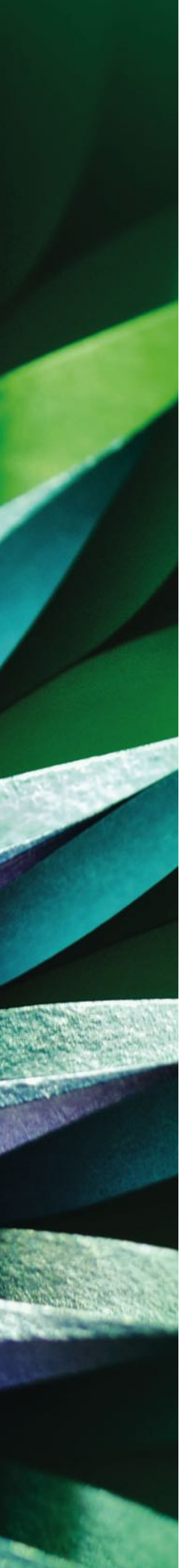

BACKGROUND PAPER

Rising Importance of Aquaculture in Asia: Current Status, Issues, and Recommendations

Aya Suzuki

RISING IMPORTANCE OF AQUACULTURE IN ASIA: CURRENT STATUS, ISSUