation and consultation in project planning), and that disenable opportunities for the poor (for example, through mechanisms that reinforce inequitable access to aquatic resources and their livelihood benefits). Scale also matters, as many of the factors that either threaten local livelihoods or open new opportunities are not within the direct influence of local communities. The cross-scale factors that emerged as significant in the case studies include such issues as seasonal migrants making use of community fishing grounds, markets that develop to provide for a demand for local products (e.g. pig rearing), and, of course, environmental factors, including the relationship between hydrological change, habitat, and fisheries productivity.
6. Built structures – by definition, purposeful modifications to the physical environment – clearly do affect livelihood outcomes, but they are by no means a “magic bullet.” This study examined the influence of changes in both directions, namely interventions to introduce new (or improved) structures as with roads and irrigation, and interventions to remove structures (large fishing gears associated with the fishing lot). In all cases, the changes were justified on the grounds of poverty reduction.

7. Progress in poverty reduction has been modest, and inequality remains high. While it will be some years before the outcomes in these particular cases can be measured conclusively, the results already raise a justifiable concern. The ability of individual households to take advantage of changes depends very clearly on other assets, especially education. In certain contexts, other assets such as livestock holding may be key, and smaller family size may be an advantage. These observations signal the need to pay close attention to the livelihood context in which changes are being introduced, and the ways in which different households may or may not be able to benefit. In essence, it means considering infrastructure as one element in a broad array of useful investments to encourage pro-poor rural development.

Recommendations

8. **Link planning of new structures to decentralised natural resources management.** Planning, construction, and operation of built structures cannot operate in a vacuum, but must have strong connections both to long-term management of the Tonle Sap’s natural resources and to local development planning. The case studies indicate that the best way to ensure community involvement and ownership is to link planning of built structures to on-going processes of decentralised rural development and natural resources management. In advance of the physical infrastructure, it is often necessary to strengthen local institutional capacity to address the new challenges for collective decision-making.

9. **Strengthen institutional mechanisms to integrate decision-making across sectors and geographic scales.** Social, economic, and ecological trade-offs stemming from alternative scenarios of infrastructure and water resources development need to be explicitly evaluated and publicly debated. Government policies and strategies should clearly prioritize the relative importance of different social and economic benefits derived from the fisheries of the Tonle Sap Lake. Efforts are also needed to overcome the communication gaps between different sectoral ministries.

10. **Adopt processes of consultation and participation in project planning that recognise the differences among local households.** More attention must be paid to participation and ownership from the very initial stages of project planning. At the planning stage, it is important to analyze sensitively how the anticipated benefits and costs of a project are likely to be distributed among different social groups, taking into account the role of local institutions and differences in household assets. Special provisions also need to be made so that the poorest groups can indeed participate effectively.

11. **Target built structure investments with an understanding of how the poorest groups can benefit.** Even when the net benefits of infrastructure
developments in terms of average household income appear to be positive, the poorest groups can be left behind. Addressing these distributional issues requires reconsidering priorities in terms of the links between infrastructure development and changes in livelihood opportunities, as well as types of infrastructure and their scale and complexity of operations. It means favoring investments in structures with high degrees of openness in terms of social groups that can access the benefits. And it means, where feasible, favoring smaller-scale projects that are more easily adapted to local needs, more easily managed locally, and less attractive for elite capture.

12. **Plan complementary investments to address the asset gaps of poorer groups.** Many households fail to take advantage of the livelihood opportunities offered by built structures because they lack other essential assets. Alongside infrastructure improvements, investments in basic education, training and technical support services, and credit may be needed, as well as support to community organizing capacity.
I INTRODUCTION

13. This report documents the results from an assessment of the influence of built structures on the livelihoods of Tonle Sap communities, as part of the livelihoods component of the “Study of the Influence of Built Structures on the Fisheries of the Tonle Sap”\(^1\). The livelihoods component aims to identify the links between built structures and socioeconomic change with a specific emphasis on fisheries, and aims to ensure that the analysis and recommendations regarding the influence of built structures incorporate the knowledge, perspectives and insights of people living in the immediate surroundings of the built structures.

14. The present study assesses possible changes in people’s livelihood strategies and outputs, including those derived from fisheries, particularly in terms of changes in livelihood portfolios, vulnerability, resource access and income. It also summarises local people’s perceptions of the connections between their livelihoods, environment, aquatic ecosystems and built structures, as well as their viewpoints on best practices for built structures with a specific focus on institutional arrangements.

15. A variety of other research studies in Cambodia have highlighted the importance of natural resources for people’s livelihoods and people’s strong dependence on them. These studies also emphasise the diversity and seasonal change in livelihood sources of rural households. Of particular note is the TA supported by the ADB as part of the preparation of the Tonle Sap Sustainable Livelihoods project – Phase 1 (ADB 2004a). An extensive participatory rural appraisal (PRA) documented the importance of fishing not only to the livelihoods of those living in the core zone of the biosphere reserve, but also to those in the transition zone. It also showed that food insecurity (essentially rice deficit) is perennial for landless and land-poor households in the lowland areas, and that a key consequence of this is increased harvesting of fish, animals, reptiles, fuelwood, building materials, and non-timber products from the flooded forests. Finally, it documented an interest in livelihood diversification among residents of the core zone and buffer zone based on a perceived decline in the fisheries resource, and a high demand among villagers in the transition zone for irrigation improvements to reduce livelihood vulnerability. Such findings help explain why there is a strong push for infrastructure development around the lake, and why the potential influence of these built structures on fisheries resources and livelihoods merit attention.

16. Yet few studies in the country have looked specifically at livelihoods in the context of built structures, or the influence of built structures on livelihoods. The analysis presented in this report seeks therefore to complement existing studies by evaluating both quantitatively and qualitatively the role of built structures in sustaining the livelihoods of the people living close to the built structures. The study considers both enabling and disenabling aspects of built structures, and consequently both positive and negative livelihood outcomes associated with them, with analysis based on the Sustainable Livelihoods Framework (SLF).

17. The study looks at the local influences of the selected built structures in their immediate surroundings. Consequently, the analysis of the livelihood outcomes, benefit and cost allocation and changes in vulnerability is done among the direct intended beneficiaries of different built structure projects. The study illustrates the complexities of the benefit allocation from the built structures, pointing out issues that should be taken into account when planning new structures and assessing their viability and contribution to poverty

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The focus on the local influences is, however, also a limitation, as the study does not address the issue of built structures’ influence on fisheries (or other livelihood implications) outside the project areas. Thus, for example the downstream impacts on fisheries or the cumulative impacts on the livelihoods dependent on the natural resources of the Tonle Sap are not assessed within this study. Such influences at broader geographic scales are, however, addressed partly by the other project components. For example, the hydrology component looks at cumulative impacts of built structures on the Tonle Sap’s flow regime, while the fisheries component includes a preliminary assessment of the influence on downstream and upstream fisheries. An upcoming synthesis report will employ findings from each of the component studies to characterise trade-offs associated with built structures in the Tonle Sap more comprehensively. This should also offer at least an indication of the livelihood implications in other areas not included in the present report.

II METHODOLOGY

18. Two key field research approaches were employed simultaneously, namely quantitative analysis using household surveys (using semi-structured questionnaires with open-ended questions as well as ranking and rating questions) and qualitative analysis using a combination of key-informant interviews and group discussions and exercises (participatory village survey methods). These two approaches were selected to enable direct assessment of the key observable and perceived influences of the built structures as well as to gauge communities’ understanding of the interconnectivity between their livelihoods, environment, aquatic ecosystems and built structures.

19. As the two approaches build on different kinds of research methods, they provide different types of information that complement each other. For both household and participatory village surveys, two or three villages were selected in each study area to cover villages with varying characteristics, in terms of livelihood assets and seasonal vulnerabilities, and in terms of the possible direct influences of the built structures, their locations, and the prominence of fishing as a livelihood strategy in the communities. The information was analysed to assess the possible influence of built structures on the livelihoods of the communities in the study areas, particularly in terms of activity patterns, resource access, and income. Qualitative analysis was focused on capturing local people’s perceptions of the interconnectivity between livelihoods, environment, aquatic ecosystems and built structures, as well as their viewpoints on best practices for built structures. The findings were synthesised using the Sustainable Livelihoods Framework as an organizing tool to describe the often complex relationships between built structures and livelihood outcomes. Each of these elements of the research approach is summarised below.

II.1 QUANTITATIVE ANALYSIS USING HOUSEHOLD SURVEYS

20. The quantitative analysis focused on the impact of built structures on livelihood activities, income, income sources and income portfolios, vulnerability and food security and the role of asset endowments. Existing studies provide a rich basis of comparative information on the general socioeconomic characteristics of communities in the Tonle Sap Basin, including diversity of their livelihood portfolios and the range of assets that they have at hand (see for example, Rab et al. 2005). However, none of these measure the specific impact of built structures, which is the rationale for undertaking additional, focused

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2 The results of the livelihoods component will thus be useful also to other projects designed to improve livelihoods opportunities for vulnerable communities in the Tonle Sap area, particularly the ADB-supported Tonle Sap Sustainable Livelihoods and Tonle Sap Lowland Stabilization projects.
surveys and analysis. Quantitative analysis focused on drawing inferences about the cause and effect relationship between built structures and livelihoods, food security and vulnerability. As such, it provides an important complement to the qualitative methods (described below), which focus on people’s perceptions of past and potential future changes.

21. In brief, the quantitative analysis used household survey data to:
   - assess changes in affected communities in terms of:
     • activity/occupation patterns
     • income, income portfolio and distribution
     • number and distribution of vulnerable households
     • consumption patterns and food security
     • access to resources, infrastructure and markets
   - analyze the role of asset endowments on changes in income, income portfolio, vulnerability and activity patterns.

22. Sound quantitative analysis requires good information on rural livelihoods from a representative sample of households in the seven selected villages around the three built structure types. In order to generate information, the research team used a combination of data collection methods in a two-step approach:
   - Step 1: key-informant interviews to gather overview information on livelihood activities, population, infrastructure, problems, etc.
   - Step 2: household surveys to gather information on demographics and education, activities/occupation, access to resources, income, assets, housing and sanitation, access to credit and infrastructure, and perceptions about the influence of built structures on livelihood outcomes.

23. To ensure that the information gathered was representative of the communities concerned, a purposive stratified random sampling approach was used. Households in the study villages were stratified, using information from Step 1, into four stratum on the basis of their main income generating activity: 1) fishing, 2) farming, 3) fishing plus farming, 4) other (non-farm & non-fishing activities). These households were further stratified by wealth status into rich and middle, poor and very poor. From each stratum 5-15 households were selected. This resulted in a total sample of 80 households in Pursat (road development) and 90 each in Kampong Thom (irrigation project) and Battambang (fishing lot), thus comprising 260 households in total.

24. In analyzing the survey data, income was estimated based on all livelihood activities as a sum of both cash and in-kind income sources, including those sold and retained for household consumption. Comparative analysis examined the contribution to total income by activities and the percentage of households engaged in each activity by study site, by village, and by income group, and assessed the change between two time periods – before the change in built structure versus the present time. The period of comparison varied between 2 and 5 years, according to the case. Additional analysis examined changes in the number of households below the poverty line, the depth of the poverty gap, income distribution and changes in income and assets, and the strength of statistical correlation between various measures of household assets and chronic poverty.

II.2 QUALITITATIVE ANALYSIS BASED ON LOCAL PERCEPTIONS

25. The aim of the qualitative case studies was to study local perceptions and local knowledge about the built structures and their influence on livelihoods. The analysis also looked at institutional arrangements in connection with built structures and local
viewpoints on best practices related to them. The qualitative approach of the livelihoods component was based on different Rapid Rural Assessment (RRA) methods, but the approach also made use of methods commonly applied in Participatory Rural Appraisals (PRA).

26. The qualitative case studies focused on the village level, but also included key-informant interviews at the provincial and district levels, with key-informants from case study projects, line agencies and NGOs. Main methods used in the qualitative case studies consisted of key-informant interviews, group discussions and exercises, and in-depth individual interviews (Figure 1). The number of interviewees differed between the case studies, but on average the group of villagers included around 10 people, while the number of key-informants (both during pre-survey and the actual survey) was between 5 and 10 people.

27. The qualitative analysis focused on:

- identification of different classes of stakeholders in relation to built structures, and
- information regarding perceptions of the interconnectivity between built structures, environment, aquatic resources and livelihoods; ideas on possible alternative livelihoods, and viewpoints on best practices for (a) planning, (b) building, and (c) operating built structures.

28. The analysis of qualitative information was based on thematic analysis of detailed field notes from the surveys. The discussions and interviews in different case study areas and with different stakeholders were written down into field notes and translated into English. In addition, part of the discussions and interviews were also recorded, allowing use of direct quotes of local perceptions. The information available from surveys—complemented by available literature—was then analysed according to themes building on the Sustainable Livelihoods Framework.

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3 As the focus was on the discussions that emerged during the surveys, different kinds of group exercises (e.g. rankings) were also aimed at facilitating discussions, rather than producing an end product in the form of a matrix or table.
II.3 SYNTHESIS OF FINDINGS USING THE SUSTAINABLE LIVELIHOODS FRAMEWORK

29. The Sustainable Livelihoods Framework (SLF) builds on the following overall idea: “A livelihood comprises the capabilities, assets and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base” (DFID, 2001). The SLF looks at livelihoods and their development with the help of different kinds of livelihood assets, livelihood strategies, vulnerability contexts, transforming processes and access to resources and institutions (ADB, 2004). As highlighted by ADB (2004), the SLF “brings attention to the inherent potential of people in terms of their skills, social networks, access to physical and financial resources, and ability to influence core institutions”. The SLF is based on “evolving thinking about poverty reduction, the way the poor and vulnerable live their lives and the importance of structural and institutional issues” (ADB, 2004).

30. Within the Built Structures study, the SLF has been used in analysing how specific built structures undermine and/or enhance different livelihood opportunities. The framework provides a way of considering the dynamic linkages between built structures and livelihoods, including the role of institutional structures and processes. It also helps in applying findings to other projects that have employed a similar framework.

31. Because the objective of the Built Structures study differs from the occasions where the SLF is normally applied, a slightly modified framework was employed based on the framework developed by Carloni & Crowley (2005) for the FAO. The main difference is that instead of focusing on the actual development of livelihoods, the aim of the Built Structures study was to look at the interconnections between livelihoods, environment, natural resources and physical capital (built structures), and analyse how physical capital impacts –either positively or negatively – the natural capital (particularly fish resources) as well as livelihoods of different social groups. Figure 2 captures how the SLF was applied within this study.

![Figure 2. The modified Sustainable Livelihoods Framework with enabling and disenabling processes for livelihood development (Carloni & Crowley 2005)](image_url)
32. In the context of this livelihoods study, the objectives of the Built Structures study have been addressed within the Sustainable Livelihoods Framework by:
   1. Considering both enabling and disenabling aspects of built structures or associated institutions, and consequently both positive and negative livelihood outcomes
   2. Analysing how different social groups are affected by built structures by identifying different stakeholders and analysing reasons behind (possible) differential allocation of benefits and losses linked to built structures
   3. Analysing quantitatively in more detail how the households' ability to take advantage of opportunities provided by the studied built structures depends on households' assets
   4. Looking at the wider institutional context, management practices and different ways of implementing existing rules in enabling and disenabling the livelihoods of different social groups, and considering institutional and management processes in different levels of planning, building and operating the built structures.
III RESULTS

33. The overall TA, “Study of the Influence of Built Structures on the Fisheries of the Tonle Sap,” considers the influence of built structures at three geographic scales – Mekong Basin, Tonle Sap Lake, and local study sites. All findings from this present study on livelihoods are at the local scale. Results are presented in this section first by individual case study, then comparative results across the three cases are presented.

III.1 CASE STUDY 1. ROAD DEVELOPMENT IN KRAKOR DISTRICT, PURSAT PROVINCE

III.1.1 Context: Linking road development to livelihood outcomes

34. Roads are often assumed to be central in triggering growth in rural areas (see e.g. ADB 2006b; ADB 2004c; Cambodia New Vision 2001; Gannon and Liu 1997; IFRTD 2005). Rural roads have potentially several benefits: they connect people to markets, and farmers get better prices for their products; they provide incentives to produce crops for sale, and they enable better information sharing which facilitates livelihood development. Roads enhance access to health, education and other amenities. Rural roads also open villages for development interventions as both state actors and NGOs have better access to them. Without roads or other types of transportation networks (e.g. canals), rural areas face economic isolation and stagnation (see e.g. ADB 2006b; ADB 2004c; Gannon and Liu 1997; UN Millennium Project 2005).

35. Different studies indicate that impacts of roads on livelihoods depend on several factors and are not straightforward (see e.g. Howe and Richards, 1984). The assumption that roads generate positive development has been questioned by findings of negative economic and social effects (Simon 1996). Poverty is not always reduced as planned or expected, but just redistributed or even increased. It is often the case that roads provide new opportunities for those who already have a good asset base, while the poorest groups may not be able to take full advantage of the enhanced infrastructure (Taylor 2004). With the increased price of land, poor people are either forced or tempted to sell their land and move elsewhere, thus risking being even further away from markets and services (ibid.).

36. There are also environmental risks related to road construction. In wetlands or floodplains, building roads may alter flood patterns, fragment the habitat for fish and other aquatic animals, and create barriers for fish migration. When a road forms a barrier to the flood, it can worsen flooding in other areas and can reduce benefits derived from floods. In the Tonle Sap area, the roads in floodplains may, on one hand, enhance access to the flooded forests and increase income, but they may, on the other hand, result in unsustainable exploitation of these resources. On the whole, the impacts of roads in floodplains are not well studied, and even less so in Cambodia. There is, however, an ongoing WWF-MRC project on roads’ impact on floods in Cambodian floodplains and deltas, which aims to set standards for environmentally friendly design and engineering practices for roads.

III.1.2 Road development at the study site

37. The case study site is located in Krakor district of Pursat province. Stung Pursat (Pursat River) is the main tributary in the province, with a large number of new construction works

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4 The project ‘Roads and Floods: Developing Economically Sound and Environmentally Friendly Guidelines’ is due to finish in 2008.
within its basin. These include five proposed dams and at least ten irrigation and water management projects, such as river diversions, reservoir upgrading and flood control dykes. Most of the projects are still at the planning or construction stage, and their impact is therefore not well known yet. Pursat province is also part of the ADB-funded Northwest Irrigation Project and it has been wisely selected – given the high number of planned projects – as an ADB pilot site for integrated river basin management.

38. Although planned irrigation structures are likely to have a remarkable impact in the Pursat sub-basin, it was decided that the case study in Pursat would be focused on roads. There are three main reasons for this decision: firstly, the (re)construction of the roads in the study area had already been completed, and the roads-dyke system therefore offered a good opportunity to study its impacts on floodplain fragmentation and loss of fish habitat as well as more broadly its social implications. Secondly, the decision to focus on roads enabled the project to cover a variety of different types of built structures around the Tonle Sap. Thirdly, the case study on irrigation schemes was already carried out in Kampong Thom, and it was assumed that at least some of the findings and recommendations from there could be applied to planned irrigation projects in Pursat.

39. The road in the case study area is a seven kilometre long secondary/tertiary road and it is built on a natural levee. It was selected for study in part because it runs parallel to the lake bank, thus raising the possibility that it might interrupt water flows and fisheries. The road passes through three communes, namely Ou Sandan, Boeng Kantout and Kampong Pou (Figure 3). There has been a very low quality oxcart road in the area since 1970s, while a better clay road was built with support from CONCERN (an international NGO) in 1995. In 2003 the road was rehabilitated into a gravel road under the Seila Program. At the same time the embankment was elevated and communal road committees were established with two representatives from each village (village chief + one member) and three members from the commune council.

40. As there are the same kinds of areas in the province without proper road connections, it is likely that similar roads will also be built in the area in the future. When compared with some of the other provinces around the Tonle Sap, the road development in Pursat’s floodplains has been moderate. The densest network of roads in the Tonle Sap floodplains currently exists in Siem Reap province, where the negative environmental impacts of the roads are most probably more severe than in Pursat.
At the same time, the rehabilitation of the national road — the major road running through the province — has led to enhanced access to the Tonle Sap’s natural resources. Some key-informants have observed that the price of the land around the national road has increased, and outsiders from urban centres have started to move in and buy land areas for cash crop cultivation. Although these trajectories are outside the scope of this case study, they do influence the development of the case study area and the whole Tonle Sap Basin.

III.1.3 Characteristics of the study villages and livelihood assets

The case study in Pursat has two different levels of analysis, involving three villages. Firstly, the case study compares Chong Khlong and Ou Ta Prok Main, which are both located along the new road but yet have distinct differences in terms of ethnicity and financial and social capital. While all the inhabitants in Chong Khlong consist of the Chvea minority group (a subgroup of Cham Muslims), Ou Ta Prok Main is a Khmer village. Secondly, the case study compares these two villages with Ou Ta Prok Up which is another Khmer village located 2 km upland from the road. The aim of this comparison is to examine the role of differences in terms of villages’ proximity to the road. Thus, Chong Khlong is also referred to as the ‘Cham village near the road,’ Ou Ta Prok Main as the ‘Khmer village near the road,’ and Ou Ta Prok Up as the ‘Khmer village far from the road.’

The survey indicates that Chong Khlong is better endowed than Ou Ta Prok, which is also validated by prior village survey data from 2002 to 2004 (SEILA Commune Database 2006; see Annex A, Table 1). Over 90 percent of the households in the three villages are engaged in rice farming and almost 80 percent in fishing (Table 1, see also Annex A, Table 2). On average, fishing is the most important source of income (in cash and in kind). However, other livelihood sources are also important. In Chong Khlong, fishing, followed by rice farming, farm labour and petty trade are the main livelihood sources, whereas in Ou Ta Prok Main and Ou Ta Prok Up, fishing, rice farming and livestock...
44. The main sources of income in the survey villages are fishing and rice farming. The estimated average household income of Chong Khlong is highest at around US$ 653, followed by Ou Ta Prok Up at US$ 569 and lowest for Ou Ta Prok Main at US$ 459 (Table 1; details in Annex A, Table 3). The major differences in financial assets seem to result partly from remittances from overseas, particularly in Chong Khlong. It may also be linked to the differences in social capital. While Ou Ta Prok has more localised social contacts, Chong Khlong has more connections to outside the village, including even some global networks, resulting therefore in better information. It seems also that Chong Khlong has better connections to those holding positions of power, such as their Cham patron in the National Assembly. Further, while both villages have some indigenous associations, they seem to be more active and better organised in Chong Khlong, possibly associated with religion. Based on the key-informant interviews and the field observations, there is an impressive internal re-distribution mechanism of wealth to the village’s poorest groups and students in Chong Khlong.

<table>
<thead>
<tr>
<th>Village location and proximity to the road</th>
<th>Chong Khlong</th>
<th>Ou Ta Prok Main</th>
<th>Ou Ta Prok Up</th>
<th>Pursat case (combined)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnic group</td>
<td>Cham</td>
<td>Khmer</td>
<td>Khmer</td>
<td></td>
</tr>
<tr>
<td>Main livelihood activities (% households participating)</td>
<td>Rice farming 91% Rice farming</td>
<td>90% Rice farming</td>
<td>100% Rice farming</td>
<td>93%</td>
</tr>
<tr>
<td></td>
<td>Fishing</td>
<td>82% Other</td>
<td>76% Livestock</td>
<td>93% Fishing</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>75% Livestock</td>
<td>70% Fishing</td>
<td>87% Other</td>
</tr>
<tr>
<td></td>
<td>Livestock</td>
<td>58% Fishing</td>
<td>60% Other</td>
<td>78% Livestock</td>
</tr>
<tr>
<td></td>
<td>Fishing</td>
<td>56% Farm Labour</td>
<td>45% Other crops</td>
<td>47% Other crops</td>
</tr>
<tr>
<td></td>
<td>Rice farming</td>
<td>32% Rice farming</td>
<td>27% Fishing</td>
<td>33% Fishing</td>
</tr>
<tr>
<td></td>
<td>Fish related</td>
<td>17% Livestock</td>
<td>21% Rice farming</td>
<td>19% Rice farming</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>13% Fishing</td>
<td>16% Others</td>
<td>19% Other</td>
</tr>
<tr>
<td></td>
<td>Petty trade</td>
<td>12% Petty trade</td>
<td>16% Livestock</td>
<td>13% Petty trade</td>
</tr>
<tr>
<td>Main sources of income (% total income)</td>
<td>Fishing</td>
<td>8% Other</td>
<td>12% Nonfarm labour</td>
<td>7% Livestock</td>
</tr>
<tr>
<td></td>
<td>Rice farming</td>
<td>12% Livestock</td>
<td>17% Rice farming</td>
<td>19% Rice farming</td>
</tr>
<tr>
<td></td>
<td>Fish related</td>
<td>16% Others</td>
<td>33% Fishing</td>
<td>33% Fishing</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>12% Petty trade</td>
<td>16% Livestock</td>
<td>13% Petty trade</td>
</tr>
<tr>
<td></td>
<td>Petty trade</td>
<td>5% other</td>
<td>15% Nonfarm labour</td>
<td>7% Livestock</td>
</tr>
<tr>
<td>Average household income (in US$ per year)</td>
<td>653</td>
<td>459</td>
<td>569</td>
<td>589</td>
</tr>
<tr>
<td>Average livestock index</td>
<td>12.05</td>
<td>6.55</td>
<td>12.00</td>
<td>10.63</td>
</tr>
<tr>
<td>Average landholding (ha)</td>
<td>0.95</td>
<td>0.84</td>
<td>0.76</td>
<td>0.89</td>
</tr>
<tr>
<td>Average yrs of schooling</td>
<td>2.13</td>
<td>2.35</td>
<td>1.86</td>
<td>2.14</td>
</tr>
<tr>
<td>Average household size</td>
<td>5.02</td>
<td>4.85</td>
<td>6.00</td>
<td>5.15</td>
</tr>
</tbody>
</table>

*Note: Livestock index was estimated using the conversion index by Taylor and Turner (1998)*

| Table 1. Key characteristics and household assets by village, road development case study, Pursat province |

45. All three villages have small landholdings with an average of less than one hectare per household (see Table 1). Inequality in landholdings is high in Chong Khlong and Ou Ta Prok Main (gini coefficient of 0.46), and relatively lower in Ou Ta Prok Up (gini coefficient 0.38). The livestock assets index in Chong Khlong and Ou Ta Prok Up is 12 while in Ou Ta Prok Main it is 6.5. Similar to landholding, the inequality in livestock assets is high in Chong Khlong and Ou Ta Prok Main and lower in Ou Ta Prok Up (gini coefficients of 0.62, 0.53 and 0.38, respectively). In Chong Khlong, the main livestock assets are cattle and poultry, while in Ou Ta Prok Main it is pigs and in Ou Ta Prok Up it is both cattle and pigs (Annex A, Table 4).

III.1.4 Influence of the road development on livelihood outcomes

46. On the whole, some of the potential benefits and risks described above (section II.1.2) have been experienced in the case study area, while some have not. Contrary to the hypothesis which led to the selection of the case study area, the environmental impacts of
47. **Overall improvement in livelihood outcomes is seen through improved market access and new livelihood opportunities.** The most frequently highlighted improvement brought by the road was better access to public services, most importantly to the health centre, followed by improved access to markets. In the past, reaching the market took a long time, making it difficult for villagers to take their products there themselves. This resulted in high dependence on middlemen that were very few due to the difficult access to the villages. The situation in the Khmer village far from the road (Ou Ta Prok Up) reflects this situation, as stated by one villager:

"It is difficult for us to bring vegetables to market and there are not so many middlemen come to buy our products such as palm sugar and vegetables and animals. They offer us low prices so we are not encouraged to grow vegetables and raise animals."

48. Now when the road connection is better, the villagers can go to market themselves. There are also more middlemen coming to the villages. As a consequence of these two changes, the villagers are less dependent on the middlemen and are able to negotiate fair prices. Better market access has also increased the incentives to produce products for sale and encouraged new activities like pig raising in Ou Ta Prok. In Chong Khlong, many villagers have themselves started to act as middlemen, buying and selling products such as fruits, chicken, fish and medicine between villages. Chong Khlong has also become a kind of a local centre for cattle trade, where Chong Khlong middlemen trade cattle from near-by areas to middlemen from other districts and towns. In terms of increased benefits for different products, the villagers pointed out that better market access is especially significant for fish, which is not easy to preserve for a long period.

49. **The household livelihood activities and income portfolios have become more diversified since the construction of the road.** The percentage of households participating in different livelihood activities has generally increased (see Annex A, Table 2). For example, more households in the Cham village near the road (Chong Khlong) are engaged in rice farming and livestock raising while in the Khmer village near the road (Ou Ta Prok Main), the increase is seen in fishing, livestock raising and farm labour. Such increases may not all be attributed to the road, however, as seen in Ou Ta Prok Up where the highest increase in the livelihood activities portfolio is observed, particularly in fishing, fishing-related activities, rice farming and farm labour.

50. Livelihood diversification implies changes in income portfolio. For instance, the contribution from fishing to the average household income has declined in all the villages. Nevertheless, fishing is still the main source of income except in the Khmer village near the road (Ou Ta Prok Main), where income from rice farming has replaced fishing as the main source of income and livelihoods by contributing about 27 percent of the household income (Annex A, Table 3).

51. The contribution of income from livestock rearing to the average household income has increased most significantly in the Khmer village near the road (Ou Ta Prok Main) from 18 percent before the road to 21 percent after the road, while in the Khmer village far from the road (Ou Ta Prok Up) it has declined from 22 percent to 13 percent. Livestock does not contribute much to the income portfolio in the Cham village as they do not engage in pig rearing, which seems to be a quite lucrative source of income for other rural households in the area. The contribution from petty trade to the total income has increased significantly except for the Khmer village far from the road, which suggests that improved roads have helped foster developments in trade and business. While the importance of petty trade to livelihoods has increased, high remunerative trade requires
some investments, which places the asset-poor households in a disadvantaged position. A similar case was observed in relation to investment in livestock encouraged by the new road, where asset-poor households had a weaker capacity to invest. As for the contribution of non-farm labour income, it remained unchanged except in the Khmer village far from the road where a significant increase was shown.

52. **Richer households have benefited more than poorer households from the road development.** Quantitative analysis of the survey data shows a strong correlation between changes in the household income and household assets like education, livestock and financial capital (Annex A, Table 5). While the average household income may have increased, further analysis reveals that the richer households experienced a significantly higher increase in their average household income compared to the poorer households (Annex A, Table 6).

53. **Locals perceive no significant impacts on fisheries.** The impacts of the road on fish abundance and flooding pattern were perceived to be minimal by the informants. According to the villagers of Ou Ta Prok and Chong Khlong, the road neither blocked nor protected their villages from flooding as the culverts built under the road let the water flow to the other side of the road. For the same reason the road does not block fish migration, either.

54. **The fact that the culverts provide new, easier opportunities for catching fish was not mentioned by the villagers, but commented on only when asked.** Although fishing activities that block fish in the mouths of culverts may disturb fish migration, the villagers did not see this as very relevant. There are also regulations related to fishing that should be enforced jointly by the Road Committee and Community Fisheries Committee, but according to the field observations these seemed to be widely ignored.

55. **Households' ability to take advantage of opportunities provided by the road depends significantly on other assets.** The Cham village near the road seemed to have benefited more and also more equally from the road than the Khmer villages. This may be due to the differences in social capital and attitudinal orientation in life. The Cham community has more connections to extra-village networks. They also have better organised social institutions, including a Muslim-influenced and locally managed income re-distribution system. These and other differences in the social asset base and in livelihood strategies that are influenced by a culturally different ‘ethos’, result in different interests and abilities to take advantage of a changed situation. While this does not mean that Cham communities are always more capable of enhancing their living standard, the differences do indicate that cultural and social issues play a significant role in how the roads and other infrastructure – and the changes they bring – influence livelihood outcomes.

56. **Management structures and institutions are key in mitigating environmental impacts and ensuring long-term maintenance.** At present the national government is focused on the core network of primary roads, while the lower levels of government, including communal road maintenance committees, are given responsibility for local roads (IFRTD 2006). Decentralised authority can potentially result in more efficient maintenance work, but this is challenged by scarce sources of revenue. Villagers in the study pointed out that the local road committee is able to undertake only small repairs, while bigger ruptures still require assistance from the commune or higher levels. This highlights the challenge of finding a balance between decentralisation and the need for an integrated approach at broader geographic scales in road planning and maintenance.

57. **Poor road maintenance has been a common problem in Cambodia (IFRTD 2006).** Roads located in flood-prone areas – like the one in study area – need special emphasis on maintenance. Successful maintenance requires a stable source of revenue, responsible and controlled use of the road, and mobilisation of special funds and labour to work in
case of road ruptures. Good communication and collaboration between the villages sharing the road is important as well, which implies capacity of commune officials to network, communicate, and share information.

58. Even though the road-related institutional structures do not require the same level of mobilization as irrigation (as in the Stung Chinit case, for example), participation is still crucial. The key-informants from the road committee stated that after the CONCERN project was finished in 1995, there was no program for maintenance. The villagers felt that as the NGO was responsible for the construction of the road, it should also be responsible for its maintenance. This resulted in poor maintenance which together with high floods in 2000-03 led to major damage to the road. With the rehabilitation of the road initiated by the Seila Program, a road committee was established and road fees were introduced. According to the informants this resulted in an increased sense of ownership, and consequently more attention has been paid to the maintenance of the road. The challenge is that while the road is used in a more responsible way at the beginning — when the road is new and its benefits more apparent — less attention is paid to its maintenance later on when the existence of the road is taken for granted.

59. While there were some challenges in finding enough funds for the road maintenance, some innovative solutions came up. For example, the middlemen coming from outside have been convinced to pay fees for road maintenance. Cooperation with the local wat (temple), initiated by the commune council members, has also been established. When a rupture occurs in the road, funds for repairing it are raised at the temple, and not only the village where the rupture occurred but also the entire commune contributes to the repairs. People generally entrust their money more easily to the monks than to the commune authorities. These examples highlight the importance of innovative solutions based on indigenous institutional networks.

III.2 CASE STUDY 2. STUNG CHINIT IRRIGATION AND RURAL INFRASTRUCTURE PROJECT, KAMPONG THOM PROVINCE

III.2.1 Context: Linking irrigation infrastructure development to livelihood outcomes

60. The Stung Chinit Irrigation and Rural Infrastructure Project (SCIRIP) is currently the largest irrigation scheme in Cambodia. The project also reflects the Cambodian government’s strategy to reduce poverty through improvements in agricultural production, especially through irrigation, as emphasised in the Second Socio-Economic Plan of Cambodia. The irrigation sector is therefore expected to gain substantial investments in future, and this trend is already evident also in the Tonle Sap area. The SCIRIP can also be seen to serve as a pilot project for the ADB’s Northwest Irrigation Sector Project (NWISP), where several irrigation schemes will be rehabilitated in Siem Reap, Battambang, Beantey Meanchey and Pursat. In addition, the ADB Lowland Stabilization Project addresses agricultural issues in the Tonle Sap area, including needs for irrigation.

61. The objective of the Stung Chinit case study is to record the most important lessons learnt from the project to inform implementation of future irrigation projects in the area and in other areas around the lake. As the project is still on-going and long-term impacts are therefore not yet evident, the emphasis is on the planning and construction process, particularly that of large-scale irrigation projects. Consequently, the case study does not focus only on physical built structures, but also looks at the interaction between the different project components and livelihood outcomes.
III.2.2 Irrigation and other infrastructure development at the study site

62. The project is located in Santuk district of Kampong Thom province, and there are two Tonle Sap tributaries in the area: Stung Chinit and Tang Krasang. The project is intended to benefit 2,400 households within 3 communes and 25 villages, mainly in Kampong Thmor commune. The irrigated area is projected to be 3,000 ha in the wet season (supplemental irrigation) and 1,800 ha in the dry season (full irrigation). The project was designed to deliver economic benefits primarily through increased agricultural income and productivity. The overall cost of project maintenance has been estimated to be US$80/ha/year, and water use fees are planned to offset these costs.

63. The physical built structures in the project consist of irrigation and drainage canals, the dam and spillway, and the related reservoir. However, the project design acknowledges that physical infrastructure alone does not have positive livelihood outcomes. Consequently, the project components also include the establishment of irrigation management groups, agricultural extension activities, and the enhancement of roads and market access. As it is not sensible or even possible to isolate the built structures as physical structures from other project activities, the case study also looks at these other project components.

Figure 4. Map of study villages at the Stung Chinit irrigation site, Kampong Thom province

III.2.3 Characteristics of the study villages and livelihood assets

64. The case study compares two villages within the Stung Chinit irrigation scheme, Snao and Sa’ang. Snao represents a head-user village which is very close to the reservoir, to the spillway and to the project offices. Villagers in Snao have experienced some losses related to the project due to the construction and relocation of households.\(^5\) Sa’ang, on

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\(^5\) One of the main points for criticism of the project’s planning and construction phase has concerned land losses and the compensation for these. The number of households relocated has also been higher than originally estimated. Not only villagers, but key-informants from the governmental line agencies also
the other hand, is an end-user village at the southern edge of the scheme. Given the high reliance of the villagers in Sa’ang on fish in the Stung River, fishing might be impacted negatively by the irrigation scheme and particularly by (re)construction of the dam and spillway. This case study does not, however, address impacts outside the project area (downstream or upstream).

65. Both of the study villages embody occupational pluralism with a strong seasonal character. As shown in Table 2, the main livelihood activities in both head-user and end-user villages are rice farming, livestock and fishing. The income sources of the people include rice farming, water melon and vegetable crops, fishing, forestry (firewood and timber cutting and non-timber forest products), sugar palm, livestock raising, trade and labour work. The main difference in asset base is that financial capital is much lower in the end-user village (Sa’ang), which is linked to the lower average household income (US$ 589, compared to an average of US$ 785 in the head-user village (Snao). In addition, the villagers in the end-user village are more dependent on fishing. In the head-user village, a significant income source consists of forestry activities (firewood, timber cutting and non-timber forest products) in an area 40 km upland from the village. In the end-user village, forestry is less important and limited only to non-timber forest product collection in the vicinity of the village. Vegetables or other upland crops are not very significant in the villages, but the project aims to augment their importance. A common characteristic in both villages is that the households with less landholding are more dependent on fish and other aquatic resources (see Table 2). In other words, fishing and other aquatic resources provide a higher proportion of income for the poorer households, even if wealthier households earn more from these activities.

<table>
<thead>
<tr>
<th>Livelihood assets</th>
<th>Snao</th>
<th>Sa’ang</th>
<th>Kampong Thom case (combined)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village location and proximity to the irrigation scheme</td>
<td>Head-user, closer to the scheme</td>
<td>End-user, farther from the scheme</td>
<td></td>
</tr>
<tr>
<td>Main livelihood activities (% households participating)</td>
<td>Rice farming 89%</td>
<td>Rice farming 91%</td>
<td>Rice farming 91%</td>
</tr>
<tr>
<td></td>
<td>Livestock 73%</td>
<td>Livestock 67%</td>
<td>Livestock 73%</td>
</tr>
<tr>
<td></td>
<td>Fishing 67%</td>
<td>Fishing 64%</td>
<td>Fishing 67%</td>
</tr>
<tr>
<td></td>
<td>Other 65%</td>
<td>Other 60%</td>
<td>Other 66%</td>
</tr>
<tr>
<td></td>
<td>Other crops 63%</td>
<td>Other crops 49%</td>
<td>Other crops 63%</td>
</tr>
<tr>
<td>Main sources of income (% total income)</td>
<td>Fishing 27%</td>
<td>Fishing 30%</td>
<td>Fishing 28%</td>
</tr>
<tr>
<td></td>
<td>Rice farming 19%</td>
<td>Rice farming 20%</td>
<td>Rice farming 19%</td>
</tr>
<tr>
<td></td>
<td>Livestock 16%</td>
<td>Livestock 14%</td>
<td>Livestock 15%</td>
</tr>
<tr>
<td></td>
<td>Petty trade 12%</td>
<td>Petty trade 13%</td>
<td>Petty trade 13%</td>
</tr>
<tr>
<td></td>
<td>Other 12% Farm labour</td>
<td>Other 13% Petty trade</td>
<td>Other 9%</td>
</tr>
<tr>
<td>Average household income (US$ per year)</td>
<td>786</td>
<td>589</td>
<td>688</td>
</tr>
<tr>
<td>Average livestock index</td>
<td>18.9</td>
<td>19.8</td>
<td>19.4</td>
</tr>
<tr>
<td>Average landholding (ha)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Average yrs of schooling</td>
<td>1.3</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Average household size</td>
<td>5.1</td>
<td>10.0</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Livestock index measures estimated using the conversion index by Taylor and Turner (1998)

Table 2. Key characteristics and household assets by village, irrigation development case study, Kampong Thom province

66. According to the household survey, the head-user village is richer in its asset base and has a higher average income than the end-user village. This finding is also consistent with prior village survey data (SEILA 2006; see Annex A, Table 7). Some of the income differences can already be related to the irrigation scheme as the location of Snao, the head-user village, with regard to the scheme is more favourable, and thus even prior to the operation some indirect benefits had been accruing there. For example, Snao highlighted the problematic nature of the compensations and resettlements. Many villagers expressed concern about the village chiefs not representing the different stakeholders in the village fairly in this process. The land losses due to the scheme have occurred in both Santuk and Baray districts (see also FACT 2004).
villagers worked as labourers during the construction phase, and the vicinity of the reservoir has brought an increasing number of tourists to the area.

67. There were no marked differences observed between the villages in terms of social capital. In both villages, several self-help and indigenous associational initiatives exist. However, the level of institutional capital in terms of links to higher level and/or state institutions seems to be rather low in both villages. This represents a common situation in the rural areas of Cambodia (cf. Pellini and Ayers 2005). Related to this, there seems to be a lack of confidence in the initiatives of higher level officials and some suspicion related to the projects coming from outside.

III.2.4 Influence of the irrigation and rural infrastructure development on livelihood outcomes

68. It is still too soon to assess the direct impacts of improved irrigation, but the influences of other aspects of the infrastructure project are noted. The Stung Chinit Irrigation and Rural Infrastructure Project (SCIRIP) has been delayed, and as a result the actual irrigation structures of the project only became operational in 2006, three years later than originally planned. The long construction period meant additional hardship for the villagers, as some of the canals were closed for long periods during the construction work and farmers were not able to get water to their fields. The water gates letting the reservoir water into the rice fields were opened on 20 July 2006.

69. Consequently, the surveys under this study were carried out too early to assess the actual impacts of the irrigation project as the first crop cultivated under the irrigation system had not even been harvested (harvest took place in December-February) when the surveys took place (in September). Instead, the case study can address only the impacts that had already emerged—mainly due to construction of the irrigation structures—and illustrate some of the possible future impacts that were addressed during the surveys.

70. Livelihood portfolios have diversified in all wealth groups, but for different reasons. In both villages, the households have become slightly more diversified in terms of their livelihood activities (see Annex A, Table 8). However, it is important to distinguish whether this change is due to a “push” (increased threats to the traditional livelihoods) or a “pull” (promising new opportunities). The poor household may diversify out of the need to make their living, while richer households may diversify in order to maximise their outcomes. In the case of the head-user village, it seems that households have been pulled to diversify because of new opportunities offered by being close to the built structures (Annex A, Table 9), while in the end-user village, diversification has resulted from a decline in income (Annex A, Table 10). This conclusion is supported by the survey result showing that in the end-user village, more households are currently engaged in farm and non-farm labour compared to before the irrigation project was built (Annex A, Table 8).

71. In the head-user village (Snao), the percentage of households participating in fishing activities has increased from 51 percent before the irrigation project to 67 percent at

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6 The delay of the project is related in part to changes in project design, including a reduction of the project area from around 7,000 ha to less than 3,000 ha. The original TA documents underestimated the costs of the project and included estimates of the internal economic rate of return which have since been revised downward.

7 Livelihood adaptation is defined as the continuous process of change to livelihoods, often geared towards enhancing security and wealth, reducing vulnerability and poverty (Ellis 2000). Adaptation can be positive or negative; it is positive if it is by choice, reversible and increases security; negative if it is out of necessity, irreversible and fails to increase security. Negative adaptation leads to the adoption of a successively more vulnerable livelihood system over time (Davis 1999).
In both villages, the percentage of households engaged in rice farming has increased marginally. The percentage of households engaged in livestock rearing has shown a significant increase from 58 percent to 73 percent in the head-user village, while it has registered a marginal decline from 69 percent to 67 percent during the same period in the end-user village. Significant increase in diversification into livestock (particularly pig rearing) in the head-user village could have resulted from increased market access (a “pull” towards livelihood diversification).

72. **The distribution of income from fishing has been affected by the reservoir.** The contribution of fishing to household income in the head-user village has increased significantly from 21 percent before the project to 27 percent at present, while in the end-user village (Sa’ang), the contribution from fishing to total income has declined from 47 percent to 30 percent. The increase in the contribution from fishing in the head-user village may be credited to the reservoir, while the villages in the end-user village reported that the decline in contribution of the fishery is due to increased competition from other fishers downstream. As shown by the quantitative study, livelihood options, particularly in the head-user village, have increased and household income portfolios have become diversified, thereby spreading risk and reducing vulnerability to food insecurity, poverty and income fluctuations. Despite a decrease in the contribution of fishing to total household income for those in the end-user village, it continues to be the highest contributor to household income on average (Annex A, Table 9).

73. **Overall, villagers in the two case study villages were not particularly concerned about the irrigation project’s possible impacts on fisheries.** For example, in the end-user village, where the involvement in fishing was clearly higher, the villagers were actually more concerned about the impacts of downstream fishing activities than on the impacts of the irrigation scheme *per se*. In general, the villagers in both cases have noticed an overall decline in the availability of fish, and this trend is feared to continue. Illegal fishing is seen as the main reason for the decline, and better control of illegal fishing activities is considered to be the key to stop the decline. At the same time, the project has brought benefits particularly to members of the head-user village as they have easy access to the reservoir as well as to the areas just downstream of the spillway. Both of these areas have seen increased availability of fish (at least temporarily) after the construction of the spillway. Finally, it is important to remember that both study villages are located within the scheme, and the project’s impacts further away downstream and upstream from the dam and spillway were therefore not assessed by the surveys.8

74. When discussing specifically the impacts caused by the irrigation structures, the main impact locals perceived was that the structures –essentially the dam and the spillway – block fish migration between the Tonle Sap and areas upstream from the reservoir. According to villagers, the reason for this is that the water flow in the spillway is too strong. In addition, there is only one way for fish to pass through the water gate (i.e. fish pass), and it still seemed unclear for villagers at this point whether the fish pass was actually functioning. In addition, during the construction phase of the dam and spillway, the partial destruction of the Stung Chinit dam in 2005 killed many fish, and villagers in the end-user village also lost their boats and fishing equipment.

75. **Households’ ability to take advantage of opportunities provided by the irrigation and infrastructure scheme depends significantly on other assets.** Households with more education and livestock holdings are better positioned to take advantage of more profitable opportunities (Annex A, Table 10). Though the direct impact of the built structure through the irrigation scheme is yet to be realised, some of the indirect impact have been felt by the households, particularly those in the head-user village. Similar to the situation in Pursat, households belonging to the richer group registered a much higher

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8 For a more thorough assessment of the impacts of the dam and irrigation system on fisheries, see the companion fisheries component report within this technical assistance study.
increase in their income (Annex A, Table 11) suggesting that the richer households have more capacity to take advantage of the opportunities. Qualitative findings also support these conclusions. The households’ possibility to make use of the emerging opportunities from the development of the irrigation structures depends very much on the larger context where the development happens. The wealthier households usually have better capacity to adapt to changes.

76. In the case of the irrigation project in Stung Chinit, it is yet too early to clearly say which groups are set to benefit most and if the project will really bring equal benefits to the villagers living in the project area. It is, however, relatively evident that – similar to many other infrastructure projects with participatory institutional arrangements – the farmers’ water-user groups in Stung Chinit, which have been set up as part of the scheme, face the possible risk of being dominated by the local elite and thus failing to include the poorest and weakest groups. In addition, the sheer scale of the Stung Chinit scheme adds to the challenge, as experiences from other irrigation projects demonstrate that equitable water distribution is more commonly achieved in smaller-scale systems than in large ones (Hussain et al. 2006).

77. The quality of local participation in infrastructure planning is key in villagers’ perception of the scheme’s suitability and their willingness to invest in long-term maintenance. The findings from the Stung Chinit irrigation project illustrate the challenges related to participation of local villagers in the planning and construction phases of the project. Based on the interviews, most villagers in both case study villages feel that they did not have possibility for real participation during the planning of the project, but were just briefed about up-coming project activities. At the same time, villagers consistently expressed a desire to have more input into technical decisions, so that the hoped-for benefits of improved irrigation would be realized. One of the reasons for the communication difficulties was related to language. As one respondent described, “They [project staff] used too technical language and we were afraid to say anything”.

78. Feedback from villagers included in the study suggests inadequate local ownership. In the case of Stung Chinit, the farmers’ participation is wanted for the maintenance of the structures, but the villagers seem to be bit hesitant about this, as they feel their participation was not encouraged during the planning and construction phases. The results from the Stung Chinit case indicate that it will be difficult to create ownership of local farmers only at the later stages of the project.

79. Comparison with other irrigation and water management projects suggests that many of the planning and management challenges of the Stung Chinit scheme may be related to its large scale. Other studies have suggested that the risks of large-scale infrastructure projects are generally greater than those of smaller-scale projects. The scale of the impacts of a possible failure is greater in a larger project while in a smaller project, there are more chances for correction during implementation and running of the scheme (Öjendal 2000). Also, participation and mobilization of local farmers is more challenging the larger the scale of the project is. There are also studies demonstrating that equitable water distribution in a smaller-scale system is more likely than in a large one (see e.g. Hussain et al. 2006). In the specific case of Cambodia, there have been concerns about large-scale projects because of the lack of sufficient capacity for their planning, construction and maintenance (Molle 2005, Öjendal 2000).

80. Examples around the world indicate that in large-scale solutions the costs of construction and running are often higher than anticipated and that the cost recovery in terms of water fees is difficult (Öjendal 2000). In the Stung Chinit scheme, some interviewed for this study are beginning to question the local economic benefits of the investment, a concern raised by other observers as well (cf. FACT 2004). In Cambodia, a special challenge is related to intersectoral coordination (cf. e.g. Ovesen et. al. 1996, Öjendal 2000, Molle 2005). Due to its scale and integrative approach, the Stung Chinit project has different
components under the responsibility of different government sector agencies. The communication and cooperation between the agencies seems, however, not to have worked as well as planned\(^9\).

### III.3 CASE STUDY 3. FISHING LOTS IN AND AROUND PREK TOAL CORE AREA, BATTAMBANG PROVINCE

#### III.3.1 Context: Linking large fishing structures and fishing lot management systems to livelihood outcomes

81. The built structure studied in the Battambang case consists of large-scale bamboo fences used in the fishing lot. The fences form a barrier across the floodplain for fish leaving the inundated floodplain on their way back to the lake when the flood recedes. The physical closure of the lot by bamboo fences starts when the water begins to recede in January and February. It is thus the lot management system, with its privileges granted to leessees, rules for restricted access and relatively effective enforcement of access, that has the main influence on local livelihoods, and not the physical structures themselves.

82. Thus, in assessing livelihood outcomes, the influence of the physical built structures (large bamboo fence gear) is inseparable from the management system of the fishing lots. The qualitative study looks broadly at how the restricted access and the management practices of the private concessions are perceived to influence the local communities. It also focuses on the successes and shortcomings of community fisheries management practices. In addition to fishing Lot #2, the study also examines the experiences of community fisheries in the area formerly covered by Lot #3. The experiences related to the release of Lot #3 are relevant in order to understand some of the opportunities, challenges and constraints that the cessation of commercial fishing lots could bring. The quantitative analysis, on the other hand, concentrates mainly on comparing the livelihood outcomes before and after the release of Lot #3.

#### III.3.2 Characteristics of the study villages and livelihood assets

83. The case study in Battambang includes two main villages, Prek Toal and Thvang. The villages differ in their location, with Prek Toal being closer to the Tonle Sap Lake (TSL), closer to Lot #2 and closer to the commune centre, while Thvang is situated 8 km upstream along Stung Sangkae without any areas connected directly to Lot #2. Villagers of these two sites have different access to fishing grounds and Community Fisheries Areas (CFA) as shown in Table 3. Additionally, Peak Kantiel, situated between Lots #1 and #2, was included in the qualitative study to represent a village\(^{10}\) under more direct influence of the lot system and with no direct access to the Community Fisheries Area.

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\(^9\) For example, agro-ecosystem analysis of the project – a prerequisite for any irrigation scheme – was carried out only after the design of the structures had already been completed. In addition, one key-informant from the project indicated that the construction of new roads and markets is not well connected with the actual scheme.

\(^{10}\) Officially, Peak Kantiel is a settlement rather than a recognized village.
According to the village survey data from the previous study (Annex A, Table 12), the village far from the TSL (Thvang) seems to be slightly better endowed than the village close to the TSL (Prek Toal). The quantitative analysis shows, however, no major differences between the livelihood portfolios of the two main case study villages, as both are predominantly fishing communities (Annex A, Table 13). The main source of livelihoods in both villages is fishing and most of the other significant activities are also fishing-related, such as processing (including fish paste, salted, and fermented fish) and marketing. The better-off families also engage in cage culture of fish and/or crocodile rearing. The possibilities for livestock raising are understandably very limited, but some chickens and pigs are raised on the floating platforms for household consumption and sale. Farming is not feasible in the area as the riverbanks are inundated for most of the year (June-January) and the flooded forests in the nearby area are protected and theoretically cannot be cleared for agricultural purposes.

The distance from the commune and less frequent connections to centres such as Chong Kneas harbour in Siem Reap make Thvang more isolated than Prek Toal. There are currently no NGOs working in Thvang, and there have been far fewer development projects than in Prek Toal where, for example, the environmental NGO “oSmoSe” has been active. The distance from the communal offices also makes Thvang less frequently patrolled by the local authorities. The internal differences and divisions are actually notable in both villages. One categorising factor for the fishers is their financial resources which distinguishes those who fish primarily for subsistence from those who market more of their catch. Ethnicity (ethnic Vietnamese and Khmer) is also an important distinguishing characteristic, as is the distinction between the villagers and the seasonal fishers from outside the area.

In terms of social capital, the villages in the Battambang case study seem to be worse off than in the two other case study sites. At the village level, the relations between the different social groups are often characterised by competition over fish resources, and solidarity between the different social groups seems to be quite low. There are also
internal patron-client relations, and the poorest groups seem to be highly indebted to their wealthier neighbors. There are, however, also more horizontal networks in the form of indigenous associations e.g. related to schools, funeral arrangements, and communal platform management that seem to work rather well. Villagers spoke of being much more comfortable in dealing with local village leaders as compared to other officials from outside the immediate area.

### Livelihood assets

<table>
<thead>
<tr>
<th></th>
<th>Prek Toal</th>
<th>Thvang</th>
<th>Battambang case (combined)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village location and proximity to Tonle Sap Lake and the fishing lot</td>
<td>Close to Lot #2 and Tonle Sap Lake</td>
<td>Far from Lot #2 and Tonle Sap Lake</td>
<td></td>
</tr>
<tr>
<td>Fishing locations and access to Community Fisheries Areas (CFA, former Lot #3)</td>
<td>Fishing in Tonle Sap Lake, Lot #2 and CFA also in Lot #4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main livelihood activities (% households participating)</td>
<td>Fishing 100% Fishing</td>
<td>96% Fishing</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td>Other 80% Other</td>
<td>96% Other</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>Fishing labour 38% Fishing labour</td>
<td>20% Fishing labour</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td>Fish culture 20% Fish culture</td>
<td>27% Fish culture</td>
<td>23%</td>
</tr>
<tr>
<td>Main sources of income (% of total)</td>
<td>Fishing 65% Fishing</td>
<td>69% Fishing</td>
<td>67%</td>
</tr>
<tr>
<td></td>
<td>Other 16% Crocodile</td>
<td>11% Other</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Fish culture 6% Petty trade</td>
<td>9% Fish culture</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Crocodile 5% Other</td>
<td>5% Petty Trade</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Fishing labour 5% Fish culture</td>
<td>3% Fish culture</td>
<td>4%</td>
</tr>
<tr>
<td>Average household income ($US per year)</td>
<td>984</td>
<td>1083</td>
<td>1033</td>
</tr>
<tr>
<td>Average livestock index</td>
<td>2.0</td>
<td>4.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Average yrs of schooling</td>
<td>3.0</td>
<td>2.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Average household size</td>
<td>5.6</td>
<td>6.2</td>
<td>5.8</td>
</tr>
</tbody>
</table>

*Livestock index measures estimated using the conversion index by Taylor and Turner (1998)*

**Table 3. Key characteristics and household assets by village, fishing lot case study, Battambang province**

### III.3.3 Influence of the fishing lots on livelihood outcomes

87. **Fishing remains the main source of income in both villages; the overall decline in fish catch per household highlights a significant vulnerability.** Survey results show a decline in the fish catch per household in both villages during the recent season (2005/2006) as compared to before the release of Lot #3 (2000/2001). That decline is most significant in the village near the TSL (Prek Toal). Such a decline in the fish catch per household may be influenced by increasing pressure from migrants coming from other provinces like Kampong Thom, Siem Reap, Kampong Cham and Banteay Meanchey. However, the sales/catch ratio remains the same in both periods. This has resulted in a drop in the contribution of fishing to the total income, but fishing remains the dominant source of income.

88. **Livelihood portfolios have diversified because of other opportunities becoming available, but also in response to the decline in income from fishing.** In both villages the livelihood portfolio has become slightly more diversified, particularly in response to the loss of income per household from fishing sources (Annex A, Table 13). But fishing is still the main livelihood source for the majority of the households, signifying the higher dependence on fishing activity.

89. The contribution of fishing to average household income has declined from 75 percent before the release of Lot #3 to 65 percent after the release in the village near the TSL (Prek Toal), and from 85 percent to 69 percent in the village far from the TSL (Thvang). (See Annex A, Table 14). The contribution from fish culture has declined in the former village but it has remained at the same level in the latter. The contribution from crocodile culture has shown a significant increase in both villages. In the village far from the TSL,
the contribution from petty trade has increased significantly from 2 percent to 9 percent. The contribution from other activities has also registered an increase in both villages.

90. **The release of fishing Lot #3 has opened access to local villages but also increased competition with outside groups; livelihood benefits for local villages are less than anticipated.** The main change in both villages due to the release of the Lot #3 was the increased access to the fishing grounds that were previously restricted during the open season from October to May. This provided new fishing grounds for those households that previously could not afford the licenses and were thus solely dependent on fishing outside the restricted area (the river, near-by flooded forest or the lake). The increased access provided better chances to secure yearround subsistence and income. For the previous sub-leasees, the change did not offer entirely new fishing grounds, but less expensive and less controlled access. The downside was, however, that the fishing domain became more crowded than before.

91. The release opened the restricted area not only for the locals, but also for fishers from outside. After the release the number of seasonal migrants, mostly from upland areas\(^{11}\), has been growing and new social tensions have emerged between these newcomers and the locals. Many local fishers pointed to the seasonal migrants when asked to explain the decline in catch per household, but there is little direct evidence. The actual role of the seasonal migrants and their indirect influence on local livelihoods requires further research, also to gain a better understanding of their motivations and possible methods to ease the pressure on Tonle Sap Lake fisheries by upland farmers.

92. **The continued operation of Lot #2 entails significant trade-offs in terms of conservation, economic returns, and equity.** Although fishing inside the lot is intensive, the exclusive management system does provide a controlled habitat for fish and other fauna, which may provide a conservation benefit as compared to more open access. The lot system with armed patrols and guards and heavy penalties and fines effectively keeps unwanted fishers out of the area, while the subleasing system provides the possibility to identify and regulate the fishers within the lot. The management system in effect channels economic benefits to the lot concessionaire, while restricting local villagers’ access to the most productive fishing areas of the Tonle Sap Lake. There are also regular complaints about restricted transportation routes that leave the fishers without access to the flooded forests on the other side of the lot.\(^{12}\)

93. On the other hand, negotiations and commercial partnerships take place (cf. Goes 2005). The lot provides rich fishing grounds for those who can afford to sublease fishing grounds (streams or lakes) or other sections of the lake from the operator. For the poorest groups, the lot provides working opportunities in patrolling and fish processing, particularly to households in the lower income group. However, outside labour increasingly appears to be substituted for this local employment, and the use of processing machines is reducing the overall labour demand.

94. Lot operations also appear to undermine the legitimacy of official management interventions and law enforcement in the eyes of local villagers. Villagers reported receiving conflicting information about the boundaries and regulations of the lot and obligations of the lot concessionaire, with the result that they frequently feel decisions are arbitrary. Interviewees regularly expressed frustration about the reluctance of fisheries officials to take action on lot practices which they suspected to be illegal or destructive. In

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\(^{11}\) Villagers reported seasonal migrants from Siem Reap, Kampong Thom, Pursat, and Banteay Meanchey provinces, as well as upland areas of Battambang, coming to access the community fishing area (formerly Lot #3) during the period February – May before returning to their home villages for the rice harvest.

\(^{12}\) Villagers reported that the concessionaire of Lot #2 does not allow villagers to travel through the lot to the common fishing area located on the other (upland) side of the lot, although this was allowed before and the villagers’ right to cross the lot seems also to be stated in the lot’s burden book.
addition, many villagers found the community fishery regulations that restrict fishing to small-scale gears hard to justify, as compared to the entitlements given to the lot operator.

95. **Households’ ability to take advantage of opportunities provided by the release of the lot depends significantly on other assets.** Wealthier and more educated households are significantly more represented in community fisheries, and are realizing a significantly higher catch per household as compared to poorer households. The study finds that there is a direct correlation between household assets and the capacity to benefit from the opportunities offered by the reforms (Annex A, Tables 15 and 16). Survey results show that chronically poor households have lower levels of education, financial capital and livestock assets. This finding is supported by the qualitative analysis that shows inequality in benefits derived by households from the community fishery areas.

96. One might anticipate that the group most benefiting from increased access to fishing areas would be the poorer fishers who, prior to the release, were unable to pay for access. Many villagers interviewed reported, however, that richer fisher groups have maintained their higher income level, and intensive large-scale fishing activities have continued despite the community fishery regulations that allow only family-scale fishing. Several interviewees claimed that local power imbalances have enabled wealthier households to capture the community fishery area’s best locations, and to restrict the access of poorer groups. These imbalances are not merely about wealth, but also reflect differences in peoples’ access to decision-making. As stated by a poor fisherman: “*If we have conflict over fishing activities with rich people who are involved in large-scale fishing activities, we can’t win...*”

### III.4 COMPARATIVE FINDINGS

97. In this section, we analyze both qualitative and quantitative findings from the three case studies from a comparative perspective, incorporating additional analyses to draw conclusions regarding trends in income inequality, poverty, and the role of household assets in influencing people’s ability to capture benefits from the changes in built structures.

**III.4.1 The institutions and processes of planning and managing built structures are highly influential in determining livelihood outcomes**

98. All case studies demonstrate that livelihood outcomes (e.g. access to natural resources, income benefits, and equity) cannot be predicted based on physical structures per se. The allocation of benefits and costs from built structures depends strongly on processes of planning and management. With poor planning and management, the built structure’s benefits threaten to be short-term and unequal (with better-off households benefiting more), and costs unbearably high for some stakeholders (e.g. downstream fishers). Well-functioning management is thus crucial for equal distribution of benefits, and consequently for poverty reduction. The success of planning and management is related to the institutional and socio-political structures at different levels of society (see also Kibler and Perroud 2006).

99. For all types of built structures, the planning phase with prompt environmental and social impact assessments is crucially important. With regard to fishing structures, the questions about planning and management primarily refer to rules about access, gear restrictions, and the enforcement of these. In terms of roads, the most important aspect of management is maintenance, which is also very important with the irrigation structures, and more complex. A common management issue for both community fisheries committees and farmers’ water user groups is conflict settlement between the users.
100. The case studies demonstrate that informal institutional structures and arrangements are often not well incorporated into the implementation of built structure projects. Yet, against the commonly held idea of the lack of social capital in Cambodia (e.g. Ovesen et al. 1996), many of the studied communities illustrated strong capacity and will to act collectively. In all case studies, the project interventions had acknowledged at the planning stage the need to set up appropriate community user groups. However, in each case, community members also reported unfulfilled expectations related to participation. A common challenge related to irrigation structures and roads was the difficulty in changing the role of recipients to active and responsible partners in maintenance.

101. While the new institutional and participatory arrangements (user groups, community fishery committees, etc.) are set up to secure more long-term and equal benefit allocation, they can also have exactly the opposite consequences. The case study on community fisheries, for example, demonstrated how community user groups can fail to include the poorest groups. This partially explains why progress in poverty reduction is slow in some areas (see section III.4.5).

III.4.2 On average, household income is rising and livelihood portfolios are diversifying, though the influence of built structures on these trends varies significantly by case.

102. Survey data shows that overall average income increased for all villages included in the study (Figure 6). In all cases, survey respondents overwhelmingly judged the changes in built structures as positive, in reference to the construction of the road in Pursat (100 percent), the irrigation scheme in Kampong Thom (96 percent), and the removal of Lot #3 in Battambang (93 percent).

103. In the case of the road development, there is strong evidence that the road is significantly contributing to improvements in income and other positive livelihood changes. The comparison between the Khmer village and the Cham village, both of which are near the road, shows that the increases in overall income are higher in the Cham village, which may be attributed to high social and financial capital among villagers that enable them to take advantage of the new livelihood opportunities emerging with the road development. For the irrigation project, it is still too soon to determine the net effects of the irrigation and infrastructure scheme, but expectations about the future point to a strong anticipated benefit in terms of an increase in average income for the villages studied. Of the two villages near the irrigation project, the income increase is higher in the head-user village, where there are both higher asset endowments and a favorable location within the core of the project area. Finally, in the case of fishing structures, both villages experienced an increase in income, but for different reasons. For the village far from the TSL, such an increase may be largely explained by gains among the wealthier households from crocodile farming and improvements in fish catch. In the village near the TSL, though some households are benefiting from the increased access offered by the removal of Lot #3, many, and particularly poorer, households are not (discussed further below in section III.4.4).
Figure 6. Change in average annual household income by village, in US$ equivalent

104. Most households are diversifying their livelihood portfolios, which appears linked variously to new opportunities from changes in built structures and to new risks. Across the three study sites, the survey results show a modest decline in the degree of reliance on wild fisheries as a source of income, but fishing and fishing-related activities remain the leading sources of income. (Figure 7). For many households, this appears to reflect a reduction in vulnerability as they shift their livelihood strategies to spread risk. For other households, particularly those who are diversifying with no gains (or only minor gains) in income, it seems to be better explained as a necessary reaction to declining opportunities from traditional livelihood sources. Note, however, that, in the case of the fishing structure, the dependence of the villages on fisheries resources is relatively high, despite increased livelihood diversification.

Figure 7. Comparison of income portfolio diversification within each case study site before and after the change in built structure, shown as percentage contribution of various livelihood activities to average household income
III.4.3 In the villages studied, the built structure changes are generally benefiting wealthier households more; many poor households are also benefiting, but at a slower rate.

105. In addition to assessing the influences of built structures on livelihoods at the aggregate level (comparisons among communities), it is important to examine the relative benefits for different social groups (comparisons among households). Who is gaining most? Who is falling behind? Answers to these questions are essential in designing future infrastructure investments and complementary policy interventions. Note, however, that evaluating such trade-offs requires a broader perspective – assessing the potential gains and losses for all communities affected, including those farther upstream and downstream. The results in this report address only the villages studied, which were all intended beneficiaries of the interventions.

106. The rural households are placed differently in terms of their capacity to benefit from the opportunities provided by the road, the irrigation scheme and related infrastructure, and by the release of the fishing lot. This survey analysis confirms that households with higher asset endowments generally have been able to capture higher return (more profitable) activities, while poorer households are left with low return activities. Poorer households lack capital to makes investments in more remunerative activities, and other assets to take advantage of the changing opportunities (see section III.4.5 below).

107. Income inequality generally remains high in the study sites. According to the survey results, it has generally been slightly reduced in most of the villages studied, except in two villages, the Khmer village far from the road (Ou Ta Prok Up) and the fishing village near the TSL (Prek Toal), where it increased (Figure 8).

![Figure 8. Change in income inequality, by village, as measured by the gini coefficient of inequality](image-url)
III.4.4 With few exceptions, chronically poor households are not yet benefiting enough to step out of poverty.

108. The two previous subsections focused on trends comparing changes among different economic groups within the study villages. In this section, we conduct the analysis with reference to the nationally-defined poverty line\textsuperscript{13}. This provides a means of assessing progress in poverty reduction, and the dynamics of households’ movements in and out of poverty. It is important to note the distinct differences among the study villages in reference to this national norm. The study villages in the road development and irrigation cases are poor compared to the average for rural Cambodia, while those in the fishing lot case are relatively well off in relation to the floating villages of the Tonle Sap.

109. In terms of absolute measures of poverty, survey results from most of the study villages indicate either no change or a slight decline (Figure 9). Despite having the lowest incidence of poverty at the initial time period (before the fishery reforms), the village near the TSL (Prek Toal) is the only village in the study where survey data shows an increase in both incidence of poverty (the percentage of households categorised as falling below the poverty line) and depth of poverty (how far below the poverty line these households are on average).

\textbf{Figure 9. Change in incidence and depth of poverty, by village}

110. The ability of villagers to rise above poverty is assessed to provide some inference about the influence of built structures. In this analysis, households are categorised as chronic poor and ‘non-chronic’ poor. The “chronic poor” are defined as households that remained

\textsuperscript{13} The poverty line is defined as the minimum requirement for subsistence living in monetary terms. Poverty line information is taken from World Bank (2005) and JICA (2001). Poverty measures were estimated using Foster, Greer, and Thorbecke's index (Foster \textit{et al}. 1984).
poor between the period prior to the built structure development (or, in the fishing lot case, prior to the removal of the fishing lot) and the current period. The “non-chronic poor” are households above poverty line during both time periods. The latter group also includes those who are “vulnerable to chronic poverty” (previously in the non-poor group but then fell below the poverty line), and those who were previously in the poor group but then managed to move above the poverty line.

111. Based on the current study, there is no indication that the chronically poor households (normally those with the lowest asset endowments) are benefiting enough to step out of poverty. The increase in the average absolute income of the chronically poor households is much lower than the non-chronic poor, highlighting again that the most disadvantaged have gained less than other households from the changes in livelihood opportunities, including those related to built structures. (See Figure 10.) The analysis shows that on average the non-chronic poor in each study village increased their incomes between 2 and 10 times more than the chronic poor, with an overall average of 3.2 times more.

![Figure 10. Change in average household income, chronic versus non-chronic poor](image)

112. Chronic poverty is severe in the road development and irrigation sites, and still significant in the fishing lot site. On average, over the period studied, there have not been large numbers of households stepping out of poverty. But the trends vary significantly by village. For the road development case study in Pursat, a significant positive trend of people moving out of poverty has been observed: 13 percent in the Cham village near the road (Chong Khlong), 10 percent in the Khmer village near the road (Ou Ta Prok Main) and 7 percent in the Khmer village far from the road (Ou Ta Prok Up). In the case of the irrigation project, chronic poverty remains high, most notably in the end-user village (Sa’ang). In the fishing lot case study, a significant percentage of households have moved out of poverty – 21 percent in the village near the TSL (Prek Toal) and 23 percent in the village far from the TSL (Thvang), but an almost equal number have slipped below the poverty line, demonstrating a relatively dynamic situation. (See Figure 11.) However, keep in mind that the time period in consideration for the fishing lot case study in Battambang is also longer – five years as opposed to three for the other cases – so more change is to be expected.
III.4.5 The capacity to take advantage of new livelihood opportunities offered by changes in built structures depends on other household assets, particularly education.

113. The study also shows a strong relationship between household asset endowments and the capacity to take advantage of opportunities offered by changes in the physical environment (built structures) and related institutions. The asset endowment of households plays a major role in determining the influence of built structures and related institutional reforms on livelihoods. This finding is consistent with other research in development economics showing that household asset endowments are critical determinants of acute and chronic poverty, vulnerability and income (Gaiha 1992, Gaiha 1989, Gunawardena 1982, Jalan and Ravallion 1998, Makhanya and Ngidi 1999).

114. Quantitative analysis of the survey data shows education is the most significant variable in explaining the ability of households to get out of poverty; next is livestock, a form of savings (see Annex A, Table 23). Landholding was not shown to be a statistically significant contributing factor to the ability of households to move out of poverty (Annex A, Table 24). Indeed, counterintuitively, in two case study villages (Sa’ang and Ou Ta Prok Main) the chronic poor actually have slightly more landholdings than the non-chronic poor (Annex A, Table 23). However, these villages also have the highest rates of chronic poverty and their landholdings are relatively small. Financial capital also seems to play a crucial role in determining the influence of built structures on chronic poverty. Physical proximity to the structure is a less important factor in making comparisons among the households studied (though location would be very important in the case of clear upstream-downstream impacts).

115. In the qualitative analysis, social capital emerged as a key factor in explaining the degree to which the benefits of changes in built structures were broadly shared or captured by more privileged households alone. In the fishing lot case, particularly in the village near the TSL (Prek Toal) the relations between the different social groups are characterised by

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14 These findings are indicated both by a simple correlation analysis (Annex A, Table 23), and by a regression analysis that measures the statistical significance of correlation independent of other variables (see Annex A, Table 24, with accompanying note.)

15 Non-chronic poor consist of three groups, namely: those who were above the poverty line in both periods, those who were previously above but then dropped below the poverty line (“vulnerable to poverty”), and those who moved above the poverty line (“out of poverty”).
competition over the fish resources, and the solidarity between the different social groups seems to be quite low. In addition, the management of community fisheries seems to be in the hands of local elites, which has resulted in an unequal distribution of benefits with poorer and weaker groups suffering more. In the road development case, on the other hand, the differences in social organisation within the villages explains in part why the Cham village (Chong Klong) – with more active and effective community organizations – has benefited somewhat more than the Khmer village (Ou Ta Prok) from opportunities brought by the new road.
IV CONCLUSIONS

116. This study has examined cases involving three different types of built structures in an effort to draw broader conclusions concerning the influence of built structures on local livelihoods around the Tonle Sap Lake and beyond. Building on the case studies, what more general conclusions can we draw?

117. First, the type of built structure clearly influences how direct benefits are distributed. The case studies illustrate that different types of built structures (roads, irrigation schemes, fishing gears) have different degrees of openness or exclusion in terms of the ability of poor households to access the livelihood opportunities enabled by the structures (see Figure 12). Overall, roads are most open as they provide public access with no direct exclusion. Irrigation is meant to bring livelihood benefits by increasing the seasonal availability of water, but still to a limited group, i.e. for landholders within the irrigation scheme and possibly to laborers and marketers nearby. In addition, the irrigation reservoir creates a new open access resource for fishing, although access to the reservoir may be limited by different kinds of regulation and management practices. Fishing structures in the lots are clearly most exclusive as they in effect funnel benefits to a small group and exclude the majority from the fishing area. Other institutional implications concern demands for conflict resolution, maintenance, and decision-making related to the distribution of direct costs and benefits from the intervention.

<table>
<thead>
<tr>
<th>Pursat case: Roads</th>
<th>Kampong Thom case: Irrigation structures</th>
<th>Battambang case: Fishing structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of exclusion</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Need to settle conflicting interests</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Maintenance / local ownership</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Importance of equal distribution</td>
<td>Relevant only in additional interventions (larger context)</td>
<td>High</td>
</tr>
</tbody>
</table>

Figure 12. Institutional implications of different built structures in the case studies

118. Yet there is also much we can say that applies across different types of built structures in different social and ecological settings. Institutions matter quite significantly, in ways that enable positive livelihood strategies (for example, through effective participation and consultation in project planning), and that disenable opportunities for the poor (for example, through mechanisms that reinforce inequitable access to aquatic resources and their livelihood benefits). (Refer to Figure 2.) This finding is also strongly supported by other studies (see, for example, Kibler and Perroud 2006). Scale also matters, as many of the factors that either threaten local livelihoods or open new opportunities are not within the direct influence of local communities. The cross-scale factors that emerged as significant in the case studies include such issues as seasonal migrants making use of community fishing grounds, markets that develop to provide for a demand for local products (e.g. pig rearing), and, of course, environmental factors, including the relationship between hydrological change, habitat, and fisheries productivity.
Built structures – by definition, purposeful modifications to the physical environment – clearly do affect livelihood outcomes, but they are by no means a “magic bullet.” This study examined the influence of changes in both directions, namely interventions to introduce new (or improved) structures as with roads and irrigation schemes, and interventions to remove structures (large fishing gears associated with the fishing lot). In all cases, the changes were justified on the grounds of poverty reduction. Yet, as the study shows, progress in poverty reduction has been modest, and inequality remains high. While it will be some years before the outcomes of these particular cases can be measured conclusively, the results already raise a justifiable concern. The ability of individual households to take advantage of changes depends very clearly on other assets, especially education. In certain contexts, other assets such as livestock holdings may be key, and smaller family size may be an advantage. These observations signal the need to pay close attention to the livelihood context in which changes are being introduced, and the ways in which different households may or may not be able to benefit. In essence, it means considering infrastructure as one element in a broad array of useful investments to encourage pro-poor rural development.
V RECOMMENDATIONS

V.1 LINK PLANNING OF NEW STRUCTURES TO DECENTRALISED NATURAL RESOURCE MANAGEMENT

120. Planning, construction, and operation of built structures cannot operate in a vacuum and must have strong connections both to long-term management of the Tonle Sap’s natural resources and to local development planning. Many infrastructure projects seem to be considered short-term and localised interventions without appropriate consideration of the larger context in which they operate. In other instances, complex project management units and systems have been set up that isolate decision-making too much from local stakeholders and authorities.

121. The case studies indicate that the best way to ensure community involvement and ownership is to link planning of built structures to on-going processes of decentralised rural development and natural resources management. In terms of roads and irrigation canals, this would mean the planning processes led by commune councils and the forthcoming provincial and district councils in particular. In planning road developments, for example, this coordination is essential so as to identify and mitigate potential environmental impacts, particularly on fish habitat and migration routes, and to ensure that more remote local communities will indeed be able to access the main road. At the maintenance stage, too, intersectoral coordination remains critical, as responsibility for the maintenance of roads falls under the Ministry of Rural Development, culverts under the MOWRAM, and regulation of fishing effort under the Fisheries Administration. In both planning and maintenance, commune councils have a natural coordinating role to play, including where appropriate local organizations such as community fishery committees, road maintenance committees, as well as informal networks such as the Buddhist sangha or Muslim networks that have local legitimacy and can mobilize collective action.

122. In advance of the physical infrastructure, it is often necessary to strengthen local institutional capacity to address the new challenges to collective decision-making. Irrigation projects, for example, tend to be technically complex, so training is likely needed to help build effective communication between engineers, local officials, and community members. Support to establish and facilitate the work of water user committees is also helpful in promoting equitable water distribution and avoiding conflicts over operation and maintenance of the system. Similarly, future analysis and decision-making regarding the possible release of additional fishing lots should carefully consider the advance preparation of new local institutions to assume management and enforcement responsibility, as well as rules and conflict resolution mechanisms to address the increased competition from fishers within and outside the local area.

V.2 STRENGTHEN INSTITUTIONAL MECHANISMS TO INTEGRATE DECISION-MAKING ACROSS SECTORS AND GEOGRAPHIC SCALES

123. The Tonle Sap Lake’s ecosystem productivity is highly sensitive to changes in the flood regime. Even relatively small changes to the quantity and timing of flood patterns, and to the connectivity of aquatic environments may have significant consequences for the productivity of the lake, with direct and indirect implications for the livelihoods of millions of people. This demands an integrated approach to the area’s water resource management, connecting existing actors and information from different sectors and levels.

124. Social, economic, and ecological trade-offs stemming from alternative scenarios of infrastructure and water resource development need to be explicitly evaluated and publicly debated. Planned developments expected to have an effect on the flood regime need to be clearly summarised together, and their possible cumulative impacts assessed.
This requires a comprehensive database including information on projected developments at different geographic scales.

125. **Government policies and strategies should clearly prioritize the relative importance of different social and economic benefits derived from the fisheries of the Tonle Sap Lake.** In the case of fishing lots and community fisheries, this should address the trade-offs regarding the role of fisheries as a source of government revenue (a benefit of the lot system), a “safety net” for vulnerable groups from around the basin (a benefit of unrestricted access for small-scale fishing), or a source of wealth generation for lakeshore communities (a potential benefit of community fisheries organizations with appropriate implementation).

126. **An integrated approach should start by overcoming the communication gaps and improving cooperation between different sectoral ministries.** Priorities here include, for example, cooperation between the Ministry of Water Resources (MOWRAM) and the Ministry of Agriculture (MAFF) in irrigation planning, and between the Fisheries Administration and Ministry of Public Works in assessing the potential influence of road development on fisheries.

V.3 **ADOPT PROCESSES OF CONSULTATION AND PARTICIPATION IN PROJECT PLANNING THAT RECOGNISE THE DIFFERENCES AMONG LOCAL HOUSEHOLDS**

127. Stakeholder consultation and participation are key factors influencing the success of infrastructure projects. The fundamental question is how to further improve actual participation and consultation so that projects can result in more equitable resource allocation and a stronger sense of ownership. When this expectation comes too late, as when locals are asked to contribute their efforts primarily for maintenance once the structure has already been built, it is extremely difficult to build a genuine partnership.

128. Therefore, **more attention must be paid to participation and ownership from the very initial stages of project planning.** Active involvement of commune councils from the project area is required in reviewing potential infrastructure developments. At the village level, identification of existing networks (both formal and informal) and cooperation with locally respected leaders in all stages of the project is crucial. Regular information sharing is important so that the division of responsibilities is clear and the expectations not unrealistic.

129. **At the planning stage, it is important to analyze sensitively how the anticipated benefits and costs of a project are likely to be distributed among different social groups, taking into account the role of local institutions and differences in household assets.** The case studies demonstrate the importance of recognizing the heterogeneity of communities as well as the social groups within communities, considering not only wealth and income, but also education, ethnicity, the strength of social networks, and local power relations.

130. **Special provisions need to be made so that the poorest groups can indeed participate effectively.** A variety of approaches have been shown to be effective. NGOs that have legitimacy in the area, good local knowledge, and experience working with the more vulnerable households can sometimes be good intermediaries in bringing local insights and helping organise consultations with the poorest groups. Consultations conducted separately with more vulnerable groups, with women, or with ethnic minorities that protect individuals’ confidentiality can help ensure a more frank sharing of views. And, quite practically, it is important to provide appropriate compensation (such as meals and transportation) so that participation does not become an economic burden for the people involved. Even with such efforts, however, successful participation is not a uniquely local process. It is also contingent on the broader context of governance,
particularly the degree of accountability of public officials, which either encourages or discourages people from making the effort (and sometimes assuming the risk) of seeking a voice in public decision-making.

V.4 TARGET BUILT STRUCTURE INVESTMENTS WITH AN UNDERSTANDING OF HOW THE POOREST GROUPS CAN BENEFIT

131. This research has shown that even when the net benefits of infrastructure developments in terms of average household income appear to be positive, the poorest groups can be left behind. Addressing these distributional issues requires reconsidering priorities in terms of the links between infrastructure development and changes in livelihood opportunities, as well as types of infrastructure and their scale and complexity of operations.

132. **Be clear about the livelihood opportunities that structures are meant to help facilitate.** Because the influence of built structures on livelihoods varies significantly based on the institutional context, assets and vulnerabilities of households affected by the change, project planning should explicitly identify what groups are expected to benefit and how. Making these expectations clear helps facilitate informed public debate about whether the investment is worthwhile, or how it might be adapted to reach the groups intended. Such adaptations may include technical design modifications, as well as changes to the planned operation and management of the structures. With road development, for example, this may entail including smaller, feeder roads in the construction plan, or choosing labor-intensive building approaches that can help build financial capital among poorer households in the area while simultaneously developing a local skill base to support maintenance in subsequent years.

133. **Favor investments in structures with high degrees of openness in terms of social groups that can access the benefits.** Public roads are by design available to all users without a fee (apart from toll roads and possible maintenance fees), and access can be increased as the network of feeder roads expands. Irrigation systems deliver water to a defined area, so the number of people who can directly benefit is limited, though there are significant indirect benefits from associated labor opportunities, trade, etc. Large fishing structures are designed specifically to exclude the majority of fishers and channel the fish catch to a few; it would be very difficult to shift the institutional arrangements so that the benefits of such structures would be equitably distributed.

134. **Where feasible, favor smaller-scale projects that are more easily adapted to local needs, more easily managed locally, and less attractive for elite capture.** Many of the common risks encountered with large infrastructure projects are associated with their scale and complexity of operation.

V.5 PLAN COMPLEMENTARY INVESTMENTS TO ADDRESS THE ASSET GAPS OF POORER GROUPS

135. Many households fail to take advantage of the livelihood opportunities offered by built structures because they lack other essential assets. Ensuring that the poorest households have a chance to access these new opportunities is essential if infrastructure investments are to make a measurable contribution to reducing poverty.

136. **Alongside infrastructure improvements, investments in basic education, training and technical support services, and credit may be needed, as well as support to community organizing capacity.** Setting priorities for such complementary investments should be part of the local livelihood assessment associated with infrastructure planning.
In many areas, securing land rights is an essential step, as the value of agricultural land typically rises along with irrigation or road improvements, and villagers may face pressure to vacate or sell if they feel their tenure is insecure. Special attention should be given to the phasing of investments as well – in many instances it may be wise to begin support to develop these other household assets long before construction of the physical infrastructure begins.

137. **Invest in building household assets to take advantage of alternative livelihood opportunities, not to increase fishing effort.** Unlike the case with irrigated agriculture or road development, the potential advantages from the release of fishing lots and support to community fisheries stem from a more equitable distribution of economic benefits, not from an intensification of production. For communities that have depended overwhelmingly on fishing (such as most floating villages), efforts to regulate fishing and make it more sustainable need to be complemented with support for alternatives such as ecotourism, post-harvest processing, and (for those who wish) training for jobs on shore.
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Nettleton, D. & Baran, E. (2003). Fishery stakeholder groups and Livelihood Variation around the Tonle Sap Great Lake, Cambodia. TA WorldFish/ADB/IFReDITA No. T4025-CAM


Ovesen, J., I. Trankell and J. Öjendahl (1996). When Every Household is an Island – Social Organization and Power Structures in Rural Cambodia, Uppsala Research Reports in Cultural Anthropology no. 15, Department of Cultural Anthropology, Uppsala University, Sweden.


ANNEX A: DATA TABLES

Road development case study, Pursat province (Tables corresponding to section III.1)

Table 1: Village level socioeconomic indicators for the case study villages, Pursat province

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chong Khlong</td>
<td>148</td>
<td>182</td>
<td>152</td>
</tr>
<tr>
<td>Ou Ta Prok</td>
<td>152</td>
<td>182</td>
<td>158</td>
</tr>
<tr>
<td>Number of households</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of females</td>
<td>341</td>
<td>514</td>
<td>356</td>
</tr>
<tr>
<td>Number of males</td>
<td>305</td>
<td>422</td>
<td>322</td>
</tr>
<tr>
<td>Percent of houses with thatched roofs</td>
<td>38.5</td>
<td>74.7</td>
<td>23.7</td>
</tr>
<tr>
<td>Percent of houses with tiled roofs</td>
<td>25.7</td>
<td>12.1</td>
<td>25.7</td>
</tr>
<tr>
<td>Percent of houses with fibro roofs</td>
<td>2.7</td>
<td>0.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Percent of houses with zinc roofs</td>
<td>33.1</td>
<td>9.9</td>
<td>9.9</td>
</tr>
<tr>
<td>Percent of houses with concrete roofs</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent of households with cattle</td>
<td>71.6</td>
<td>95.1</td>
<td>57.9</td>
</tr>
<tr>
<td>Percent of households with pigs</td>
<td>0.0</td>
<td>93.4</td>
<td>0.0</td>
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<tr>
<td>Number of motorcycles per 100 people</td>
<td>6.5</td>
<td>0.0</td>
<td>7.4</td>
</tr>
<tr>
<td>Number of cars per 100 people</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Number of ox carts per 100 people</td>
<td>15.6</td>
<td>6.4</td>
<td>10.0</td>
</tr>
<tr>
<td>Number of bicycles per 100 people</td>
<td>10.2</td>
<td>0.0</td>
<td>12.4</td>
</tr>
<tr>
<td>Number of row boats per 100 people</td>
<td>8.5</td>
<td>3.7</td>
<td>9.4</td>
</tr>
<tr>
<td>Number of motor boats per 100 people</td>
<td>0.3</td>
<td>0.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent of households with TV</td>
<td>24.3</td>
<td>8.2</td>
<td>27.0</td>
</tr>
</tbody>
</table>

Source: Estimated using SEILA Commune Database 2006

Table 2: Changes in livelihood activities in Pursat (shown as percentage of households participating in each activity)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Pursat Before</th>
<th>Chong Khlong Before</th>
<th>Ou Ta Prok Main Before</th>
<th>Ou Ta Prok Up Before</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>76.3</td>
<td>78.8</td>
<td>82.2</td>
<td>60.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>22.5</td>
<td>23.8</td>
<td>33.3</td>
<td>33.3</td>
<td>10.0</td>
</tr>
<tr>
<td>Rice farming</td>
<td>90.0</td>
<td>92.5</td>
<td>88.9</td>
<td>91.1</td>
<td>90.0</td>
</tr>
<tr>
<td>Other crops</td>
<td>52.5</td>
<td>51.3</td>
<td>60.0</td>
<td>57.8</td>
<td>40.0</td>
</tr>
<tr>
<td>Livestock</td>
<td>62.5</td>
<td>66.3</td>
<td>53.3</td>
<td>55.6</td>
<td>60.0</td>
</tr>
<tr>
<td>Farm labour</td>
<td>26.3</td>
<td>31.3</td>
<td>20.0</td>
<td>22.2</td>
<td>40.0</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>10.0</td>
<td>12.5</td>
<td>4.4</td>
<td>6.7</td>
<td>20.0</td>
</tr>
<tr>
<td>Petty trade</td>
<td>28.3</td>
<td>29.8</td>
<td>15.6</td>
<td>15.6</td>
<td>11.7</td>
</tr>
<tr>
<td>Other</td>
<td>79.2</td>
<td>79.4</td>
<td>74.6</td>
<td>75.6</td>
<td>76.0</td>
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Annex A
Table 3: Changes in livelihood portfolio diversification in Pursat (shown as percent contribution to the total household income)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Pursat Before</th>
<th>Current</th>
<th>Chong Khlong Before</th>
<th>Current</th>
<th>Ou Ta Prok Main Before</th>
<th>Current</th>
<th>Ou Ta Prok Up Before</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>37.5</td>
<td>28.9</td>
<td>42.8</td>
<td>31.8</td>
<td>24.9</td>
<td>16.2</td>
<td>33.9</td>
<td>32.5</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>7.1</td>
<td>8.8</td>
<td>8.6</td>
<td>12.9</td>
<td>5.3</td>
<td>1.0</td>
<td>3.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Rice farming</td>
<td>16.2</td>
<td>19.4</td>
<td>14.8</td>
<td>17.2</td>
<td>20.0</td>
<td>27.0</td>
<td>16.8</td>
<td>18.9</td>
</tr>
<tr>
<td>Other crops</td>
<td>2.0</td>
<td>1.9</td>
<td>2.5</td>
<td>2.2</td>
<td>1.6</td>
<td>1.9</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Livestock</td>
<td>9.5</td>
<td>8.9</td>
<td>2.9</td>
<td>3.8</td>
<td>18.4</td>
<td>21.4</td>
<td>22.1</td>
<td>13.2</td>
</tr>
<tr>
<td>Farm labour</td>
<td>5.0</td>
<td>5.6</td>
<td>7.4</td>
<td>8.1</td>
<td>1.5</td>
<td>1.8</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>2.8</td>
<td>3.8</td>
<td>3.5</td>
<td>3.4</td>
<td>2.2</td>
<td>2.5</td>
<td>1.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Petty trade</td>
<td>6.5</td>
<td>9.4</td>
<td>4.6</td>
<td>8.4</td>
<td>13.7</td>
<td>16.2</td>
<td>4.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Other</td>
<td>13.5</td>
<td>13.4</td>
<td>13.1</td>
<td>12.3</td>
<td>12.2</td>
<td>12.1</td>
<td>16.3</td>
<td>18.9</td>
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</tbody>
</table>

Table 4: Percentage of household by assets (Pursat)

<table>
<thead>
<tr>
<th>Livestock assets</th>
<th>Pursat</th>
<th>Chong Khlong</th>
<th>Ou Ta Prok Main</th>
<th>Ou Ta Prok Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock</td>
<td>87.5</td>
<td>86.7</td>
<td>90.0</td>
<td>86.7</td>
</tr>
<tr>
<td>Cows/oxen</td>
<td>27.5</td>
<td>40.0</td>
<td>10.0</td>
<td>13.3</td>
</tr>
<tr>
<td>Buffalo</td>
<td>45.0</td>
<td>46.7</td>
<td>45.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Pigs</td>
<td>32.5</td>
<td>0.0</td>
<td>70.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Chickens</td>
<td>66.3</td>
<td>66.7</td>
<td>55.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Ducks</td>
<td>25.0</td>
<td>33.3</td>
<td>20.0</td>
<td>6.7</td>
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Table 5: Correlation between assets and changes in income (Pursat)

<table>
<thead>
<tr>
<th>Correlation coefficient of the household asset with changes in income</th>
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<tbody>
<tr>
<td>Landholding</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Pursat</td>
</tr>
<tr>
<td>Chong Khlong</td>
</tr>
<tr>
<td>Ou Ta Prok Main (0.15)</td>
</tr>
<tr>
<td>Ou Ta Prok Up</td>
</tr>
</tbody>
</table>

Table 6: Income change by chronic poor vs. non-chronic poor (Pursat)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Village</th>
<th>Change in average household income (US$)</th>
<th>Average household income (US$)</th>
</tr>
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<tbody>
<tr>
<td>Overall Average</td>
<td>Pursat</td>
<td>91.2</td>
<td>589.2</td>
</tr>
<tr>
<td>Chronic Poor</td>
<td>Chong Khlong</td>
<td>22.3</td>
<td>312.3</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>38.9</td>
<td>327.3</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>25.6</td>
<td>443.4</td>
</tr>
<tr>
<td>Non-Chronic Poor</td>
<td>Chong Khlong</td>
<td>249.7</td>
<td>1,164.9</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>67.0</td>
<td>702.6</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>154.0</td>
<td>737.1</td>
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</tbody>
</table>
Irrigation case study, Kampong Thom province (Tables corresponding to section III.2)

**Table 7: Village level socioeconomic indicators for case study villages, Kampong Thom province**

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th></th>
<th>2003</th>
<th></th>
<th>2004</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Snao</td>
<td></td>
<td>Sa'ang</td>
<td></td>
<td>Snao</td>
<td></td>
</tr>
<tr>
<td>Number of households</td>
<td>172</td>
<td>71</td>
<td>172</td>
<td>69</td>
<td>195</td>
<td>69</td>
</tr>
<tr>
<td>Number of females</td>
<td>423</td>
<td>186</td>
<td>448</td>
<td>186</td>
<td>450</td>
<td>187</td>
</tr>
<tr>
<td>Number of males</td>
<td>396</td>
<td>163</td>
<td>409</td>
<td>171</td>
<td>434</td>
<td>173</td>
</tr>
<tr>
<td>Percent of houses with thatch roofs</td>
<td>66.9</td>
<td>22.5</td>
<td>66.9</td>
<td>23.2</td>
<td>67.7</td>
<td>23.2</td>
</tr>
<tr>
<td>Percentage of houses with tiled roofs</td>
<td>23.3</td>
<td>42.3</td>
<td>23.3</td>
<td>43.5</td>
<td>21.5</td>
<td>43.5</td>
</tr>
<tr>
<td>Percent of houses with fibro roofs</td>
<td>0.0</td>
<td>5.6</td>
<td>1.2</td>
<td>5.8</td>
<td>1.0</td>
<td>5.8</td>
</tr>
<tr>
<td>Percent of houses with zinc roofs</td>
<td>5.8</td>
<td>18.3</td>
<td>4.7</td>
<td>18.8</td>
<td>4.1</td>
<td>18.8</td>
</tr>
<tr>
<td>Percent of houses with concrete roofs</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent of households with cattle</td>
<td>88.4</td>
<td>93.0</td>
<td>88.4</td>
<td>95.7</td>
<td>92.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Percent of households with pigs</td>
<td>62.8</td>
<td>91.5</td>
<td>59.9</td>
<td>94.2</td>
<td>76.9</td>
<td>91.3</td>
</tr>
<tr>
<td>Number of motorcycles per 100 people</td>
<td>1.3</td>
<td>1.1</td>
<td>1.6</td>
<td>1.4</td>
<td>3.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Number of cars per 100 people</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Number of ox carts per 100 people</td>
<td>15.8</td>
<td>18.1</td>
<td>15.1</td>
<td>17.6</td>
<td>14.7</td>
<td>17.5</td>
</tr>
<tr>
<td>Number of bicycles per 100 people</td>
<td>12.2</td>
<td>19.8</td>
<td>11.7</td>
<td>19.3</td>
<td>12.4</td>
<td>18.9</td>
</tr>
<tr>
<td>Number of row boats per 100 people</td>
<td>3.1</td>
<td>1.4</td>
<td>2.3</td>
<td>1.4</td>
<td>2.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Number of motor boats per 100 people</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent of households with TV</td>
<td>12.8</td>
<td>8.5</td>
<td>13.4</td>
<td>15.9</td>
<td>14.9</td>
<td>34.8</td>
</tr>
</tbody>
</table>

*Source: Estimated using SEILA Commune Database 2006*

**Table 8: Livelihood activities diversification in Kampong Thom (shown as percentage of households participating in each activity)**

<table>
<thead>
<tr>
<th>Activities</th>
<th>Kampong Thom</th>
<th></th>
<th>Snao</th>
<th></th>
<th>Sa'ang</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>Current</td>
<td>Before</td>
<td>Current</td>
<td>Before</td>
<td>Current</td>
</tr>
<tr>
<td>Fishing</td>
<td>58.9</td>
<td>66.7</td>
<td>51.1</td>
<td>66.7</td>
<td>66.7</td>
<td>64.4</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>10.0</td>
<td>10.0</td>
<td>6.7</td>
<td>10.0</td>
<td>13.3</td>
<td>6.7</td>
</tr>
<tr>
<td>Rice farming</td>
<td>86.7</td>
<td>91.1</td>
<td>88.9</td>
<td>91.1</td>
<td>84.4</td>
<td>91.1</td>
</tr>
<tr>
<td>Other crops</td>
<td>66.7</td>
<td>63.3</td>
<td>53.3</td>
<td>63.3</td>
<td>80.0</td>
<td>48.9</td>
</tr>
<tr>
<td>Livestock</td>
<td>63.3</td>
<td>73.3</td>
<td>57.8</td>
<td>73.3</td>
<td>68.9</td>
<td>66.7</td>
</tr>
<tr>
<td>Farm labour</td>
<td>32.2</td>
<td>42.2</td>
<td>33.3</td>
<td>42.2</td>
<td>31.1</td>
<td>42.2</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>18.9</td>
<td>18.9</td>
<td>31.1</td>
<td>18.9</td>
<td>6.7</td>
<td>31.1</td>
</tr>
<tr>
<td>Petty trade</td>
<td>11.1</td>
<td>12.2</td>
<td>11.1</td>
<td>12.2</td>
<td>11.1</td>
<td>13.3</td>
</tr>
<tr>
<td>Other</td>
<td>62.1</td>
<td>66.3</td>
<td>61.6</td>
<td>65.2</td>
<td>58.7</td>
<td>60.2</td>
</tr>
</tbody>
</table>
Table 9: Income portfolio diversification in Kampong Thom (shown as percent contribution to the total household income)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Kampong Thom Before</th>
<th>Kampong Thom Current</th>
<th>Snao Before</th>
<th>Snao Current</th>
<th>Sa'ang Before</th>
<th>Sa'ang Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>33.6</td>
<td>28.0</td>
<td>20.7</td>
<td>26.7</td>
<td>47.4</td>
<td>29.6</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Rice farming</td>
<td>19.6</td>
<td>19.3</td>
<td>25.7</td>
<td>18.6</td>
<td>13.0</td>
<td>20.3</td>
</tr>
<tr>
<td>Other crops</td>
<td>3.7</td>
<td>3.5</td>
<td>4.9</td>
<td>3.6</td>
<td>2.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Livestock</td>
<td>13.9</td>
<td>15.0</td>
<td>17.4</td>
<td>16.2</td>
<td>10.1</td>
<td>13.3</td>
</tr>
<tr>
<td>Farm labour</td>
<td>6.2</td>
<td>6.5</td>
<td>1.8</td>
<td>1.9</td>
<td>11.0</td>
<td>12.8</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>6.4</td>
<td>5.4</td>
<td>11.6</td>
<td>8.8</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Petty trade</td>
<td>7.1</td>
<td>9.2</td>
<td>8.8</td>
<td>12.2</td>
<td>5.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Other</td>
<td>11.5</td>
<td>12.8</td>
<td>12.4</td>
<td>11.8</td>
<td>10.5</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Table 10: Correlation between assets and changes in income (Kampong Thom)

<table>
<thead>
<tr>
<th></th>
<th>Landholding</th>
<th>Livestock asset</th>
<th>Education</th>
<th>Household size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kampong Thom</td>
<td>(0.07)</td>
<td>0.05</td>
<td>0.17</td>
<td>(0.18)</td>
</tr>
<tr>
<td>Snao</td>
<td>(0.09)</td>
<td>0.03</td>
<td>0.20</td>
<td>0.17</td>
</tr>
<tr>
<td>Sa'ang</td>
<td>(0.08)</td>
<td>0.04</td>
<td>0.13</td>
<td>(0.15)</td>
</tr>
</tbody>
</table>

Table 11: Income change by chronic poor vs. non-chronic poor (Kampong Thom)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Village/province</th>
<th>Change in average household income (US$)</th>
<th>Average household income (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined average change</td>
<td>Kampong Thom</td>
<td>91.2</td>
<td>687.6</td>
</tr>
<tr>
<td>Chronic Poor</td>
<td>Snao</td>
<td>105.3</td>
<td>482.8</td>
</tr>
<tr>
<td></td>
<td>Sa'ang</td>
<td>53.4</td>
<td>401.6</td>
</tr>
<tr>
<td>Non-Chronic Poor</td>
<td>Snao</td>
<td>285.3</td>
<td>1,281.5</td>
</tr>
<tr>
<td></td>
<td>Sa'ang</td>
<td>(88.6)</td>
<td>1,224.9</td>
</tr>
</tbody>
</table>
Fishing lot case study, Battambang province (Tables corresponding to section III.3)

Table 12: Village level socio-economic indicators in case study villages, Battambang

<table>
<thead>
<tr>
<th></th>
<th>2002 Thvang</th>
<th>2003 Prek Toal</th>
<th>2004 Thvang</th>
<th>2004 Prek Toal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of households</td>
<td>180</td>
<td>467</td>
<td>200</td>
<td>497</td>
</tr>
<tr>
<td>Number of females</td>
<td>545</td>
<td>1308</td>
<td>576</td>
<td>1346</td>
</tr>
<tr>
<td>Number of males</td>
<td>516</td>
<td>1270</td>
<td>505</td>
<td>1242</td>
</tr>
<tr>
<td>Percentage of houses with thatch roofs</td>
<td>38.3</td>
<td>58.9</td>
<td>35.5</td>
<td>60.4</td>
</tr>
<tr>
<td>Percentage of houses with tiled roofs</td>
<td>0.6</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent of houses with fibro roofs</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent of houses with zinc roofs</td>
<td>60.6</td>
<td>39.6</td>
<td>64.0</td>
<td>37.2</td>
</tr>
<tr>
<td>Percent of houses with concrete roofs</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Percent of households with cattle</td>
<td>2.8</td>
<td>2.4</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Number of motorcycles per 100 people</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Number of cars per 100 people</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Number of ox carts per 100 people</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Number of bicycles per 100 people</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Number of row boats per 100 people</td>
<td>38.8</td>
<td>27.9</td>
<td>39.1</td>
<td>29.0</td>
</tr>
<tr>
<td>Number of motor boats per 100 people</td>
<td>6.1</td>
<td>6.6</td>
<td>6.9</td>
<td>7.3</td>
</tr>
<tr>
<td>Percentage of households with TV</td>
<td>48.3</td>
<td>36.4</td>
<td>51.5</td>
<td>36.2</td>
</tr>
</tbody>
</table>

Source: Estimated using SEILA Commune Database 2006

Table 13: Livelihood activities diversification in Battambang (shown as percentage of households participating in each activity)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Battambang Before</th>
<th>Battambang Current</th>
<th>Prek Toal Before</th>
<th>Prek Toal Current</th>
<th>Thvang Before</th>
<th>Thvang Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>97.8</td>
<td>97.8</td>
<td>100.0</td>
<td>100.0</td>
<td>95.6</td>
<td>95.6</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>10.0</td>
<td>6.7</td>
<td>11.1</td>
<td>8.9</td>
<td>8.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Fish culture</td>
<td>12.2</td>
<td>23.3</td>
<td>17.8</td>
<td>20.0</td>
<td>6.7</td>
<td>26.7</td>
</tr>
<tr>
<td>Crocodile</td>
<td>2.2</td>
<td>6.7</td>
<td>0.0</td>
<td>4.4</td>
<td>4.4</td>
<td>8.9</td>
</tr>
<tr>
<td>Rice farming</td>
<td>1.1</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Other crops</td>
<td>3.3</td>
<td>4.4</td>
<td>2.2</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Livestock</td>
<td>3.3</td>
<td>8.9</td>
<td>0.0</td>
<td>4.4</td>
<td>6.7</td>
<td>13.3</td>
</tr>
<tr>
<td>Fishing labour</td>
<td>18.9</td>
<td>28.9</td>
<td>22.2</td>
<td>37.8</td>
<td>15.6</td>
<td>20.0</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>4.4</td>
<td>4.4</td>
<td>0.0</td>
<td>0.0</td>
<td>8.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Petty trade</td>
<td>7.8</td>
<td>8.9</td>
<td>11.1</td>
<td>11.1</td>
<td>4.4</td>
<td>6.7</td>
</tr>
<tr>
<td>Other</td>
<td>88</td>
<td>88</td>
<td>82.2</td>
<td>80.0</td>
<td>93.3</td>
<td>95.6</td>
</tr>
</tbody>
</table>
### Table 14: Income portfolio diversification in Battambang (shown as percent contribution to the total household income)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Battambang Before</th>
<th>Battambang Current</th>
<th>Prek Toal Before</th>
<th>Prek Toal Current</th>
<th>Thvang Before</th>
<th>Thvang Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>80.1</td>
<td>67.4</td>
<td>75.2</td>
<td>64.8</td>
<td>85.1</td>
<td>69.4</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>1.3</td>
<td>0.6</td>
<td>1.6</td>
<td>0.7</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Fish culture</td>
<td>7.7</td>
<td>4.3</td>
<td>13.2</td>
<td>6.3</td>
<td>2.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Crocodile</td>
<td>1.6</td>
<td>8.2</td>
<td>0.0</td>
<td>4.6</td>
<td>3.2</td>
<td>11.0</td>
</tr>
<tr>
<td>Rice farming</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Other crops</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Livestock</td>
<td>0.2</td>
<td>0.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Fishing labour</td>
<td>1.1</td>
<td>2.7</td>
<td>1.2</td>
<td>5.4</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>0.8</td>
<td>0.8</td>
<td>0.0</td>
<td>0.0</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Petty trade</td>
<td>2.2</td>
<td>5.6</td>
<td>2.8</td>
<td>1.9</td>
<td>1.6</td>
<td>8.5</td>
</tr>
<tr>
<td>Other</td>
<td>4.8</td>
<td>9.9</td>
<td>5.8</td>
<td>16.0</td>
<td>3.8</td>
<td>4.6</td>
</tr>
</tbody>
</table>

### Table 15: Correlation between assets and changes in income (Battambang)

<table>
<thead>
<tr>
<th></th>
<th>Livestock assets</th>
<th>Education</th>
<th>Household size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battambang</td>
<td>0.293</td>
<td>0.107</td>
<td>0.066</td>
</tr>
<tr>
<td>Prek Toal</td>
<td>-</td>
<td>0.031</td>
<td>0.123</td>
</tr>
<tr>
<td>Thvang</td>
<td>0.674</td>
<td>0.219</td>
<td>(0.004)</td>
</tr>
</tbody>
</table>

### Table 16: Income change by chronic poor vs. non-chronic poor (Battambang)

<table>
<thead>
<tr>
<th>Groups (Chronic poor and non-chronic poor)</th>
<th>Village/province</th>
<th>Change in average household income (US$)</th>
<th>Average household income (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall average change</td>
<td>Battambang</td>
<td>112.2</td>
<td>1033.8</td>
</tr>
<tr>
<td>Chronic Poor</td>
<td>Prek Toal</td>
<td>13.3</td>
<td>505.5</td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>62.0</td>
<td>540.1</td>
</tr>
<tr>
<td>Non-Chronic Poor</td>
<td>Prek Toal</td>
<td>131.4</td>
<td>1148.9</td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>163.3</td>
<td>1438.4</td>
</tr>
</tbody>
</table>
**Comparative findings (Tables corresponding to section III.4)**

**Table 17: Change in average household income by village**

<table>
<thead>
<tr>
<th>Province</th>
<th>Village</th>
<th>Income Change (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pursat</td>
<td>Chong Khlong</td>
<td>113.26</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>48.74</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>80.66</td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>Sa'ang</td>
<td>34.44</td>
</tr>
<tr>
<td></td>
<td>Snao</td>
<td>189.30</td>
</tr>
<tr>
<td>Battambang</td>
<td>Prek Toal</td>
<td>101.16</td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>123.24</td>
</tr>
</tbody>
</table>

**Table 18: Change in income inequality, by village, as measured by the gini coefficient of inequality**

<table>
<thead>
<tr>
<th>Province</th>
<th>Village</th>
<th>Gini Index</th>
<th>Before</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pursat</td>
<td>Chong Khlong</td>
<td>0.45</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>0.39</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>0.21</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>Snao</td>
<td>0.43</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sa'ang</td>
<td>0.47</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>Battambang</td>
<td>Prek Toal</td>
<td>0.35</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>0.40</td>
<td>0.39</td>
<td></td>
</tr>
</tbody>
</table>

**Table 19: Incidence of poverty (Head Count Index) by village**

<table>
<thead>
<tr>
<th>Province</th>
<th>Village</th>
<th>Incidence of Poverty (%)</th>
<th>Before</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pursat</td>
<td>Chong Khlong</td>
<td>73</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>75</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>67</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>Snao</td>
<td>58</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sa'ang</td>
<td>89</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>Battambang</td>
<td>Prek Toal</td>
<td>33</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>49</td>
<td>49</td>
<td></td>
</tr>
</tbody>
</table>
### Table 20: Depth of poverty (Poverty Gap Index) by village

<table>
<thead>
<tr>
<th>Province</th>
<th>Village</th>
<th>Depth of Poverty (%)</th>
<th>Before</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pursat</td>
<td>Chong Khlong</td>
<td>36</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>42</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>31</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>Snao</td>
<td>32</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sa'ang</td>
<td>57</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Battambang</td>
<td>Prek Toal</td>
<td>15</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>17</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

### Table 21: Changes in average income, chronic vs. non-chronic poor

<table>
<thead>
<tr>
<th>Province</th>
<th>Village</th>
<th>Average Income Change (US$)</th>
<th>Chronic Poor</th>
<th>Non-Chronic Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pursat</td>
<td>Chong Khlong</td>
<td></td>
<td>22.30</td>
<td>249.70</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td></td>
<td>38.92</td>
<td>66.97</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td></td>
<td>25.63</td>
<td>154.00</td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>Snao</td>
<td></td>
<td>105.26</td>
<td>285.34</td>
</tr>
<tr>
<td></td>
<td>Sa'ang</td>
<td></td>
<td>53.40</td>
<td>(88.64)</td>
</tr>
<tr>
<td>Battambang</td>
<td>Prek Toal</td>
<td></td>
<td>13.30</td>
<td>131.36</td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td></td>
<td>62.00</td>
<td>163.30</td>
</tr>
</tbody>
</table>

### Table 22: Dynamics of poverty

<table>
<thead>
<tr>
<th>Province</th>
<th>Village</th>
<th>Percentage</th>
<th>Chronic Poverty</th>
<th>Vulnerability</th>
<th>Out of Poverty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pursat</td>
<td>Chong Khlong</td>
<td>60</td>
<td>0</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>65</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>53</td>
<td>0</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>Snao</td>
<td>53</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sa'ang</td>
<td>85</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Battambang</td>
<td>Prek Toal</td>
<td>26</td>
<td>14</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>40</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>
### Table 23. Household assets and chronic poverty

<table>
<thead>
<tr>
<th>Province</th>
<th>Village</th>
<th>Assets</th>
<th>Education (years of schooling of household head)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Land (ha)</td>
<td>Livestock Index</td>
</tr>
<tr>
<td>Pursat</td>
<td>Chong Khlong</td>
<td>Chronic poor</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-chronic poor</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Main</td>
<td>Chronic poor</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-chronic poor</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Ou Ta Prok Up</td>
<td>Chronic poor</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-chronic poor</td>
<td>0.70</td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>Snao</td>
<td>Chronic poor</td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-chronic poor</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>Sa’ang</td>
<td>Chronic poor</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-chronic poor</td>
<td>1.50</td>
</tr>
<tr>
<td>Battambang</td>
<td>Prek Toal</td>
<td>Chronic poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-chronic poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thvang</td>
<td>Chronic poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-chronic poor</td>
<td></td>
</tr>
</tbody>
</table>

### Table 24. Determinants of poverty (Probit estimation)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pursat (Road development)</th>
<th>Kampong Thom (Irrigation development)</th>
<th>Battambang (Release of Fishing Lot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>If male headed</td>
<td>-0.59 (0.49)</td>
<td>0.21 (0.38)</td>
<td>-0.71 (0.45)</td>
</tr>
<tr>
<td>Age of household head</td>
<td>0.02 (0.01)</td>
<td>0.00 (0.01)</td>
<td>0.01 (0.01)</td>
</tr>
<tr>
<td>Household size</td>
<td><strong>0.23</strong> (0.10)</td>
<td>0.06 (0.06)</td>
<td><strong>0.31</strong> (0.08)</td>
</tr>
<tr>
<td>Education of household head</td>
<td>-0.02* (0.07)</td>
<td>-0.11* (0.08)</td>
<td>-0.08* (0.06)</td>
</tr>
<tr>
<td>Livestock assets</td>
<td>-0.01* (0.01)</td>
<td>-0.02* (0.01)</td>
<td></td>
</tr>
<tr>
<td>Landholding</td>
<td>-0.16 (0.26)</td>
<td>0.11 (0.22)</td>
<td></td>
</tr>
<tr>
<td>Number of observations</td>
<td>70</td>
<td>82</td>
<td>86</td>
</tr>
<tr>
<td>LR chi2(8)</td>
<td>17.25</td>
<td>20.82</td>
<td>19.05</td>
</tr>
<tr>
<td>Prob &gt; chi2</td>
<td>0.03</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Pseudo R2</td>
<td>0.19</td>
<td>0.21</td>
<td>0.16</td>
</tr>
</tbody>
</table>

**Note:** This table shows the results of a regression analysis (probit estimation) to estimate which factors are significant in explaining the ability of households in the case study villages to move out of poverty. Only the bold figures are statistically significant, noted as follows: *** significant at 1%; ** significant at 5%; * significant at 10%. A positive value indicates a positive correlation with poverty, whereas a negative value indicates that the variable is significant in explaining the ability of households to move out of poverty. “If male headed” is a dummy variable (binary). Standard error is shown in parenthesis. All regression estimates include constant. The estimation controlled for location using village dummies.
Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Livelihoods Component

ENABLING ALTERNATIVE LIVELIHOODS FOR AQUATIC RESOURCE DEPENDENT COMMUNITIES OF THE TONLE SAP

SUMMARY RESEARCH NOTE

Prepared by

Dil Bahadur RAHUT\textsuperscript{1}, HAP Navy\textsuperscript{2}, and Blake D. RATNER\textsuperscript{1}

\textsuperscript{1}WorldFish Center
\textsuperscript{2}IFReDI

January 2007
I INTRODUCTION

1. This research note is provided as a supplement to the technical report, “Influence of Built Structures on Livelihoods: Case Studies of Road Development, Irrigation, and Fishing Lots,”¹ as part of the livelihoods component of the “Study of the Influence of Built Structures on the Fisheries of the Tonle Sap.”² The technical report assesses possible changes in people’s livelihood strategies and outputs, including those derived from fisheries, particularly in terms of changes in livelihood portfolios, vulnerability, resource access and income. It also summarises local people’s perception of the connections between their livelihoods, environment, aquatic ecosystems and built structures, as well as their viewpoints on best practices for built structures with a specific focus on institutional arrangements.

2. As described in the main technical report, all three study sites show an overall decline in fishing as a proportion of household income, a trend that is consistent with reports of a declining catch per household from other areas around the Tonle Sap. In such a context, the ability of poorer households in particular to diversify their livelihood portfolios, reducing their dependence on the natural resource base, is a key factor in reducing vulnerability.

3. In developing recommendations to improve the ability of rural households to diversify their livelihoods, it is important to understand what the livelihood priorities are for local communities, what alternatives are available, and what constraints prevent some households from taking advantage of these alternatives. This research note is meant to answer these questions.

4. In preparing this research note, data collected through the household surveys³ was analyzed with specific reference to these questions, and to identify issues for focus group discussions among selected survey participants. Focus group discussions were organized in two villages in each of the three study sites⁴, with participants selected to have a balance in gender and wealth groups (poorer, medium, and richer). The village chief and vice-chief were also included in each focus group, for a total of 10-12 people per group. Existing and alternative livelihood scenarios were discussed and evaluated by the focus group participants. Constraints to livelihood diversification were identified and ranked, as well as suggestions about addressing these constraints.

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² Asian Development Bank TA 4669-CAM. Financed by the Government of Finland, with the Cambodian National Mekong Committee as executing agency and the WorldFish Center as implementing agency.

³ For a description of the methodology used in the household surveys, please see the main technical report.

⁴ The villages are Chong Khlong and Ou Ta Prok in Ou Sandan commune, Krakor District, Pursat province (road development case study), Snao and Sa’ang villages in Kampong Thma Commune in Santuk District, Kampong Thom province (irrigation development case study), and the floating villages of Prek Toal and Thvang in Kaoh Chiveang commune, Aek Phnum district, Batambang province (fishing lot case study). For a description of the study sites and their socioeconomic characteristics.
5. The results of these discussions have been integrated into the recommendations of the main report addressing investment in household assets to better enable poorer households to take advantage of alternative livelihood opportunities.

6. The research note is organized according to the three questions addressed: (i) What are the current livelihood activities in the study sites? (ii) What are the preferred livelihood activities? (iii) What are the constraints associated with livelihood diversification, and what do locals see as priorities for overcoming these constraints? In addressing each question, we note differences by income group, and where relevant, by gender.

II CURRENT LIVELIHOOD ACTIVITIES

7. **Fishing is the most important source of household income in all three study sites.** The contribution is of course highest in the floating villages of Battambang, where fishing accounts for about 67 percent of total household income. But even in the road development (Pursat) and the irrigation (Kampong Thom) cases, where almost all households (90 percent) are rice farmers, fishing still accounts for a higher percentage of household income than rice farming (28-29 percent from fishing versus 19 percent from rice farming in both cases). (See Figure 1.)

8. In terms of the percentage of households participating, the most prevalent livelihood activities in the road development (Pursat) and irrigation (Kampong Thom) cases are rice farming, fishing, and livestock rearing, in that order. In the fishing lot case (Battambang), fishing is the most prevalent, with virtually all households participating, and fish labour is the second most common livelihood activity (with 29 percent of households participating).

9. **Besides fishing, rice farming and livestock rearing, households in the study sites are engaged in a wide variety of other livelihood activities.** These can be categorized as fishing-related activities (such as fish processing, making and repairing fishing gear), other crops (such as corn and vegetables), farm labour (wage labour in agriculture), fishing labour (including wage labour with the fishing lots), non-farm labour (wage labour outside the fishing and agriculture sectors), and petty trade (including marketing and selling of groceries, fish, agricultural products, and other goods).

10. **There are consistent gender differences in many livelihood activities.** The following activities are predominately male: fishing, fishing labour, carpentry, poultry and livestock rearing, buying and selling livestock, and serving as porters. Women are engaged in selling fishery and agricultural products in the public markets and operating neighborhood convenience stalls, tending to gardens and various vegetable crops, and collecting rattan and various other natural resources. Many other livelihood activities commonly have participation of both men and women.
11. **Even in nearby villages, the pattern of livelihood activities among richer or poorer households varies significantly.** The following analysis examines the percentage contribution to total household income by dividing households into three income groups (terciles) and comparing these groups.\(^5\) While one might expect, for example, that the higher income households consistently rely more on petty trade and less on fishing as a source of income, the analysis

\(^5\) It is important to note that these income groups (terciles) are formed by dividing surveyed households *within each village* according to current annual income. This is useful in making comparisons to assess the relative importance of different livelihood activities to each income group. But keep in mind that the groupings are relative to other households in the same village, such that in a village with overall lower income (Chong Khlong, for example), households in the “higher income” group in fact earn less on average than households in the “medium income” group in Prek Toal, where overall incomes are higher. For analysis based on an absolute measure of poverty (the national poverty line), see the main technical report.
shows that the pattern is inconsistent from one village to the next. This implies that even nearby villages have a significantly different local context influencing livelihood choices.

12. **In the road development case study (Pursat), fishing is a more significant income source for poorer villagers in one village near the road, while in a nearby village the opposite is true.** Poorer households in the Cham village near the road (Chong Khlong) derive slightly more income from fishing while in the Khmer village (Ou Ta Prok) richer households derive significantly more of their income from fishing activities. In Chong Khlong the poorer households derive significantly more of their income from rice farming, but in Ou Ta Prok each of the income groups derives about the same proportion of their income from rice farming. In Chong Khlong petty trade seems to be dominated by the higher income households but in Ou Ta Prok, it is the poorer households who depend more on petty trade. (See Table 1.)

<table>
<thead>
<tr>
<th></th>
<th>Chong Khlong</th>
<th>Ou Ta Prok</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>Middle</td>
<td>Upper</td>
</tr>
<tr>
<td>Fishing</td>
<td>36.7</td>
<td>33.6</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>10.7</td>
<td>18.9</td>
</tr>
<tr>
<td>Rice farming</td>
<td>33.1</td>
<td>25.0</td>
</tr>
<tr>
<td>Other crops</td>
<td>1.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Livestock</td>
<td>7.9</td>
<td>8.7</td>
</tr>
<tr>
<td>Farm labour</td>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>2.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Petty trade</td>
<td>0.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Other</td>
<td>6.1</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Table 1. Household income portfolios by income group (tercile) for villages studied in the road development case study, Pursat

13. **In the irrigation case study site (Kampong Thom), rice farming represents a significantly higher proportion of income for poorer households.** In the end-user village (Sa’ang), fishing is significantly more important to the richer households, while in the head-user village (Snao) no such distinction is evident. (See Table 2.)

<table>
<thead>
<tr>
<th></th>
<th>Snao</th>
<th>Sa’ang</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower</td>
<td>Middle</td>
</tr>
<tr>
<td>Fishing</td>
<td>26.0</td>
<td>30.4</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Rice farming</td>
<td>34.3</td>
<td>21.3</td>
</tr>
<tr>
<td>Other crops</td>
<td>2.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Livestock</td>
<td>9.0</td>
<td>14.2</td>
</tr>
<tr>
<td>Farm labour</td>
<td>7.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>7.5</td>
<td>18.4</td>
</tr>
<tr>
<td>Petty trade</td>
<td>0.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Other</td>
<td>13.5</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Table 2. Household income portfolios by income group (tercile) for villages studied in the irrigation case study, Kampong Thom

14. **In the floating villages in Battambang, fishing is the dominant source of income for richer and poorer groups alike.** Crocodile culture is important to
richer households only, and fishing labour is an important income source primarily for poorer households. (See Table 3.)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Prek Toal</th>
<th></th>
<th>Thvang</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower</td>
<td>Middle</td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>Fishing</td>
<td>66.8</td>
<td>71.1</td>
<td>61.4</td>
<td>58</td>
</tr>
<tr>
<td>Fishing related activities</td>
<td>5.1</td>
<td>0</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>Fish culture</td>
<td>7.3</td>
<td>5.5</td>
<td>6.4</td>
<td>10</td>
</tr>
<tr>
<td>Crocodile</td>
<td>0</td>
<td>0</td>
<td>7.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Rice farming</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Other crops</td>
<td>0</td>
<td>0.7</td>
<td>0.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Livestock</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.6</td>
</tr>
<tr>
<td>Fishing labour</td>
<td>11.6</td>
<td>0.8</td>
<td>6.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Non-farm labour</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Petty trade</td>
<td>0.4</td>
<td>6.1</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>8.8</td>
<td>15.8</td>
<td>17.8</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Table 3. Household income portfolios by income group (tercile) for villages studied in the fishing lot case study, Battambang

III PREFERRED LIVELIHOOD ACTIVITIES

15. When asked about diversifying their livelihoods, people in the study villages typically look to activities that are already established in the area, meaning that someone has already demonstrated the option to be economically viable. The following results summarize the focus group discussions. The results from the two villages in each site did not differ significantly, so the results are presented here by study site rather than by village. We also note distinctions in terms of the preferences between the relatively poorer households and the relatively richer households. (See Table 4.)

16. In the road development study site (Pursat), where the road has increased market access, poorer households are seeking to increase production of a range of agricultural products. They hope to improve and diversify their livestock rearing activities, expand production of vegetable crops such as water melon, cucumber, long bean, cabbage, morning glory, and also hope to extend rice farming to two times per year. In Ou Ta Prok village, the poorer households also wish to diversify into fish culture, in particular Pangasius djambal (trey pra), Channa striata (trey ros), and Clarias batrachus (trey andeng). The richer households are also seeking to intensify rice farming, vegetable growing and livestock raising, as well as to improve non-farm livelihood activities such as grocery selling and livestock trade.

17. In the irrigation study site (Kampong Thom) the poorer households are seeking to benefit from the anticipated irrigation by intensifying rice farming to two crops per year, and diversifying vegetable production. Vegetable crops identified by the villagers include morning glory, water melon, cucumber, mung bean, tomato, cabbage, bitter gourd, wax gourd, and mushroom. In the livestock sector, the poorer households are looking to raise

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6 For the focus group discussions, participants were divided into wealth groups based on judgment by the village leader and common agreement among the participants.
The richer households too are looking to intensify rice farming, vegetable growing (watermelon, cucumber, long bean, black cabbage, Chinese cabbage, head cabbage, kiny cabbage and mushroom) and livestock raising (chicken, ducks and pigs). In addition, richer households are seeking to diversify into some non-farm livelihood activities such as motor repairs and grocery selling.

18. In the fishing lot study site (Battambang), the poorer households are primarily seeking to improve their livelihoods through additional fishing-related activities and fish culture. For fish culture, they cited in particular *Pangasius djambal* (trey bra), *Channa striata* (trey ros), and *Clarias batrachus* (trey andeng). In addition, they are seeking additional income through working as fishing labour, collecting wood for sale and expanding poultry raising. The richer households want to maintain their existing activities, including fishing, grocery selling, motorized boat taxi, fish and crocodile culture, fish processing and fish trade.

<table>
<thead>
<tr>
<th>Very poor &amp; poor households</th>
<th>Road development case (Pursat)</th>
<th>Irrigation case (Kampong Thom)</th>
<th>Fishing lot case (Battambang)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Intensify and diversify livestock raising (cows/oxen, buffalo, chickens, ducks -- and pigs in Ou Ta Prok only)</td>
<td>• Intensify fishing</td>
<td>• Intensify fishing</td>
</tr>
<tr>
<td></td>
<td>• Intensify fishing activities</td>
<td>• Sugar palm making</td>
<td>• Fish culture</td>
</tr>
<tr>
<td></td>
<td>• Intensify rice farming</td>
<td>• Vegetable growing</td>
<td>• Fishing labour</td>
</tr>
<tr>
<td></td>
<td>• Vegetable growing</td>
<td>• Livestock raising (chickens, ducks and pigs)</td>
<td>• Collecting firewood for sale</td>
</tr>
<tr>
<td></td>
<td>• Fish culture</td>
<td>• Intensify rice farming</td>
<td>• Livestock raising (chickens, ducks and pigs in the dry season)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medium &amp; richer households</th>
<th>Road development case (Pursat)</th>
<th>Irrigation case (Kampong Thom)</th>
<th>Fishing lot case (Battambang)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Intensify rice farming</td>
<td>• Intensify fishing</td>
<td>• Intensify fishing</td>
</tr>
<tr>
<td></td>
<td>• Vegetable growing</td>
<td>• Intensive fishing (chickens, ducks and pigs)</td>
<td>• Intensive and diversify non-farm activities like grocery selling at home, motorized boat taxi, fish trade</td>
</tr>
<tr>
<td></td>
<td>• Intensify and diversify livestock raising (cows/oxen, buffalo, chickens and ducks)</td>
<td>• Vegetable growing</td>
<td>• Fish and crocodile culture</td>
</tr>
<tr>
<td></td>
<td>• Improve existing non-farm activities like grocery selling and cow/oxen and buffalo trade</td>
<td>• Intensify rice farming</td>
<td>• Fish processing</td>
</tr>
<tr>
<td></td>
<td>• Intensify and diversify non-farm activities like motor repairs, grocery selling, and trading</td>
<td>• Intensify and diversify non-farm activities</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Livelihood activities that households seek to pursue, distinguished by wealth group

19. Notably, in almost all cases, villagers hope to increase their income by **intensifying fishing**. The one exception is the richer group in the Pursat case, which did not identify this as a preference. People’s preferences as expressed in the focus groups are closely linked to observations about what activities others in the village or nearby villages are successfully engaged in now. This implies that there remains a very significant gap between what people now say they prefer and what may indeed be viable, i.e. the future mix of livelihood activities that the local ecosystems and/or economies may be able to sustain at higher levels.
IV CONSTRAINTS TO LIVELIHOOD DIVERSIFICATION AND LOCAL PERCEPTIONS ABOUT ADDRESSING THESE

20. The constraints to livelihood diversification identified by villagers are remarkably consistent across the three cases studied. The two most important obstacles are lack of capital / access to credit facilities, and inadequate extension services. Villagers say that limited financial assets prevents them from diversifying into economically attractive livelihood activities, particularly as alternatives to fishing and collection of wild natural resources. Also very important in their view is the limited knowledge about methods of production and marketing strategies for alternative products, which they seek extension services to address, along with support for inputs such as improved rice seed varieties, fish seed and feed. In the irrigation (Kampong Thom) and fishing lot (Battambang) cases, access to markets ranked as the third major obstacle, while in Pursat it ranked fourth. (This is not surprising as market access was identified as the major benefit of road improvement in the Pursat case.) The remaining obstacles identified were lack of skills and technical knowledge (for example, about livestock raising), poor or inadequate infrastructure, and lack of awareness about the opportunities available for livelihood diversification. (See Table 5.)

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Road devt. case (Pursat)</th>
<th>Irrigation case (Kampong Thom)</th>
<th>Fishing lot case (Battambang)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to credit facilities</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Inadequate extension services and agricultural inputs</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Markets</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Skills and technical knowledge</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Lack of awareness/information about alternative livelihood opportunities</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 5. Constraints to livelihood diversification, as ranked by village focus groups

21. Low-interest microcredit lending was identified – by poorer and richer villagers alike – as the most important way to assist households to overcome the constraints to livelihood diversification. Because most households do not have appropriate collateral to seek loans from the formal banking system, and because their loan requirements are very small, they typically now rely on informal lending at very high rates of interest.

22. Other priorities include technical assistance and inputs, information about livelihood alternatives and market opportunities. In the road development (Pursat) and irrigation (Kampong Thom) cases, technical assistance and training is sought in such areas as sewing, fish culture,
livestock raising, vegetable cultivation, and intensive rice farming. In the case of the floating villages in Battambang, technical assistance and training is sought in such areas as poultry and pig raising, crocodile and fish culture, and sewing, in addition to government support to community fisheries with effective enforcement.

<table>
<thead>
<tr>
<th></th>
<th>Road development case (Pursat)</th>
<th>Irrigation case (Kampong Thom)</th>
<th>Fishing lot case (Battambang)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very poor &amp; poor households</td>
<td>• Credit service with low interest rate (1-2% per month)</td>
<td>• Credit service with low interest rate (1-2% per month)</td>
<td>• Credit service with low interest rate (1-2% per month)</td>
</tr>
<tr>
<td></td>
<td>• High yield rice seed, fertilizer and low-lift-pumps</td>
<td>• High yield rice seed, fertilizer and enough water</td>
<td>• Technical assistance for fish culture</td>
</tr>
<tr>
<td></td>
<td>• Technical assistance for farming, livestock raising and fish culture</td>
<td>• Technical assistance for vegetable farming</td>
<td></td>
</tr>
<tr>
<td>Medium &amp; richer households</td>
<td>• Credit service with low interest rate (1-2% per month)</td>
<td>• Credit service with low interest rate (1-2% per month)</td>
<td>• Technical assistance for fish and crocodile culture</td>
</tr>
<tr>
<td></td>
<td>• High yield rice seed, fertilizer and low-lift-pump</td>
<td>• High yield rice seed, fertilizer and enough water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Technical assistance for farming, livestock raising and fish culture</td>
<td>• Technical assistance for vegetable farming</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Marketing channels for palm sugar</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Equipment for farming</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Assistance from Fisheries Administration to create a community fishery</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Summary of solutions sought by villagers to address the constraints to livelihood diversification

V CONCLUSION AND RECOMMENDATIONS

23. Promoting rural development that enables new livelihood alternatives or expands the number of participants that can viably take part in existing alternatives is an indirect means of reducing competition and pressure on the natural resource base, fisheries included. This is especially important in areas where fishing is the leading source of income, as it is currently in the road development (Pursat) and irrigation (Kampong Thom) cases included in this study, or where it is the dominant source of income, as is the case with the floating villages of Battambang.
24. **Efforts at promoting livelihood diversification should include a mix of reducing constraints to enable poorer households to enter into existing alternatives, and cautiously experimenting with newer options.** Outside interventions often focus on new and original, or “boutique” options which may be appealing to project designers but are unproven in the area. Because villagers typically look to activities that are already established in the area (a reasonable way of managing risk for the household), it is likely to be much easier to facilitate livelihood diversification by enabling people to access the livelihood options they are already seeking. Other alternatives will need a longer time to establish as viable. Many will prove inappropriate even if they are technically feasible, for example, because they entail unacceptably high risk or require social organization that may not exist.

25. **Yet, some local expectations about intensifying existing livelihood activities – fishing in particular – are unrealistic.** For communities that have depended overwhelmingly on fishing (such as most floating villages), efforts to regulate fishing and make it more sustainable need to be complemented with support to alternatives such as ecotourism, post-harvest processing, improvements to equity and efficiency in fish trade, and (for those who wish) training for jobs on shore.

26. **Microfinance is in high demand and is perhaps the simplest measure to help families overcome barriers to livelihood diversification.** In terms of the sustainable livelihoods framework, microcredit is a means of increasing household financial assets to permit very modest investments in other livelihood activities. Successful microcredit initiatives require investment in social capital at the same time, to build the patterns of trust among borrowers so that they can monitor and support one another in implementing their business plans and repaying the loans.

27. **In responding to the high demand for technical support services and training, a variety of public-private partnerships should be assessed to provide cost-effective and locally appropriate solutions.** Enabling commune councils select among alternative service providers and allocate local budgets accordingly is one approach. Competitive bidding for service provision contracts at the provincial level is another approach, as has been tried with the health sector in Cambodia. Similarly, the demand for information about livelihood alternatives and about access to markets suggests room for exploring public-private partnerships in incubating business models, for example with aquaculture or small fish processing enterprises.

28. **Complementary investments in basic education and public health are likewise critical for the longer term.** As the analysis in the main technical report demonstrated, many households fail to take advantage of the livelihood opportunities offered by improvements in infrastructure because they lack other essential assets, education in particular. In terms of the sustainable livelihoods framework, investments in education and health are a means of raising human capital assets particularly for poorer households, increasing their chances of moving and staying out of poverty.
INFLUENCE OF BUILT STRUCTURES ON TONLE SAP FISHERIES

SYNTHESIS REPORT
INFLUENCE OF BUILT STRUCTURES ON TONLE SAP FISHERIES
INFLUENCE OF BUILT STRUCTURES ON TONLE SAP FISHERIES

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This document is a synthesis of eleven scientific studies produced under the project, Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (TA 4669-CAM):

- J. Koponen, S. Tes, and J. Mykkänen. *Influence of built structures on Tonle Sap hydrology and related parameters*
- M. Kruskopf. *Impacts of built structures on tropical floodplains worldwide*
- S. Nguyen Khoa and P. Chet. *Review of Tonle Sap built structure Environmental Impact Assessments (EIA) with regard to fisheries*
- E. Baran, N. So, S. Leng, R. Arthur, and Y. Kura. *Relationships between bioecology and hydrology among Tonle Sap fish species*
- E. Baran E., N. So, R. Arthur, S.V. Leng, Y. Kura. *Bioecology of 296 fish species of the Tonle Sap Great Lake (Cambodia)*.
- E. Baran, T. Jantunen, M. Hakalin, P. Chheng. "*BayFish-Tonle Sap*, a model of the Tonle Sap fish resource*
- T. Jantunen. *Integration of databases to the BayFish – Tonle Sap fish production model*
- R. Arthur, E. Baran, N. So, S. Leng, S. Prum, S.H. Pum. *Influence of built structures on Tonle Sap fish resources*
- B.D. Ratner, D.B. Rahut, M. Käkönen, N. Hap, M. Keskinen, S. Yim Sambo, L. Suong, and R. Chuenpagdee. *Influence of built structures on local livelihoods: case studies of roads, irrigation, and fishing lots*
- D.B. Rahut, N. Hap, and B.D. Ratner. *Enabling alternative livelihoods for aquatic resource dependent communities of the Tonle Sap*

Readers interested in further details concerning the research methodology and findings, as well as references, are requested to consult these source documents. These detailed scientific reports are available at:

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We are also grateful to the participants of the three stakeholder workshops held during the course of the study, for their input and feedback on the study and its results.

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1. INTRODUCTION

The inland fishery resources of Cambodia, originating mainly from the Tonle Sap Lake, rank first in the world for their productivity and fourth for their total catch. The floodplains’ contribution to income, employment, and food security is higher than in any other country. However, the natural productivity of the Tonle Sap’s floodplains will be threatened if the flood pulse, the temporarily submerged habitats, and the fish migration routes of the Tonle Sap Lake are not given attention. In relation to this, the influence of built structures, which modify the hydrology of the system, need to be better assessed in ecological and socioeconomic terms. A review of global research has shown these influences to be complex and very significant (see Table I).

What are built structures?

Built structures consist of a variety of man-made structures that contribute to changing the hydrology of a natural system. They can:

(i) oppose water outflow (e.g. dams, weirs, irrigation schemes, dykes);
(ii) prevent water inflow (e.g. embankments, polders, levees);
(iii) change water inflow or outflow (e.g. roads, canals, large-scale fishing gears);
(iv) degrade water quality (e.g. factories, mines, sewers).
This document is a synthesis of the major findings and recommendations of a study on the influence of built structures on the fisheries of the Tonle Sap Lake. This 13 month study, funded by the Government of Finland through the Asian Development Bank, was carried out between May 2006 and May 2007 by the Cambodian National Mekong Committee (CNMC) and the WorldFish Center. The multidisciplinary study analysed the influence and impact of built structures on hydrology, fish, and ultimately on people. The project established a database of major structures around the Tonle Sap Lake. Hydrologists modeled the influence of infrastructure on the flow and quality of water. Environmental scientists analyzed information about how infrastructure affects the environment. Experts in ecology and fish biology assessed the direct impacts on fisheries. Social scientists and economists evaluated the influence of infrastructure development on people’s livelihoods, and studied local people’s insights related to the planning, construction, and operation of built structures.

The study assessed the impact of infrastructure on Tonle Sap fisheries on three separate scales. The first covered the entire Mekong Basin including upstream areas which have an impact on the hydrology, ecology and fisheries of the Tonle Sap Lake. The second scale focused on the Tonle Sap tributaries. The third covered the Tonle Sap floodplains and includes the lake itself. The project also undertook three case studies. These included a new road development in Krakor district in Pursat province and the newly-rehabilitated Stung Chinit irrigation scheme in Baray and Santhouk districts in Kompong Thom province. The third case study looked at the impact of large-scale fishing fences in the area of Prek Toal, a floating village in Aek Phnum district of Battambang province.
### Table I: Overview of types of built structures and of their consequences

<table>
<thead>
<tr>
<th>Structure type</th>
<th>Hydrological and environmental changes</th>
<th>Socioeconomic changes</th>
<th>Positive consequences</th>
<th>Negative consequences</th>
<th>Specific impact on fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydropower and irrigation dams</strong></td>
<td>Reduction or drying up of floodplains</td>
<td>Changes in income distribution</td>
<td>Power generation</td>
<td>Reduced water storage capacity in wetlands</td>
<td>Reduced species richness and diversity</td>
</tr>
<tr>
<td></td>
<td>Changes in discharge and water level (modified base and peak flows)</td>
<td>Increased regional demand and prices of fish</td>
<td>Increased agricultural production</td>
<td>Reduced floodplain connectivity, hence loss of natural productivity</td>
<td>Reduction of fish stock</td>
</tr>
<tr>
<td></td>
<td>Modified seasonal flows (in particular dry season flows)</td>
<td>Stabilization of downstream flows</td>
<td></td>
<td>Loss of habitats, foraging and breeding areas for fish</td>
<td>Falling catch rates</td>
</tr>
<tr>
<td></td>
<td>Decreased flooding (frequency, extent, duration and magnitude of floods)</td>
<td>Increased water availability in the dry season</td>
<td></td>
<td>Inhibition of movement and migration of fish</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modified water turbidity</td>
<td></td>
<td>Changes in fish migrations and distribution</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Increased water salinity in deltas</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td><strong>Dykes, roads</strong></td>
<td>Habitat partitioning</td>
<td>Improved access to markets, education and health</td>
<td>Control of water levels</td>
<td>Reduced water storage capacity in wetlands</td>
<td>Reduction of fish stock</td>
</tr>
<tr>
<td></td>
<td>Changes in the level of the water table</td>
<td>Increased average wealth</td>
<td>Protection from extreme or flash floods</td>
<td>Reduction of floodplain connectivity</td>
<td>Increased catchability of fish</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Increased access to resources</td>
<td></td>
<td>Restriction of fish migrations</td>
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<td></td>
<td></td>
<td></td>
<td>Changes in species richness and diversity</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Changes in species distribution</td>
</tr>
<tr>
<td><strong>Irrigation schemes</strong> (aspects not covered by dams)</td>
<td>Increased pollution (pesticides and herbicides)</td>
<td>Changes in income distribution</td>
<td>Increased crop production security</td>
<td>Loss of natural aquatic productivity</td>
<td>Reduction of species richness and diversity</td>
</tr>
<tr>
<td></td>
<td>Vegetation changes</td>
<td>Changes in access rights</td>
<td></td>
<td>Loss of habitats (incl. fish foraging and breeding areas)</td>
<td></td>
</tr>
<tr>
<td><strong>Canals</strong></td>
<td>Changes in water availability</td>
<td>Changes in income distribution</td>
<td>Increased agricultural production</td>
<td>Introduction of alien species (if between watersheds)</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Changes in access rights</td>
<td>Increased water availability in the dry season</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Increased area accessible to fish</td>
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</tr>
</tbody>
</table>

Source: Report "Impacts of built structures on tropical floodplains worldwide"
Influence of built structures on Tonle Sap fisheries

Hydrological Scenarios

To assess the potential hydrological impact of new water development infrastructure in the future, the study examined three scenarios based on different levels of future development on the Mekong River mainstream, and one scenario for the Tonle Sap watershed:

- **Baseline scenario**—represents the existing level of water storage based on the actual situation in 2000 when there was only one hydro-electric dam in the Upper Mekong Basin with a relatively small water-storage capacity of less than one cubic kilometer.

- **Intensive Basin Development scenario**—represents a combined water-storage capacity of 55 cubic kilometers, assuming that seven more hydro-electric dams are built across the mainstream by 2025 in the Upper Mekong Basin. This assumes that China and Lao PDR will each have a water-storage capacity of about 23 cubic kilometers, including almost five cubic kilometers for the Nam Ngum 1 reservoir alone. Thailand and Viet Nam would account for the remaining nine cubic kilometers.

- **Extreme Basin Development scenario**—adds to the second scenario seven more dams on the Mekong mainstream in Lao PDR, Cambodia and Thailand, boosting the total storage capacity to 140 cubic kilometers. The additional 85 cubic kilometers would come from dams in Lao PDR (Luang Prabang, Pa Mong, and Thakek), Cambodia (Stung Treng and Sambor) and Thailand (Sayabouri).

- **Limited Development scenario for the Tonle Sap watershed**—assumes a combined storage capacity of 5.5 cubic kilometers. This adds to the Baseline scenario the hydro-electric and irrigation dams on seven tributaries that flow into the lake, notably the Stung Sen.
Inland fisheries are vital to the Lower Mekong Basin with the combined catches of Cambodia, Lao PDR, Thailand and Viet Nam worth about two billion dollars a year. In terms of volume, annual production by the four countries exceeds 2.5 million tonnes, providing food and income for many of the Lower Basin’s 60 million inhabitants, especially the rural poor. Almost 80 percent of the annual catch is from rivers and other natural water bodies. The rest mainly comes from reservoirs and aquaculture. In the Upper Mekong Basin in China and Myanmar, fish production is estimated to be relatively small.

Cambodia alone has the world’s most productive inland fishery. A single hectare of floodplain can produce up to 230 kilograms of fish a year. In terms of value, the overall fishing sector accounts for 10 to 12 percent of gross domestic product (GDP) and contributes more to income, jobs and food security than in any other country. By volume, Cambodia has the...
world’s fourth-richest inland fisheries after China, India, and Bangladesh, with the annual catch conservatively estimated at about 400,000 tonnes. Tonle Sap fisheries account for almost two-thirds of the total catch in Cambodia.

If the Tonle Sap Great Lake is the heart of Cambodia, the annual “flood pulse” is what keeps it alive. The flood pulse is a scientific concept referring to the cyclical changes between high and low water levels. It emerged as a new way of describing river ecology two decades ago, gaining broad acceptance worldwide. The Tonle Sap ecosystem has adapted to the exceptionally high natural variability of the lake. Thus, between the dry and the wet season the volume of the lake increases from about 1.3 km$^3$ up to 75 km$^3$, its surface area varies from 2,500 km$^2$ up to about 15,000 km$^2$, and its water level increases from 1.4 m to 10.3 m above sea level.

Fifty seven percent of the water in the Tonle Sap Lake comes from the Mekong River. During an average wet season, about 52 percent comes in directly through the Tonle Sap River, and 5 percent flows overland through the floodplain from the Mekong. Another 30 percent comes from rivers that flow directly into the lake and about 13 percent comes from rainfall over the lake itself. This means that upstream developments and structures potentially influence almost two thirds of the water flowing into the Tonle Sap Lake. Among upstream countries, Lao PDR contributes 19 percent of Tonle Sap water, while China and Thailand contribute 9 and 10 percent respectively.
The Tonle Sap Lake accounts for about 60 percent of Cambodia's inland fisheries production. In 2006, the Inland Fisheries Research and Development Institute of the Fisheries Administration estimated the value of fisheries and other aquatic resources of the Tonle Sap Lake conservatively at $233 million a year. The report based its figures on incomes for an estimated 209,000 households dependent on aquatic resources in Kampong Chhnang, Siem Reap, Battambang, Pursat and Kampong Thom.

About 150,000 households had annual incomes of $1,000 or less, averaging $470 a year or about $78 per person.

The productivity of Tonle Sap fisheries is affected by infrastructure development. Construction, earthworks and related activities all affect hydrology including seasonally-submerged habitats and fish-migration routes. Dams, irrigation schemes and dikes, for example, oppose outflows of water, whereas embankments, polders and levees prevent inflows. Roads, railways and canals can affect both inflows and outflows. Other developments like factories and sewers may degrade water quality.

With Cambodia's growing population, fishing pressure is also intensifying. Production is now more than three times higher than in 1940 when it was estimated at 120,000 tonnes. Since then, Cambodia's population has also tripled. In 2003, the Department of Fisheries warned that individual catch rates had plunged to less than 200 kilograms a head, down from almost 350 kilograms a head in 1940. With fewer big species caught, the average value of catches is also declining. Moreover, catches are increasingly dominated by smaller, short-lived and rapidly-reproducing fish species which tend to be worth less.

2.2. BUILT STRUCTURES IN THE TONLE SAP BASIN AND BEYOND

More than fourteen thousand built structures have been identified in the study sites of the Tonle Sap Basin. An overview of these main structures is given in Table II and Table III.

Table II: Number of structures identified in the Tonle Sap Basin

<table>
<thead>
<tr>
<th>Structure</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER STORAGE (reservoirs)</td>
<td>55</td>
</tr>
<tr>
<td>WATER ROUTING (canals)</td>
<td>3992</td>
</tr>
<tr>
<td>FLOW CONTROL (dams, embankments, dikes, gates, weirs, pumping and other stations)</td>
<td>3294</td>
</tr>
<tr>
<td>FISHING (bagnets, barrages, fences)</td>
<td>473</td>
</tr>
<tr>
<td>AGRICULTURE (rice fields, crop fields, plantations, irrigated areas)</td>
<td>5267</td>
</tr>
<tr>
<td>TRANSPORT (bridges, docks, harbors, ferries)</td>
<td>1315</td>
</tr>
<tr>
<td>POLLUTION SOURCES (mines)</td>
<td>62</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>14,458</strong></td>
</tr>
</tbody>
</table>

Source: Report “Tonle Sap built structures database - built structures statistics”
Built structures found in the Tonle Sap Basin vary in their type, design, and size, making it difficult to assess their influence on the hydrology of the lake. Counting all existing structures in the Tonle Sap Basin (i.e. over 44 percent of the whole country) is a titanic undertaking; during this project only 3 study areas could be covered in detail. Roads cannot be easily counted (their length, width or design might be more important than their number). Counting structures also relies on automatic mapping (e.g. to identify rice fields), with subsequent uncertainties. Categorizing them into simple, distinct groups is often tricky (e.g. difference between weirs, dykes and embankments). Fishing fences can be identified as long as they are not under vegetation cover or underwater (which is often the case with extensive nylon barriers). Canals are many but include a large majority of canals from the Khmer Rouge period that are not actually operational. Major pollution sources (mines, factories, etc.) can be counted, but not diffuse pollution sources due to agriculture or human settlements. Last, the influence of many structures depends on how they are designed and operated. For instance a sluice gate in an irrigation scheme counts as one structure, but its role depends whether it is open or closed, and when; similarly a floodplain road that counts as one structure will have a different influence depending upon the number and size of its culverts.

Table III: Basic statistics on built structures included in the study areas covered

<table>
<thead>
<tr>
<th>Province</th>
<th>Area (km²) flooded by medium floods</th>
<th>Length of roads (km)</th>
<th>Number of bridges</th>
<th>Length of embankments and dykes (km)</th>
<th>Area of reservoirs (km²)</th>
<th>Number of dams</th>
<th>Area (km²) of irrigation schemes</th>
<th>Length of fish fences (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stung Treng</td>
<td>0</td>
<td>42</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oddar Meanchey</td>
<td>31</td>
<td>800</td>
<td>106</td>
<td>7</td>
<td>9</td>
<td>2</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Preah Vihear</td>
<td>0</td>
<td>603</td>
<td>138</td>
<td>25</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Banteay Meanchey</td>
<td>1348</td>
<td>970</td>
<td>118</td>
<td>245</td>
<td>16</td>
<td>23</td>
<td>236</td>
<td></td>
</tr>
<tr>
<td>Siem Reap</td>
<td>2825</td>
<td>1161</td>
<td>158</td>
<td>587</td>
<td>28</td>
<td>0</td>
<td>615</td>
<td>45</td>
</tr>
<tr>
<td>Battambang</td>
<td>3332</td>
<td>1144</td>
<td>187</td>
<td>300</td>
<td>13</td>
<td>0</td>
<td>1507</td>
<td>77</td>
</tr>
<tr>
<td>Kampong Thom</td>
<td>3626</td>
<td>1102</td>
<td>99</td>
<td>163</td>
<td>43</td>
<td>2</td>
<td>462</td>
<td></td>
</tr>
<tr>
<td>Kratie</td>
<td>269</td>
<td>401</td>
<td>36</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pailin</td>
<td>0</td>
<td>148</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pursat</td>
<td>1612</td>
<td>996</td>
<td>242</td>
<td>81</td>
<td>0</td>
<td>0</td>
<td>334</td>
<td></td>
</tr>
<tr>
<td>Kampong Chhnang</td>
<td>1964</td>
<td>543</td>
<td>87</td>
<td>255</td>
<td>0</td>
<td>0</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Kampong Cham</td>
<td>1642</td>
<td>478</td>
<td>53</td>
<td>265</td>
<td>2</td>
<td>0</td>
<td>193</td>
<td></td>
</tr>
<tr>
<td>Kampong Speu</td>
<td>0</td>
<td>109</td>
<td>6</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Kandal</td>
<td>506</td>
<td>272</td>
<td>50</td>
<td>108</td>
<td>0</td>
<td>0</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>17156</strong></td>
<td><strong>8932</strong></td>
<td><strong>1311</strong></td>
<td><strong>2064</strong></td>
<td><strong>111</strong></td>
<td><strong>38</strong></td>
<td><strong>3526</strong></td>
<td><strong>124</strong></td>
</tr>
</tbody>
</table>

Source: Report “Tonle Sap built structures database - built structures statistics”

Hydropower development has recently become a priority in Cambodia and continues to be a high priority in the region. Table IV below details a number of sites (in Cambodia or on rivers flowing into Cambodia) that have been considered for hydropower development.
The development of water resources in the Mekong River Basin is not just for hydropower but also for irrigation and flood mitigation, especially in the Lower Basin. For example, the Mekong River Commission’s Basin Development Plan estimated in 2003 that Vietnam had 580 irrigation projects within the watersheds of the Se San and Sre Pok rivers, two major Mekong tributaries flowing into Cambodia. The schemes irrigate more than 46,000 hectares of rice paddies and coffee plantations. The irrigation water demand there is forecast to reach 3.8 billion cubic meters a year by 2010, up more than a third from 2.8 billion cubic meters in 2001. That represents 63 percent of the dry-season runoff, which can only be withdrawn by adding extensive infrastructure. Further irrigation development and rehabilitation is therefore planned, with 658 works expected in the central highlands by 2010. In Cambodia many irrigation schemes were built under the Khmer Rouge regime and their rehabilitation is a priority under the Basin Development Plan.

### Table IV: Sites with existing hydropower capacity or proposed for development

<table>
<thead>
<tr>
<th>River/Site</th>
<th>Multi-site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sre Pok</td>
<td>3 sites in Cambodia: 787 MW.</td>
</tr>
<tr>
<td></td>
<td>7 sites in Viet Nam: 841 MW</td>
</tr>
<tr>
<td>Se San</td>
<td>2 sites in Cambodia: 582 MW / 3042 GW;</td>
</tr>
<tr>
<td></td>
<td>5 sites in Viet Nam: 1516 MW</td>
</tr>
<tr>
<td>Se Kong</td>
<td>2 sites in Lao PDR: 390 MW / 1269 GW</td>
</tr>
<tr>
<td>O Phlai</td>
<td>4 sites: 21 MW / 147 GW</td>
</tr>
<tr>
<td>Stung Pursat I</td>
<td>4 sites: 96 MW / 485 GW</td>
</tr>
<tr>
<td>Prek Liang</td>
<td>3 sites: 121 MW / 581 GW</td>
</tr>
<tr>
<td>Prek Por</td>
<td>3 sites: 34 MW / 204 GW</td>
</tr>
<tr>
<td>Prek Ter</td>
<td>3 sites: 50 MW / 269 GW</td>
</tr>
<tr>
<td>Stung Battambang</td>
<td>3 sites: 73 MW / 384 GW</td>
</tr>
<tr>
<td>Prek Chhlong</td>
<td>2 sites: 31 MW / 203 GW</td>
</tr>
<tr>
<td>Prek Kam</td>
<td>2 sites: 8 MW / 53 GW</td>
</tr>
<tr>
<td>Prek Kreing</td>
<td>2 sites: 14 MW / 85 GW</td>
</tr>
<tr>
<td>Prek Rweei</td>
<td>2 sites: 12 MW / 128 GW</td>
</tr>
<tr>
<td>Stung Mongkol Borey</td>
<td>2 sites: 14 MW / 97 GW</td>
</tr>
<tr>
<td>Mekong Sambor 2</td>
<td>3300 MW / 14870 GW</td>
</tr>
<tr>
<td>O Chum II</td>
<td>1 MW / 4.4 GW</td>
</tr>
<tr>
<td>Kamchay</td>
<td>180 MW / 550 GW</td>
</tr>
<tr>
<td>Prek Chbar</td>
<td>5 MW / 32 GW</td>
</tr>
<tr>
<td>Stung Atay</td>
<td>110 MW / 588 GW</td>
</tr>
<tr>
<td>Stung Cheay Areng</td>
<td>260 MW / 1350 GW</td>
</tr>
<tr>
<td>Stung Chikreng</td>
<td>2 MW / 8 GW</td>
</tr>
<tr>
<td>Stung Chinit</td>
<td>5 MW / 23 GW</td>
</tr>
<tr>
<td>Stung Sreng</td>
<td>7 MW / 69 GW</td>
</tr>
<tr>
<td>Stung Staung</td>
<td>4 MW / 23 GW</td>
</tr>
<tr>
<td>Stung Sva Slapp</td>
<td>4 MW / 20 GW</td>
</tr>
<tr>
<td>Stung Tanat</td>
<td>4 MW / 27 GW</td>
</tr>
<tr>
<td>Stung Tatay</td>
<td>80 MW / 250 GW</td>
</tr>
<tr>
<td>Stung Treng</td>
<td>980 MW / 4870 GW</td>
</tr>
<tr>
<td>Upper Prek Ter</td>
<td>15 MW / 77 GW</td>
</tr>
<tr>
<td>Upper Stung Siem Reap</td>
<td>1.7 MW / 7 GW</td>
</tr>
</tbody>
</table>

*Capacity installation (MW) / Energy production (GW)*

*Source: Report "Influence of built structures on Tonle Sap fish resources"*
**2.3. POLICY CONTEXT**

Infrastructure development is one of the four priority areas of the government’s Rectangular Strategy, focusing on growth, employment, equity and efficiency. With gross domestic product expanding by more than 13 percent, Cambodia had one of the world’s fastest-growing economies in 2005. The economy expanded by an estimated 10.4 percent in 2006 and is forecast to grow by around 9 percent in 2007. Under its National Strategic Development Plan for 2006 to 2010, the government is placing greater emphasis on enhancing physical infrastructure, especially in rural areas (Figure 4). Priorities include roads and irrigation facilities, with a major focus on attracting private-sector investment. Under the five-year plan, priorities include enacting a road law, rehabilitating 2,000 kilometers of primary and secondary roads and rehabilitating or rebuilding existing irrigation and drainage systems. Other priorities include expanding the storage capacity of surface water, promoting water-harvesting technologies, developing groundwater resources and flood-mitigation measures, and strengthening water-use groups. The strategic development plan emphasizes the importance of keeping water resources free of contaminants to support the ecological system, especially fisheries. Public investment allocations are estimated at $3.5 billion per year, with transport alone accounting for 15 percent of projected outlays. In its assessment of the five-year plan, the International Monetary Fund has said that infrastructure development, especially in rural areas, will be "critical" to broadening Cambodia’s economic base for sustained growth.

Enhancing the agricultural sector, including sustainable access to fisheries for the poor, is another main priority of the Rectangular Strategy. Priorities for fisheries include community-based development and improving the livelihoods of poor people with better processing, handling, storage, transport and trade facilities. Other priorities include sustaining water bodies and promoting aquaculture. Under the plan for 2006 to 2010, support is being provided to Commune Councils to undertake rural infrastructure projects such as rehabilitating roads and building small bridges and culverts, wells, sanitation structures, schools, water gates and small irrigation systems.

Strategies to develop, manage and preserve the Mekong River’s water and related resources are the responsibility of the Cambodian National Mekong Committee. The committee is comprised of 10 ministries (Land Management, Urban Planning and Construction; Planning; Foreign Affairs and International Cooperation; Environment; Water Resources and Meteorology; Agriculture, Forestry and Fisheries; Industry, Mines and Energy; Public Works and Transport; Tourism; and Rural Development). One of the committee’s aims is to contribute to sustainable economic and infrastructure development. Parliamentary oversight for this area primarily rests with National Assembly Commission No. 3 (Economy, Planning, Investment, Agriculture, Rural Development, Environment and Water Resources) and National Assembly Commission No. 9 (Public Works, Transport, Post and Telecommunications, Industry, Mines and Energy, and Commerce).
In his foreword to the five-year plan, Samdech Prime Minister Hun Sen highlighted the importance of ensuring that all resources from both the government and external development partners are directed to priorities and sectors chosen by the government. “It is time now that resources begin to be properly directed and effectively used to maximize the benefits for the disadvantaged and deprived to lift them into the mainstream,” he said. The prime minister also said that social and economic growth should be equitable with opportunities and benefits affordable and accessible to all, both geographically and between the rich and the poor.

The prime minister has also highlighted the Tonle Sap Lake’s crucial role as an important fish habitat. “We must try our best to preserve and sustain the national fishery resources for our younger generations to come” he said at the National Fish Day ceremony in 2006.

Cambodia’s policy priorities for growth and infrastructure development are clear, as are priorities for protection of the aquatic environment and sustainable rural livelihoods. Balancing these priorities involves conscious trade-offs that need to be more clearly understood and debated. The purpose of this study is to sharpen awareness among decision-makers and other stakeholders about the trade-offs associated with infrastructure development, in particular by better appreciating the influence on fisheries.
Influence of built structures on Tonle Sap fisheries
3. FINDINGS AND RECOMMENDATIONS

Findings detailed below result from a synthesis and integration of studies at different scales and in various disciplines. The recommendations point to key principles and actions needed, based on the findings that are detailed just after each recommendation. These recommendations are meant to help decision-makers in maximizing the economic and social returns from investments in infrastructure while minimizing adverse impacts on the environmental sustainability of the Tonle Sap Lake and on the people who live around the lake.

3.1. NATIONAL-LEVEL DECISION MAKING

This section focuses on water development infrastructure in the Mekong River Basin that may affect water resources, fisheries and livelihoods around the Tonle Sap Lake. The recommendations of this section are for national decision-makers; these include policymakers in the 10 ministries that are members of the Cambodian National Mekong Committee as well as lawmakers in the National Assembly and Senate commissions that oversee infrastructure development. The recommendations are also targeted at domestic and foreign investors in the private sector as well as international donors.

3.1.1. INFLUENCE OF BUILT STRUCTURES IN THE MEKONG RIVER BASIN

**RECOMMENDATION 1**

When planning infrastructure development, avoid irreversible changes to water flows, especially those affecting seasonal flooding or breaking the natural "connectivity" between various water bodies around the Tonle Sap.
(See also Recommendations 2, 6)
Modifying water flows and flood patterns are the biggest threats to the ecology of floodplains. Once lost, the costs of rehabilitating the ecological functions of floodplains are very high. Any structure affecting water within a floodplain or in rivers upstream is assumed to have some influence on the floodplain environment and should be treated with caution. Most declines in fisheries production in tropical floodplains are either directly or indirectly related to changes in water flows. Seasonal flooding and connectivity are essential for maintaining the ecology of floodplains. Experts generally agree with this conclusion, which is supported by numerous experiences in tropical floodplains in Asia, Africa and South America. These are reported in more than 300 journal articles, reports and books that were reviewed for the study.
The biggest impact of upstream development on the inflows of Mekong River water into the Tonle Sap Lake will be felt in dry years when the upstream reservoirs withhold the most water in relation to the Mekong’s total flow. Hydrological modeling shows that inflows into the lake would decline by between 4.5 cubic kilometers under the Intensive Development scenario and by 11 cubic kilometers under the Extreme Development scenario. Under the Intensive scenario, that represents 4 percent in a wet year and 10 percent in a dry year. Under the Extreme scenario, inflows would fall by about 10 percent in a wet year and 25 percent in a dry year. The strength of these findings is supported by hydrological modeling by the Mekong River Commission since 2001.

Upstream developments will delay the onset of the annual flood in the Tonle Sap Lake and shorten its duration. Under the Intensive scenario in a dry year, the flood would be delayed by up to 12 days depending upon the location and altitude, and its duration would be a week shorter (see Figure 6 and Figure 7). Under the Extreme scenario, the flood would be delayed by one month and its duration would be two weeks shorter.

**Figure 6: Upstream developments result in flood arriving later.**
The simulation, based on 1998 actual hydrological data (very dry year), highlights the difference in flood arrival time between the Baseline and Intensive Development scenarios. The legend shows the number of days delayed. **Source:** Report *Influence of built structures of Tonle Sap hydrology and related parameters*
Upstream developments will also decrease the height and surface area of the flood. Under the Intensive Development scenario in a dry year, the maximum height would be about half a meter lower and the surface area about 10 percent smaller. The main losses would occur in very high areas that are flooded for short periods.
Influence of built structures on Tonle Sap fisheries

Dams upstream will sharply reduce the input of sediments into the Tonle Sap Lake, adversely affecting the recycling of nutrients and possibly threatening dry-season habitats, especially in areas with high fish productivity. The Upper Mekong Basin is the source of more than 50 percent of the suspended sediments in downstream areas of the Lower Basin. The planned cascade of eight dams in the Extreme Development scenario has the potential to trap nearly all of these sediments (see Figure 9). Loss of sediments in flood water would result in a loss of natural soil fertility (hence a loss of rice production or higher production costs due to increased use of fertilizers). It could also lead to increased erosion along the Mekong's banks and possibly to a lower survival rate for fish eggs, their buoyancy being reduced. These findings about sedimentology must be treated with caution, however, as the sediment processes of the Mekong are not very well known. For example, the origin of very fine sediments of most importance to the Tonle Sap Lake has not been studied.

Delays in the onset of the flood will result in delays in the arrival of oxygen-rich waters. Dissolved oxygen levels in Tonle Sap water generally decline during dry season, until the inflow of oxygen-rich water at the beginning of flood season. While fish may swim to more oxygenated waters, eggs and larvae unable to move may be adversely affected if the arrival of the flood is delayed. Flow changes may also have an impact on the drift of fish larvae and juveniles, which usually end up on the northern and eastern shores of the lake. Under the Intensive Development scenario, eggs and floating particles tend to drift more towards the western shore, indicating possible negative impacts on highly-productive fishing.

RECOMMENDATION 3

In addition to considering the seasonal impact on water flows, planning of upstream water developments should specifically take into account possible ecological consequences of the changes in flooding, including loss of flooded forests, reduced inflows of sediments, lower oxygen levels, and changes in the drift of fish larvae and juvenile fish.

Figure 9: Upstream developments result in decreased sediment input in the lake.
Simulation based on 1997 data. Reduced sedimentation is caused by trapping by dams upstream. The most impacted areas shown in dark overlap with areas with high fisheries productivity.

Source: Report “Influence of built structures of Tonle Sap hydrology and related parameters”
Influence of built structures on Tonle Sap fisheries lots in the northern part of the lake. This finding is, however, based only on computer simulations and needs to be verified by observations in the field.

Upstream developments will expand the edge of the lake during the dry season, destroying some flooded-forest areas if they are permanently submerged. Under the Intensive Development scenario, hydrological modeling shows that the surface area of the lake will expand by between 300 and 900 square kilometers in the dry season in an average year (Figure 10). That is equivalent to between a 15 and 45 percent increase in the lake's dry-season size. Permanent flooding of some areas is likely to kill the flooded forests that are located along the lake edge and cannot tolerate permanently flooded conditions, as they require temporary emersion to complete their lifecycle. This forest acts as a buffer protecting the floodplain against storms and rough water conditions on the lake; this oxygen and nutrient rich habitat is also important to fish as a breeding, feeding and shelter area. The scope of the study did not include assessing the possible impacts of an expanded dry-season lake on the flooded-forest plant species or invasive species such as the water hyacinth (*Eichornia crassipes*) or mimosa (*Mimosa pigra*).

![Figure 10: Upstream developments result in higher water levels in the dry season.](image_url)

Source: Report "Influence of built structures of Tonle Sap hydrology and related parameters"

**RECOMMENDATION 4**

The livelihood benefits of floodplains should be properly evaluated and integrated into basin-wide water development planning, with particular focus on the impact of dams on fisheries.
In terms of ecological and social benefits, floodplains are among the most valuable landscapes in the world. A global review of tropical floodplains completed during the study found that fish and other natural resources are the primary benefits, followed by the replenishment of nutrients and fertile soils for farmlands and pastures. However, much is still unknown about the ecological functions of floodplains and how to value them properly. This is a reason why the impact of man-made structures on tropical floodplains is not well documented with the exception of large dams. Most of the available information is qualitative rather than quantitative. Valuations should be conducted in such a way that the results can be integrated into more conventional economic cost-benefit analyses of proposed investments in water development projects, and allow more thorough economic analyses of the predicted returns for different investment options.

Dams are the main type of structure having an impact on fisheries production, through their negative impact on fish migrations. In the Mekong Basin, 87 percent of fish species for which information is available are migratory species. Sixteen percent of these species are known to be sensitive to hydrological migration triggers that will be modified by dam construction. Since the bulk of the catch actually consists of a small number of species groups that are predominantly sensitive to hydrological migration triggers, a very large proportion of the total catch is likely to be affected by river modifications (96 percent of the catch at Khone Falls, Southern Laos). The most important impact of flow modification due to upstream built structures would be experienced during the dry season and at the beginning of the rainy season.

The study found no examples of positive long-term impacts of dams on fisheries, nor any effective mitigation measures in the Mekong Basin. Reservoirs are sometimes presented as a way to create new fisheries upstream, but this usually does not compensate for the loss of downstream fisheries. Similarly, fish passes are often proposed to help fish migrate. However, there are no examples of fish passes that work in the Mekong Basin. This is mainly due to ecological factors and the intensity of migrations which fish passes cannot accommodate. Out of the hundreds of species in the Mekong Basin, only nine are known to breed in reservoirs. The effectiveness of the new fish pass at Stung Chinit completed in 2006 has not yet been assessed.

Even a small percentage lost in fisheries will amount to tens of thousands of tonnes and millions of dollars when considering the total production of 2.6 million tonnes each year. The loss would also affect millions of people with fisheries-associated livelihoods. For instance, the fish groups that are extremely sensitive to hydrological triggers include shark catfishes (Pangasiidae), which are commercially important to both capture fisheries and aquaculture. Among the 10 fish groups that dominate the Tonle Sap catch, four are sensitive to such triggers. They account for 18 percent of the volume of the Tonle Sap catch and 14 percent of its value. On the other hand, several environmental impact assessments (EIAs) conclude that negative impacts on fisheries would be minor because of biases or flaws in their approach such as a limited scope, or because of a focus on percentages lost rather than on tonnage and livelihood values lost. In general, most dam projects in the Mekong Basin lack undisputable EIAs and detailed baseline studies that would allow the full range of cost-benefit analyses.

RECOMMENDATION 5

Adopt regional guidelines such as the Strategic Environmental Framework for the Greater Mekong Sub-region (GMS), which promote strategic environmental assessments addressing the cumulative impacts of multiple development projects.
Large infrastructure projects increasingly require cumulative-impact and strategic-environmental assessments. Most structures are not isolated from the surrounding environment. The cumulative impact of many structures can be assessed, although this is complicated as it is more than simply adding up the individual impacts of each structure. In general, impact assessments rarely quantify benefits that might be lost. Existing guidelines and recommendations on how to implement EIAs typically do not include instructions on how to consider specific environmental characteristics of floodplains, how to assess the impacts of projects on floodplain ecosystems, or how to include economic valuation of the lost benefits of floodplains.

3.1.2. INFLUENCE OF BUILT STRUCTURES IN THE TONLE SAP WATERSHED

The influence of hydropower and irrigation projects within the Tonle Sap Lake's catchment basin would significantly add to the impact of developments upstream in the Mekong Basin. Even smaller dams within the Tonle Sap catchment would have an impact similar to upstream dams in reducing inflows of water in the wet season and increasing dry-season flows. Figure 11 shows the influence on water level of Tonle Sap developments in the case of the Tonle Sap scenario that adds hydro-electric and irrigation dams across seven tributaries that flow into the lake. Impacts of Tonle Sap projects are felt earlier than those of upstream projects. The combined impact of Tonle Sap projects and Mekong upstream projects is significantly higher than the impacts assessed separately.

RECOMMENDATION 6

Give special attention to infrastructure developments within the Tonle Sap Basin, because these have direct impacts on fisheries, and because they can magnify the influence of upstream changes in water flows.

Figure 11: Impact of the potential Tonle Sap dam developments on the lake water levels.

Source: Report “Influence of built structures of Tonle Sap hydrology and related parameters”
Table V: Water storage potential of existing and planned hydropower and irrigation reservoirs in the sub-basins of the Tonle Sap watershed.

<table>
<thead>
<tr>
<th>Sub-basin</th>
<th>net storage capacity million m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sen</td>
<td>2900</td>
</tr>
<tr>
<td>Slaung</td>
<td>550</td>
</tr>
<tr>
<td>Chikreng</td>
<td>160</td>
</tr>
<tr>
<td>Mongkol Borey</td>
<td>115</td>
</tr>
<tr>
<td>Srong</td>
<td>610</td>
</tr>
<tr>
<td>Chinit</td>
<td>390</td>
</tr>
<tr>
<td>Pursat</td>
<td>860</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5585</td>
</tr>
</tbody>
</table>

Source: Report “Influence of built structures of Tonle Sap hydrology and related parameters”

RECOMMENDATION 7

Improve the Environmental Impact Assessment process, particularly the coverage of fisheries, coupled with capacity-building for EIA practitioners.

Environmental Impact Assessments (EIAs) should be improved for Tonle Sap infrastructure projects that may have a significant impact on water and aquatic resources. Access to Environmental Impact Assessments for Tonle Sap development projects is difficult, reports being scattered across various ministries and provincial and district government offices or with project developers. Very few are available at the Ministry of Environment or other relevant ministries. Assessments are not systematically recorded or classified. The study evaluated in detail only 10 reports, mostly involving projects funded by external donors. Reports for other projects were unavailable because they were either inaccessible or did not exist.

Tonle Sap EIAs tend to be narrowly focused, covering a fraction of the area, the resources, the time period, and the people possibly impacted. These EIAs are often geographically limited to the project area, which provides at best a partial estimate of the impact on fisheries. They tend to be narrowly focused on short-term biological and physical changes to water flows and fish (Table VI); few assessments mention other aquatic resources like crabs, shrimps and snails - important sources of food for many people, especially the poor. They neglect longer-term impacts on the ecological system and livelihoods. Moreover, they do not systematically address socioeconomic consequences of impacts on fisheries and there are wide variations in coverage. Last, participation of stakeholders is generally very limited due to lack of a systematic mechanism for the consultation of local communities, provincial authorities, and local or international NGOs in the EIA process.
Influence of built structures on Tonle Sap fisheries

The quality of the Environmental Impact Assessments (EIAs) of Tonle Sap projects that might have a significant impact on water resources and fish is insufficient. The EIA process refers to the overall mechanism in place to request, submit, accept and monitor project EIAs. Increased awareness of the importance of EIA practice should be supported. There is need for improving the capacity of EIA practitioners in: i) defining the scope with a holistic approach; ii) increasing the use of available knowledge through systematic consultations of local stakeholders and of scientists; iii) making use of methods that deal with scarce data and uncertainty; iv) using methods for valuation of trade-offs between the various costs (esp. social and environmental) and benefits of built structure projects, and by v) improving stakeholder participation and the transparency of the process.

One of the major findings of the study is that the Tonle Sap Lake has almost 300 species, making it the third-richest lake in the world in terms of fish diversity. A review of scientific literature identified 296 species, more than twice the number recorded before. That makes the lake the richest in the world only after Lake Malawi (433 species) and Lake Tanganyika (309 species), both in Africa (Figure 12). The dominant families in the Tonle Sap Lake are carps and minnows (Cyprinidae) with 108 species, sheatfishes (Siluridae) with 20 species, bagrid catfishes (Bagridae) and loaches (Cobitidae) with 17 species and shark catfishes (Pangasiidae) with 14 species (Figure 13).

Table VI: Fish-related aspects of Tonle Sap Environmental Impact Assessments.

<table>
<thead>
<tr>
<th>Fisheries aspect and scale of assessment</th>
<th>Coverage</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical habitat (e.g. water bodies, vegetation)</td>
<td>High</td>
<td>Covered in most EIA reports</td>
</tr>
<tr>
<td>Fish ecology (e.g. migration)</td>
<td>High</td>
<td>Covered in most EIA reports</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Medium</td>
<td>Focus on fish species diversity</td>
</tr>
<tr>
<td>Ecological integrity</td>
<td>Very Low</td>
<td>Only a few components of the ecosystem considered</td>
</tr>
<tr>
<td>Fisheries production</td>
<td>Medium</td>
<td>Focus on fishing effort</td>
</tr>
<tr>
<td>Livelihood of fishers and fishing communities</td>
<td>Low</td>
<td>Focus on a few livelihood assets and functions</td>
</tr>
<tr>
<td>Institutional arrangements</td>
<td>Low</td>
<td>Not much considered</td>
</tr>
<tr>
<td>Management of fisheries</td>
<td>Low</td>
<td>Not much considered</td>
</tr>
<tr>
<td>Consideration of other key relevant sectors</td>
<td>Low</td>
<td>Most EIAs are sectoral</td>
</tr>
<tr>
<td>Spatial scales</td>
<td>Very Low</td>
<td>Focus on project boundaries</td>
</tr>
<tr>
<td>Temporal scales</td>
<td>Very Low</td>
<td>Focus on short-term impacts</td>
</tr>
</tbody>
</table>

Source: Report "Review of Tonle sap built structures Environmental Impact Assessments (EIA) with regard to fisheries"

**RECOMMENDATION 8**

*Impact assessments and regional negotiations over water allocation should take into account the unique importance of the Tonle Sap Lake for fisheries productivity and fish diversity not only in Cambodia but throughout the Mekong system.*

One of the major findings of the study is that the Tonle Sap Lake has almost 300 species, making it the third-richest lake in the world in terms of fish diversity. A review of scientific literature identified 296 species, more than twice the number recorded before. That makes the lake the richest in the world only after Lake Malawi (433 species) and Lake Tanganyika (309 species), both in Africa (Figure 12). The dominant families in the Tonle Sap Lake are carps and minnows (Cyprinidae) with 108 species, sheatfishes (Siluridae) with 20 species, bagrid catfishes (Bagridae) and loaches (Cobitidae) with 17 species and shark catfishes (Pangasiidae) with 14 species (Figure 13).
The Tonle Sap Lake’s importance in sustaining the health of Mekong fisheries is reaffirmed by the fact that it is home to a large proportion of fish species found in the Mekong River system. Although it accounts for only 11 percent of the Mekong Basin in terms of surface area, the Tonle Sap watershed has almost a third of all species recorded in the river and almost half of all the families. This qualifies the lake as an exceptional hotspot for biological diversity and calls for special attention by national and international institutions.

Overall, the Tonle Sap Lake has 23 species whose annual migrations are triggered by changes in water levels, and another 3 species triggered by changes in water flows. These fishes, accounting for about 10 percent of the species documented for the Tonle Sap Lake, are particularly sensitive to the hydrological consequences of infrastructure development such as delays in the arrival of floodwaters, increased water levels in the dry season and changes in the speed of the current. The impact of changing water levels on the remaining 90 percent of Tonle Sap species is still unknown.

**RECOMMENDATION 9**

*When assessing the impact of infrastructure development on Tonle Sap fisheries, focus on species that are economically important and that depend on hydrological triggers for migration. In particular, prioritize trey sleuk russey (Paralaubuca typus), trey chhkok and trey sraka kdam (two species from the Cyclocheilichthys genus) and trey pra (species from the Pangasius genus) as indicator species.*
Changes in water levels affect the annual migrations of these indicator species which account for 13 percent of the Tonle Sap Lake's catch, or between 38,000 tonnes and 56,000 tonnes a year. It is not clear how sensitive the two species of trey riel (Henicorhynchus genus) are to changes in water levels as their migrations may also be triggered by the phases of the moon. But if they are included, the proportion of the catch whose migration is triggered by changing water levels jumps to 38 percent, amounting to between 110,000 tonnes and 164,000 tonnes a year.

For trey sleuk russey (Paralaubuca typus), reproductive migrations and their dependence on environmental triggers are clearly documented. As for trey pra (Pangasius species), seven are very sensitive to hydrological migration triggers and three are less sensitive. These catfishes are highly valuable to both capture fisheries and aquaculture. Of the seven Cyclocheilichthyis species, trey chhkok (Cyclocheilichthyis enoplos), the most abundant by far, is very sensitive to hydrological triggers.

**RECOMMENDATION 10**

In designing fisheries management strategies and conducting impact assessments, consider three ecological groups of fishes rather than the traditional two. This highlights the importance of species which rely on tributaries as dry season refuges.

Fish species are currently classified under two ecological groups known as "white" and "black" fishes, but another category is needed. White fishes migrate between floodplains where they feed and the Mekong mainstream where they breed. Black fishes spend their whole lifecycle in floodplains and can resist harsh environmental conditions. However, this classification into two ecological 'guilds' is too crude to reflect major responses to changes in water flow or quality. For example, several species spend the dry season in tributaries such as Stung Pursat and Stung Chinit where they may be sensitive to infrastructure development. Management plans should therefore consider "grey" fishes as a third group with intermediate patterns of behavior. The recommendation to consider "grey" fishes as a third group is based on interviews with 102 experienced Tonle Sap fishermen and is supported by studies in the western and central African floodplains as well as Bangladesh.

### 3.2. SUB-NATIONAL LEVEL DECISION MAKING

This section focuses on infrastructure issues that are of relevance to decision-makers at local levels (province, district, and commune). Local decision-makers include provincial administrators and policymakers in the provincial departments of the 10 ministries that are members of the Cambodian National Mekong Committee. The recommendations also aim to inform district administrators, Commune Councils, community fishery committees, domestic and foreign investors in the private sector, international donors and non-governmental organizations.
3.2.1. LOCAL INFLUENCE OF LAND STRUCTURES

The following findings are from the case study on floodplain roads in Pursat province.

**RECOMMENDATION 11**

Explicitly take water flows and fish-migration routes into account when planning and building roads on floodplains, using culverts and bridges to avoid blocking complex networks of channels. Also ensure that planning addresses how these structures will be managed and maintained.

The velocity of water flows on the floodplain is generally very slow compared to the lake so the impact of roads depends on where they are placed. Locals at the Pursat study site expect that roads themselves will not have a significant impact on the abundance of fish or composition of species, compared to other pressures from rising fish demand and destructive fishing practices. They also consider culverts and gates effective as mitigation measures for allowing water flow. The views expressed in interviews with locals were unanimous but contradict the ecological literature highlighting the negative impacts of habitat fragmentation by roads on local fisheries. A possible explanation for this contradiction is that the culverts act as bottlenecks and make fish easier to catch, camouflaging any reduction in the overall fish stocks. (See Recommendation 13 below for maintenance and management recommendations)

Road-management committees have an important role to play in fisheries protection by instituting rules that prohibit culverts from being blocked by fishing gears. This is a commendable practice at the Pursat study site that should be encouraged elsewhere in the country. But these rules are not always followed and more intensive fishing gears are being deployed. The committees need to pay more attention to fisheries issues and coordinate their work with other stakeholders.

**RECOMMENDATION 12**

Coordinate road development among ministries and also with local institutions, particularly Commune Councils, to ensure proper planning and maintenance.

Management structures and institutions are key to minimizing any negative impacts of roads and ensuring their long-term maintenance. At the planning stage, effective coordination is essential to identify the potential impacts of a new road on the environment, notably fish habitats and migration routes, and to ensure that remote communities have access. At the maintenance stage, inter-ministerial coordination is critical. The Ministry of Rural Development is responsible for maintaining roads, while the Ministry of Water Resources and Meteorology is responsible for culverts and the Fisheries Administration of the Ministry of Agriculture, Forestry and Fisheries is responsible for regulating fisheries.

In both planning and maintaining roads, Commune Councils have a natural coordinating role to play with local bodies, such as community-fishery and road-maintenance committees, and traditional and religious institutions, such as Buddhist and Islamic institutions, which can mobilize collective action. Assuring their participation in the planning and design of the road development can make maintaining and managing the structure more efficient in those cases where local bodies are responsible for these tasks.
Villagers interviewed most frequently cited the main benefits of new roads as access to public services and markets. They noted that market access was especially significant for selling fish, which is difficult or expensive to preserve for long periods. Villagers believed better access to markets allowed them to get better prices for their fish. Roads also increased access to villages by fish wholesalers. With more fish being traded, villagers reported that there was now less fish being kept for local consumption. Better market access has also increased the incentives to produce goods to sell at markets and boosted local trade in fruit, cattle, poultry, and medical supplies.

Following the construction of a new road in Pursat, the contribution of fishing to average household incomes declined in all villages surveyed. Fishing is still the main source of income in some villages but has been eclipsed by rice farming in some cases. This finding is based on quantitative analysis and is consistent with lessons from road projects elsewhere. In Bangladesh, for instance, road projects in rural areas have sharply reduced poverty by boosting farm output and wages and reducing the cost of inputs and transport.

Average incomes rose much more sharply in richer households after the road construction. Quantitative analysis showed that changes in household incomes are strongly correlated with assets such as education, cattle and savings. In other words, richer households are likely to be more capable of taking advantage of the potential benefits of a road.

Social and cultural factors also influence who benefits more from built structures. In Pursat, the study found that an ethnic Cham village seemed to benefit more from the new road than ethnic Khmer villages. The Cham village had more connections to networks with other villages and also had institutions that were better organized, notably a locally-managed Islamic system for redistributing incomes.

Clarifying the benefits of a road project facilitates informed public debate about whether an investment is worthwhile and how it might be modified to benefit the poorest households. Modifications may entail building small feeder roads or using labor-intensive construction methods to develop local skills among the poorest groups. Skills acquired could later be used for maintaining the road.

To increase the household assets of the poorest groups, the study identified the top priorities as credit, agriculture, forestry and fisheries extension services and other skills training. Specific priorities could be based on local participatory assessments with services provided by government extension activities, micro-finance institutions and non-governmental agencies. Credit could focus on productive investments related to extension activities.
3.2.2. LOCAL INFLUENCE OF HYDROLOGICAL STRUCTURES

The following findings are from the case study on the Stung Chinit irrigation scheme and small-scale private reservoirs in Kampong Thom province.

Recommendation 14

Assess the ecological impacts of dams and reservoirs at the planning stage. Determine the pros and cons in the long run so that informed decisions can be made and mitigation measures taken.

Small-scale reservoirs on the floodplain so far have had a relatively limited influence on the flow and quality of water around the Tonle Sap Lake. Private irrigation structures are being extensively developed on the floodplain. As an illustration of this trend, Figure 14 shows recent developments in Kompong Thom province over an area of about 30 square kilometers. The overall storage capacity of the floodplain is quite limited as the depth of water trapped is only about one and a half meters. Existing reservoirs in the Tonle Sap floodplain have a surface area of less than 100 square kilometers with a storage capacity of about one-tenth of a cubic kilometer. Even if another 400 square kilometers of reservoirs were built, it would increase storage capacity to barely half a cubic kilometer of water. That compares to annual inflows into the Tonle Sap Lake ranging from 44 to 107 cubic kilometers in recent years. Although irrigation in the upper reaches of the floodplain traps a significant part of the flood, its overall impact on the floodplain’s seasonal inundation is limited. Field measurements showed that the irrigation structures also had a limited impact on water quality.

Figure 14: Recent private irrigation schemes in Kampong Thom

Source: Report “Influence of built structures of Tonle Sap hydrology and related parameters”
Although the impact of existing reservoirs on Tonle Sap tributaries is relatively small individually, the cumulative impact of many new ones may significantly affect water flows into the lake. The study modeled the newly-rehabilitated irrigation scheme at Stung Chinit and also included field sampling. The reservoir takes less than a week to fill in June when water flows are not particularly high. Field measurements showed that its impact on water flows was insignificant (see Figure 15). Simulations indicated the concentration of suspended sediments in the reservoir at slightly less than 20 milligrams a liter, down from 25 milligrams in naturally-flowing waters upstream. Measurements didn’t show any clear impact from trapping sediments (see Figure 16). The measurements did not show any clear impact on nutrients in the reservoir either. The spillway efficiently aerated the water flowing out of the reservoir, boosting oxygen levels. Simulations showed that the concentration of oxygen in the reservoir is not as high as the natural stream but nevertheless still high, even at the bottom. (See also Recommendation 6, Figure 11)

Figure 15: Stung Chinit reservoir’s impacts on flows. Measurements between September and November 2006. Green bars represent the inflow, while brown and sand bars show the outflow.
Source: Report “Influence of built structures of Tonle Sap hydrology and related parameters”

Figure 16: Limited impact of Stung Chinit reservoir on sedimentation. Sediment outflow measured between September and November 2006. Brown bars represent the sediment input, while purple bars show the sediment output.
Source: Report “Influence of built structures of Tonle Sap hydrology and related parameters”
Although the Stung Chinit reservoir adversely affects fish migration between upstream areas and floodplains, conditions in the reservoir itself are favorable for fish, creating a new fishing ground. The Stung Chinit reservoir provides an important new fishing ground close to some villages but has also flooded some rice fields. Fishermen interviewed in upstream and central areas believed the reservoir could become a productive fishing ground. But they were concerned that any immediate gains might simply reflect the retention of fish in the reservoir and that the positive impact could be short-lived. In the longer term, they were concerned that the reduced connection to downstream areas would erode the reservoir’s production eventually. Although it is too early to determine the final impact of the reservoir, this is a very real possibility. Fishermen also highlighted the need to assess the fish pass as they were not convinced that it was working as planned. Maintaining downstream flows and upstream migration is important to the sustainability of fish catches. Villages downstream seem to have borne several costs and received fewer benefits from the irrigation scheme. All people interviewed downstream blamed flow changes for reduced fish abundance and smaller catches from the river. Rice-field fisheries also seem to have suffered. Respondents mentioned that local fish abundance was closely linked to the seasonal flooding of the lake with bigger floods leading to more fish. Downstream groups were also concerned about controls over releasing reservoir water and the risk of floods from upstream.

![The fish pass of Stung Chinit reservoir](Photo E. Baran)
Effective fish passes should be considered for any irrigation scheme in Cambodia to maintain the natural connectivity between upstream and downstream areas. Features to be taken into account before construction include the biological and physiological characteristics of migrating species as well as the position, width and height of the fish pass. However, the efficiency of the fish pass in Stung Chinit could not be assessed given the timing of the project vs. that of migrations, and because of the existence of an alternative waterway for fish to swim past the reservoir.

Since the scheme started operating only in May 2006, the study could not assess the full nature of its impact and instead focused on short-term impacts during the start-up phase that might highlight some of the possible longer term effects. The study highlighted the need for follow-up studies to assess the agricultural gains from irrigation and changes to fisheries. For managing the release of water, researchers should consider using tools such as Environmental Flow Assessment (EFA) and Downstream Response to Imposed Flow Transformation (DRIFT) methodologies, and incorporating lessons from sluice-gate management in Bangladesh.

Irrigation schemes offer opportunities for a large range of economic activities. In Stung Chinit, livelihoods were found to be diversifying in all income groups. Among households close to the reservoir, the proportion engaged in fishing has risen markedly. The proportion of households raising livestock has also increased. Livelihoods in downstream areas are also diversifying, albeit due to declining incomes from fishing. The study found that households with more education and livestock holdings were better placed to take advantage of more profitable opportunities.

Securing land rights is essential as agricultural land values typically increase with improvements in irrigation. Poorer households may face pressure to vacate or sell land if their tenure is insecure. Villagers in the study identified credit, agricultural and fishery extension services and market access as key constraints that need to be addressed. Complementary investments to improve household assets should be based on participatory assessments in project areas.

Getting villagers to take part in infrastructure planning is a key factor in shaping their perceptions of a scheme’s suitability and their willingness to invest in its long-term maintenance. Villagers in the Stung Chinit case study felt they did not really take part in the planning phase but were just briefed about upcoming activities without adequate two-way communication taking place. They complained that their own knowledge of irrigation was not appreciated and that engineers ignored their insights into perceived mistakes in establishing tertiary canals. Project staff wanted farmers to help maintain the irrigation scheme. Having not been encouraged to take part in the planning and construction phases, villagers seemed to be hesitant.
Table VII: Brief summary of generic upstream and downstream influences of irrigation schemes

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant hydrological changes</td>
<td>Creation of reservoir; reduced connection to rice fields; reduced connection between upstream and downstream sections</td>
<td>Reduced flow</td>
</tr>
<tr>
<td>Water quality</td>
<td>Much poorer</td>
<td>Poorer</td>
</tr>
<tr>
<td>Fish size</td>
<td>Increased size of some fish</td>
<td>Stable or decreased fish sizes</td>
</tr>
<tr>
<td>Fishing effort</td>
<td>Fishing in reservoir; Distance to fishing grounds reduced</td>
<td>Increased use of efficient gears; Distance to fishing grounds increased</td>
</tr>
<tr>
<td>Fish price</td>
<td>Decreased</td>
<td>Increased</td>
</tr>
<tr>
<td>Fishing lease price</td>
<td>n/a</td>
<td>Decreased</td>
</tr>
<tr>
<td>Fish abundance</td>
<td>Increased for some species</td>
<td>May increase for direct beneficiaries of irrigation but decrease for others who lose out from decline in fish abundance</td>
</tr>
<tr>
<td>Direct livelihood opportunities</td>
<td>May increase with reservoir fishing</td>
<td>May increase with reservoir fishing</td>
</tr>
<tr>
<td>Indirect livelihood opportunities</td>
<td>Depends on other household assets to take advantage of new opportunities for processing, petty trade, etc.</td>
<td>Depends on household assets</td>
</tr>
<tr>
<td>Resource access</td>
<td>Some households typically lose land to the reservoir, but may increase access to fishing areas created</td>
<td>May not be directly affected, but the benefits from access may decline if the river is less productive</td>
</tr>
</tbody>
</table>

Source: Report “Influence of built structures on Tonle Sap fish resources”

3.2.3. LOCAL INFLUENCE OF FISHING STRUCTURES

The following findings are primarily from the case study on large-scale fishing fences and associated management practices in Battambang province.

RECOMMENDATION 17

Promote future studies on how large-scale fishing fences affect the movement of fish and longer-term fish recruitment, and appropriate mitigation measures.

Laboratory experiments demonstrated that bamboo or nylon fishing fences cause only minimal resistance to water flows and do not slow down water recession, whereas it is clear that the fences and the nets obstruct fish movements. A water retention effect becomes significant at current speeds that are much higher than those usually measured on the floodplain (Figure 18). Nylon nets attached to bamboo fences have an even smaller impact on water flows. On the other hand, the fences have a clear impact on fish movement - even more so when nylon nets are attached. The mesh size of the nets is typically five millimeters whereas the space between the bamboo slats is between 10 and 15 millimeters. In both cases, most fish are trapped.
Over the whole lake, the length of bamboo fences within fishing lots currently in operation after the fishery reforms amounts to 409 km, which represents 34 percent of the periphery of the lake. By nature, fishing fences are meant to trap fish and increase the catch rate, thereby decreasing the overall fish survival rate. However, the lack of information on the size or composition of the fish stock and on the critical migration corridors does not allow estimates of the length of fences that should achieve the best compromise between high catches and sustainability.

Figure 18: The influence of fishing fences on Tonle Sap flood recession is minimal. Experiment conducted in a laboratory fixed bed flume in Bangkok. (Photo J. Mykkanen)
Source: Report "Influence of built structures on Tonle Sap hydrology and related parameters"

Figure 19: Aerial view of one of the 82 fishing lots currently in operation in Cambodia. (Photo E. Baran)

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2 This figure is higher than the figure shown in Table III, which only covers the main study areas that have been digitized in great detail.
In the case study area, there are two fisheries management systems (fishing lots and community fisheries). How they differ in terms of their actual impact on fisheries resources is unclear. In practice, social equity is not a priority for the lot management. Access to fishing grounds within the lot is limited to those who work for the lease owner or who can afford the fees, and the benefits are concentrated among a small number of individuals. On the other hand, community fisheries were created specifically to provide more equitable access to fisheries among local community members. Fishing practices under these management systems differ, but how these differences influence fisheries sustainability is unclear.

Both management systems suffer from a prevalence of highly destructive fishing practices, such as electro-fishing, damming and pumping water out of streams. These destructive practices have an adverse impact on dry-season habitats as they reduce the size of flooded areas and streams and increase the turbidity of other water bodies. The dry-season habitats are important refuges, especially for the “black” fish species like trey ros (Channa striata) and trey kranh (Anabas testudineus). While community fisheries seem to permit greater connectivity of habitats within the overall system due to an absence of large-scale fishing fences, the poor capacity to combat destructive fishing methods in community fisheries areas is adversely affecting fish and habitats.

The case study illustrates that there are trade-offs between productivity, equity and possibly sustainability in the two management systems in operation at the site. These trade-offs need to be better understood when management options are selected for particular fishing grounds. More investigation is needed on the relative sustainability of the management systems used in the Tonle Sap Lake in terms of their effects on fish recruitment and survival, and the effects of the gears used on fish and fisheries.

In the study area, the release of a fishing lot following the 2001 fisheries reform has given both local villagers and outsiders access to new fishing grounds which are now more crowded. Local villagers said the benefits of the release have been less than expected. Our surveys indicated a reduction in the contribution of fish to average household incomes of between 10 and 16 percent depending upon the area. Open access to the fishing grounds during the previously-restricted season from October to May has attracted not only locals but also growing numbers of migrants from upland and other areas, competing over fish. Social tensions have subsequently emerged.

Fishing remains the main source of income in villages of Prek Toal and Thvang but accounts for a declining share of total income. Catches have fallen among poor households in recent years. The decline may reflect more intense fishing pressure caused by migrants from other provinces. Among rich households, catches have recently increased.
Community fishery members in the study area are mainly from wealthier and more educated households with significantly higher catches than non-members. Interviews indicated that richer fishing households had maintained their relatively high incomes and that intensive commercial fishing had continued despite community regulations allowing family-scale fishing only. Several indicated that a wealthier minority had captured the community fishery’s best locations and restricted access by poorer people.

### 3.2.4. LOCAL INFLUENCE OF BUILT STRUCTURES IN GENERAL

The case studies found a number of common lessons applicable to the various types of built structures. The following are the lessons and recommendations.

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**RECOMMENDATION 20**

Ensure that negative impacts of built structures are addressed through the management and operational aspects of projects in addition to technical and engineering measures.

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All the case studies show clearly that management and social issues associated with built structures, such as access to benefits, use rights and regulations, and operations, can be perceived at the local level as much more crucial than the technical design of the structure itself. This aspect is essential and calls for an approach to built structures that does not focus only on engineering solutions as mitigation measures for possible negative impacts.

**RECOMMENDATION 21**

Improve management of fisheries around built structures adapted to the newly created social dynamics and fishing environment, through better enforcement of regulations and coordination of stakeholders, including community fisheries, government agencies, donors, and non-governmental organizations.

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The study highlighted local perceptions according to which household catches, fish abundance and species diversity are all falling. While the overall catch in an area may actually be steady or even expanding, household catches may be declining because more people are fishing or more fishing gears are being used. Local people interviewed in all study sites reported increased fishing pressure (use of larger and more efficient gears), increased domestic demand and increased exports. The exclusion of some people from certain fishing grounds has also reportedly led to the exploitation of new grounds which are often located in more distant areas.

Access to fisheries and their benefits is likely to become increasingly contentious. This raises the need for explicit considerations of what benefits are expected and how they are shared. Many of those interviewed also called for better enforcement measures and clampdowns on illegal practices such as electro-fishing.

The case studies found that coordination between fishing communities, local authorities, management committees and fisheries officers was either limited or absent at all three study sites. The unanimous view was that closer collaboration was needed between all stakeholders. In Prek
Toal, efforts are needed to control the illegal pumping of water and the expansion of fishing grounds in the fishing lot as well as unregulated activities and intensified fishing in the community fishery that have led to conflicts. In Stung Chinit, there was clear evidence of the potential for conflicts. Downstream villages are concerned about how water management will affect fisheries and flooding. Earlier water conflicts between farming and fishing communities were cited as one reason for the scheme falling into disuse before it was rehabilitated.

Stakeholder participation in the planning of built structure development and environmental impact assessments is generally very limited. There is no systematic mechanism for involving local communities, provincial and district authorities, and non-governmental organizations. This raises issues of transparency and the need to allocate resources to communications at the local and national levels. The general conclusion among village stakeholders is that they are supposed to be consulted but that consultations aren’t effective. This view needs to be treated cautiously, however, as it is based on a limited number of interviews.

The study found gaps in communications between ministries. For irrigation planning, cooperation needs to be enhanced between the Ministry of Water Resources and Meteorology and the Ministry of Agriculture, Forestry and Fisheries. For assessing the impacts of roads on fisheries, better cooperation is needed between the Fisheries Administration and the Ministry of Public Works and Transport.

Commune Councils should play an active role in planning roads and irrigation canals. To improve fisheries management, community fishery committees must be strengthened and their links to Commune Councils clarified. Identifying formal and informal village networks and cooperating with locally-respected leaders is crucial at all stages of a project. Regular sharing of information is important to clarify the division of responsibilities and keep expectations realistic.

All three case studies found that institutions determine the costs and benefits of infrastructure development and deeply influence livelihood issues such as access to natural resources, income benefits and equity. With poor planning and management, benefits may be short term and the rich may benefit more than the poor. Some stakeholders - such as downstream fishing communities - may pay an unbearably high price. Adequate planning is therefore crucial for the equitable distribution of benefits and poverty reduction. The study also found that institutions such as user groups and community fisheries may be unable to secure more equitable long-term benefits if they are dominated by certain people or if they fail to include the poorest groups.
Different types of infrastructure benefit different groups of people. Most public roads, for example, are available to all users without a fee and access can be increased as the network of feeder roads expands. On the other hand, irrigation schemes deliver water to a defined area so the number of people who benefit directly is limited. At the other extreme, large commercial fishing structures exclude most people and benefit only a few.

The study found that most people’s livelihoods were diversifying as new opportunities and risks arose from new infrastructure. However, all case studies showed that fishing and related activities were still the main source of income (Figure 20).

**Figure 20: Sources of livelihoods and changes after a new structure.**
Source: Report "Influence of built structures on local livelihoods: case studies of roads, irrigation, and fishing lots"

Infrastructure development is generally benefiting richer households. Many poor households are also benefiting but not at the same rate. The three case studies found that rural households had different capacities to benefit from opportunities arising from infrastructure development. The chronic poor - those who remained in poverty throughout the period studied - saw a modest increase in household incomes. The average income gains for other groups were more than three times higher. Although road development in Pursat has led to a sharp decline in the percentage of people living in poverty, the chronic poor are generally not
yet benefiting enough. In the villages around the irrigation scheme in Kampong Thom, the poorest households are more affluent but are still below the poverty line.

The three case studies showed strong ties between household assets, especially education, and the ability to take advantage of new opportunities. After education, the next most significant asset explaining the ability of households to get out of poverty was livestock, a form of savings. Financial capital also seems to play a crucial role in the influence of infrastructure development on chronic poverty. It was also found that social capital was a key factor in explaining the degree to which benefits were more broadly shared or enjoyed by privileged households.

Setting priorities for complimentary investments in areas such as education should be part of livelihood assessments associated with infrastructure planning. Special attention should be given to the phasing of such investments. In many cases, it may be wise to start making complementary investments even before the construction of physical infrastructure begins.
INFLUENCE OF BUILT STRUCTURES ON TONLE SAP FISHERIES

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Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap.
Infrastructure and Tonle Sap fisheries
How to balance infrastructure development and fisheries livelihoods?

THE CHALLENGE FACING DECISION-MAKERS IN CAMBODIA
Cambodia’s inland fisheries are the most intensive worldwide and the fourth largest overall after China, India, and Bangladesh. Almost two-thirds of Cambodia’s catch, conservatively estimated at 400,000 metric tons annually, comes from the Tonle Sap watershed. In terms of value, the overall fishing sector accounts for 10 to 12 percent of gross domestic product (GDP) and contributes more to income, jobs and food security than in any other country. The value of the fish catch from the Tonle Sap Lake is estimated at $233 million a year.

Yet, the sustainability of the Tonle Sap fisheries is in question. One of the main threats is rapid infrastructure development in the Mekong River Basin upstream as well as in the Tonle Sap catchment basin. For example, hydropower development continues to be a high priority in the Mekong region in general, with numerous new projects under construction or proposed for development in the near future. Irrigation and flood mitigation, especially in the Lower Basin, are also the focus of significant investments.

Built structures such as dams, irrigation schemes, and roads all have numerous economic benefits. However, their impact on water flows, which in turn affects seasonally-submerged habitats and fish-migration routes, may also lead to negative hydrological, environmental and social side effects. A major challenge for decision-makers is to understand the trade-offs associated with infrastructure development and find ways to minimize adverse impacts on the sustainability of Tonle Sap fisheries while maximizing social and economic benefits.

The Cambodian government’s Rectangular Strategy, focusing on growth, employment, equity and efficiency, highlights the importance of developing infrastructure and enhancing the agriculture sector, including sustainable access to fisheries for the poor. Under the plan for 2006 to 2010, support is being provided to Commune Councils to undertake rural infrastructure projects such as rehabilitating roads and building small bridges and culverts, wells, sanitation structures, schools, water gates and small irrigation systems.

"It is time now that resources begin to be properly directed and effectively used to maximize benefits for the disadvantaged and the deprived, to lift them into the mainstream," Samdech Prime Minister Hun Sen said in his foreword to the five-year plan. The Prime Minister has also highlighted the Tonle Sap’s crucial role as an important fish habitat. "We must try our best to preserve and sustain the national

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1 Built structures consist of a variety of man-made structures that contribute to changing the hydrology of a natural system. They can: (i) oppose water outflow (e.g. dams, weirs, irrigation schemes, dykes); (ii) prevent water inflow (e.g. embankments, polders, levees); (iii) change water inflow or outflow (e.g. roads, canals, large scale fishing gears); (iv) degrade water quality (e.g. factories, sewers).
fishery resources for our younger generations to come," he said during the National Fish Day ceremony in 2006.

Cambodia's policy priorities for growth and infrastructure development are clear, as are priorities for the protection of the aquatic environment and sustainable rural livelihoods. Balancing these priorities involves conscious trade-offs, and there is an urgent need for information that can document these trade-offs as the country's economy rapidly progresses.

THE STUDY

This document summarizes some of the major findings and recommendations of a study on the influence of built structures on the fisheries of the Tonle Sap. The research, funded by the Government of Finland through the Asian Development Bank, was carried out between May 2006 and March 2007 by the WorldFish Center with partners. The Cambodian National Mekong Committee was the Executing Agency of the study. Research partners included the Inland Fisheries Research and Development Institute and the Tonle Sap Biosphere Reserve Secretariat in Cambodia and a consortium of Finnish scientists.

The multidisciplinary study analysed the influence of these structures as well as the potential influence of planned water development projects upstream in the Mekong River system. The study considered influences on hydrology, fish, the environment, and ultimately on people around the Tonle Sap.

The study, based on a number of future water development scenarios, aims to provide guidance for decision-makers as to how to minimize adverse impacts on the sustainability of Tonle Sap fisheries while maximizing the benefits of infrastructure development. While the study's findings and recommendations are directed in particular at decision-makers, they are also relevant to scientists and development professionals working with government agencies, research institutions, donors and non-governmental organisations, and the public more broadly.

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1 A more complete summary of findings and recommendations is provided in a companion synthesis report, "Influence of Built Structure on Tonle Sap Fisheries", available from the Cambodian National Mekong Committee, and online at www.worldfishcenter.org, along with the full set of scientific reports on which the policy brief is based.

2 To assess the potential hydrological impact of new water development infrastructure in the future, the study examined three scenarios based on different levels of future development on the Mekong River mainstream: a "baseline scenario" representing the actual situation in 2000; an "intensive basin development scenario", representing a combined water-storage capacity of 55 cubic kilometers, including seven more hydro-electric dams built across the mainstream in the Upper Mekong by 2025; and an "extreme basin development scenario", assuming an additional seven dams on the mainstream in Lao PDR, Cambodia, and Thailand, and additional dams on Mekong tributaries, boosting the total storage capacity to 140 cubic kilometers. The study also considered one scenario for the Tonle Sap watershed, assuming limited development of dams on the seven lake tributaries, with a combined storage capacity of 5.5 cubic kilometers.
WHAT ARE THE CURRENT AND POSSIBLE FUTURE INFLUENCES OF BUILT STRUCTURES ON THE FISHERIES OF THE TONLE SAP?

At the level of the Mekong Basin, the most significant built structure type evaluated was large-scale dams and associated reservoirs.

The construction of dams upstream in the Upper Mekong Basin, as well on tributaries of the Tonle Sap, promises numerous benefits. Dams produce reservoirs used for irrigation, and hydroelectric power that can create opportunities for new economic activities. Yet, these benefits come at a significant cost.

By using hydrological modeling, the study showed that upstream damming in "intensive" and "extreme" development scenarios could reduce inflows to the lake by ten to twenty-five percent in dry years. The annual flood could also be delayed for up to a month and end up as soon as two weeks earlier than normal. The height of the floodwaters, and the surface area covered, would also significantly decline.

Dams would have a major impact on fisheries. First, they could disrupt migration patterns and routes. Eighty-seven percent of Mekong River Basin fish species for which information is available are migratory. For these species, the physical presence of dams would block normal migration routes leading to a drop in fish stocks and catches. Sixteen percent of these migratory fish species are also known to be sensitive to hydrological triggers; thus delays to the onset of the flood or changes to water level are likely to disrupt fish migration patterns. Because these migratory species make up a dominant part of Cambodia’s annual fish harvest, these changes caused by damming could seriously impact Cambodia’s fisheries. The loss of even a small percentage of this fishery represents tens of thousands of tons and millions of dollars worth of fish.

Second, upstream damming would also threaten fisheries by adversely affecting water quality. Drops in the amount of oxygen in the water and changes in drift patterns could have a negative impact on fish eggs, larvae, and juveniles. More importantly, upstream damming would trap massive amounts of sediment, which is expected to reduce the overall water productivity and subsequent fish productivity. At the same time, sediment trapping would also have a negative impact on soil fertility resulting in a drop in rice production or an increase in production costs due to heightened use of fertilizers.

While the reservoirs created by damming are sometimes presented as a way to create new fisheries upstream, a review of literature worldwide shows that this typically would not compensate for the loss of fisheries downstream. In the Mekong, only 9 species are known to breed in reservoirs.
Finally, according to hydrological modeling, upstream damming would increase discharge in the dry season, which would then expand the surface area of the lake by between 300 and 900 square kilometers. These rising water levels would result in the Tonle Sap flooded forest being permanently inundated in the dry season, and ultimately in its dying. This would correspond to the destruction of a crucial breeding and feeding habitat for numerous fish species. More generally, with 296 fish species, the Tonle Sap Lake is the third richest lake in the world in terms of fish diversity; it has almost a third of all species and half of all families recorded in the Mekong Basin, which makes it a very significant biodiversity hotspot to be protected.

At the level of the Tonle Sap Basin, the study also assessed localized influences of specific types of built structures.

The first case study examined the influence of road development in floodplains. The socioeconomic advantages of road construction are numerous. Roads provide better access to public services and markets, allowing increased trade in fish and other products, and reduce dependent on fisheries by increasing alternative livelihood options. The low velocity of water flows on the floodplains means that roads do not significantly impact the rise and fall of floodwaters. However, the location and design of roads is key in determining their impact on fish habitat and migration. The scientific literature points to habitat fragmentation as a frequent negative impact of road construction on fisheries.

In addition to technical and engineering measures, negative impacts of built structures should be addressed through management and operational measures. The road management committee in the case study area, for example, prohibits culverts on the road from being blocked by fishing gears, a commendable practice that should be encouraged elsewhere in the country.

The second case study examined the influence of irrigation schemes. Hydrological structures including small-scale reservoirs in the Tonle Sap floodplain so far have had a limited impact on water flows and water quality due to the smaller overall volume of water they are able to trap. However, the cumulative effect of these reservoirs might be significant if their number continues to increase. A case study on the Stung Chinit reservoir showed that irrigation schemes can offer a range of opportunities for economic development to some villages that directly benefit from the irrigation. The Stung Chinit reservoir has created a relatively productive fishing ground, allowing for livelihood diversification, although the local fishermen interviewed are concerned that the reduced connection to downstream areas could eventually erode reservoir production, and hence such positive impacts on fisheries could be short-lived. On the other hand, villages downstream seem to have already suffered a reduction of fish in the river and the rice fields, and are also concerned that releasing the reservoir's water could cause flash flooding.
The third case study examined the influence of fishing lot fences as large scale structures. Bamboo fences and nylon nets attached to the fences are unique to the Tonle Sap Lake and its floodplain; their total length currently amounts to 409 kilometers. Experiments conducted for this study have shown that these fishing fences do not significantly reduce the speed of water flows. On the other hand, the fences have a clear impact on fish movement, even more so when nylon nets are attached. A better understanding of the fish stock and ecology, including migration corridors, is essential to determine the optimal length and design of large-scale fishing fences to ensure a sustainable level of harvest.

The livelihood influence of built structures is closely linked to the way they are operated and managed. This is especially evident in the case of fishing structures, which can be used under two management regimes (fishing lots and community fisheries). How different these two systems are in terms of actual impacts on fisheries resources is unclear. What is clear is that both management systems suffer from a prevalence of highly destructive fishing practices such as electro-fishing, damming and pumping of water out of streams. The case study illustrates that there are trade-offs between productivity, equity and possibly sustainability. These trade-offs need to be better understood when management options are selected for particular fishing grounds.

**WHAT ARE THE IMPLICATIONS FOR PLANNING BUILT STRUCTURES?**

The impact of built structures is heavily influenced by institutional decision-making. Therefore, sound planning is needed to ensure the maximization of advantages and minimization of disadvantages from infrastructure development.

Environmental Impact Assessments (EIAs) are an important step in the process of developing new structures. The study showed that EIAs for Tonle Sap infrastructure projects have so far been limited in terms of both technical content and processes. They tend to focus on the geographic area of the project, which provides at best a partial estimate of their impact, and on the short-term biological and physical changes to water flows and fisheries. Furthermore, they do not systematically address socioeconomic issues and lack a comprehensive mechanism for the consultation of stakeholders such as local communities, provincial authorities, and non-governmental organizations. Finally, EIAs have failed to quantify or even address the cumulative impact of large-scale infrastructure projects, which involves more than just adding up their individual impacts.
Broader precautions in development planning are needed at the international, national, and sub-national levels. Plans should encompass linkages between hydrology, fisheries, livelihoods, and environmental concerns. While such integration might not always be feasible at the local level due to resource constraints, higher-level assessments of built structures should integrate the impact on the entire Tonle Sap ecosystem. The whole range of positive and negative impacts of infrastructure developments need to be identified to clarify the range of options available to stakeholders and to support decision-making. One way to facilitate constructive debate, initiate difficult trade-offs, build stakeholder consensus, and maintain transparency is to include public consultation throughout the infrastructure development process. Closer communication is also needed between various stakeholders, including the various ministries responsible for irrigation and road building.

Negative impacts of built structures do not depend solely on technical and engineering factors; they also depend significantly on the way structures are managed and operated. All the case studies clearly showed that management and social issues associated with built structures, such as access to benefits, use rights and regulations, and operations, can be perceived at the local level as more crucial than the technical design of the structure itself. Finally, infrastructure investments should be planned so that poor households can best take advantage of new livelihood opportunities. Such planning could include extension activities, complementary investments in education, micro-finance, and community development by both the government and non-governmental organizations.

Currently, projects such as dam building may yield the majority of their benefits to upstream regions or national economies, while downstream communities are forced to bear most of the costs. Likewise, the benefits of roads, irrigation schemes, and fishing lots tend to go more to wealthier groups. With sound planning, the benefits of future infrastructure development can be shared more equitably.
RECOMMENDED ACTION POINTS FOR PLANNING INFRASTRUCTURE PROJECTS THAT AFFECT TONLE SAP FISHERIES

Based on the lessons learned from the basin-wide scenario evaluation as well as local case studies, the following recommendations were developed. They aim to help decision-makers maximize the benefits of infrastructure development, while minimizing its adverse effects. These action points are divided into two sections: those relevant to national and to sub-national decision-making.

NATIONAL-LEVEL DECISION-MAKERS
The following recommendations are for national decision-makers, including policymakers in the 10 ministries that are members of the Cambodian National Mekong Committee, as well as lawmakers in the National Assembly and Senate commissions that oversee infrastructure development. They are also targeted at domestic and foreign investors in the private sector and at international donors.

Recommendation 1
When planning infrastructure development, avoid irreversible changes to water flows, especially those affecting seasonal flooding or breaking the natural "connectivity" between various water bodies around the Tonle Sap.

Recommendation 2
In assessing plans for dams and other water developments upstream on the Mekong mainstream, highlight the significant impacts on flooding in the Tonle Sap Lake.

Recommendation 3
In addition to considering the seasonal impact on water flows, planning of upstream water developments should specifically take into account possible ecological consequences of the changes in flooding, including loss of flooded forests, reduced inflows of sediments, lower oxygen levels, and changes in the drift of fish larvae and juvenile fish.

Recommendation 4
The livelihood benefits of floodplains should be properly evaluated and integrated into basin-wide water development planning, with particular focus on the impact of dams on fisheries.
Recommendation 5
Adopt regional guidelines such as the Strategic Environmental Framework for the Greater Mekong Sub-region (GMS), which promote strategic environmental assessments addressing the cumulative impacts of multiple development projects.

Recommendation 6
Give special attention to infrastructure developments within the Tonle Sap Basin, because these have direct impacts on fisheries, and because they can magnify the influence of upstream changes in water flows.

Recommendation 7
Improve the Environmental Impact Assessment process, particularly the coverage of fisheries, coupled with capacity-building for EIA practitioners.

Recommendation 8
Impact assessments and regional negotiations over water allocation should take into account the unique importance of the Tonle Sap Lake for fisheries productivity and fish diversity not only in Cambodia but throughout the Mekong system.

Recommendation 9
When assessing the impact of infrastructure development on Tonle Sap fisheries, focus on species that are economically important and that depend on hydrological triggers for migration. In particular, prioritize trey sleuk russey (*Paralaubuca typus*), trey chhkok and trey sraka kdam (two species from the Cyclocheilichthys genus) and trey pra (species from the Pangasius genus) as indicator species.

Recommendation 10
In designing fisheries management strategies and conducting impact assessments, consider three ecological groups of fishes rather than the traditional two. This highlights the importance of species which rely on tributaries as dry season refuges.

SUB-NATIONAL DECISION-MAKERS
The following recommendations are aimed at decision-makers at the sub-national level, including provincial administrators and officials in the provincial departments of the 10 ministries that are members of the Cambodian National Mekong Committee, as well as district administrators, Commune Councils, community fishery committees, domestic and foreign investors in the private sector, and international donors and non-governmental organizations.

ROADS

Recommendation 11
Explicitly take water flows and fish-migration routes into account when planning and building roads in floodplains, using culverts and bridges to avoid blocking complex networks of channels. Also ensure that planning addresses how these structures will be managed and maintained.
Recommendation 12
Coordinate road development among ministries and also with local institutions, particularly Commune Councils, to ensure proper planning and maintenance.

Recommendation 13
Ensure that road planning takes into account the poorest groups by clarifying who will benefit and how. Provide alternative livelihood support services targeting poorer families to help them accumulate household assets, such as education, cattle and savings.

IRRIGATION

Recommendation 14
Assess the ecological impacts of dams and reservoirs at the planning stage. Determine the pros and cons in the long run so that informed decisions can be made and mitigation measures taken.

Recommendation 15
Analyze the social and economic costs and benefits of irrigation projects for different social groups at the planning stage. Make complementary investments to make sure poorer households can take advantage of new opportunities.

Recommendation 16
Provide training to Commune Councils to build effective communication channels between local officials, engineers and villagers. Support the establishment of water-user committees to promote equitable distribution of water and avoid conflicts over operating and maintaining the system.

FISHING LOTS

Recommendation 17
Promote future studies on how large-scale fishing fences affect the movement of fish and longer-term fish recruitment, and appropriate mitigation measures.

Recommendation 18
Decisions on where and how large-scale lot systems are implemented should take into account economic, social, and ecological trade-offs as compared to other management options such as community fisheries.

Recommendation 19
When fishing lots are released and access opened to local communities, there are opportunities for relatively wealthier households to capture more of the benefits. Pay specific attention to institutional mechanisms to ensure equity and manage conflicts.
OVERALL RECOMMENDATIONS FOR LOCAL INFRASTRUCTURE PLANNING

Recommendation 20
Ensure that negative impacts of built structures are addressed through the management and operational aspects of projects in addition to technical and engineering measures.

Recommendation 21
Improve management of fisheries around built structures adapted to the newly created social dynamics and fishing environment, through better enforcement of regulations and coordination of stakeholders, including community fisheries, government agencies, donors, and non-governmental organizations.

Recommendation 22
Hold systematic consultations between national and local stakeholders throughout the project development and help local people articulate their needs and concerns. Evaluate and publicly debate the social, economic and ecological trade-offs arising from different development scenarios before deciding on a specific option.

Recommendation 23
Link infrastructure planning to the decentralized institutions for rural development and natural resource management (commune, district, and provincial councils).

Recommendation 24
Analyze how the costs and benefits of a project affect different social groups, taking the role of local institutions and differences in household assets into account. Considering the importance of poverty alleviation in Cambodia’s development agenda, make special provisions to involve the poorest groups in project planning.

Recommendation 25
Complement infrastructure projects with investments in basic education, training and technical support.
INFRASTRUCTURE AND TONLE SAP FISHERIES
How to balance infrastructure development and fisheries livelihoods?

Editors: Eric BARAN, So SOPHORT, Yumiko KURA and Blake RATNER

This policy brief was written as part of a series of scientific studies produced under the project Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (TA 4669-CAM).

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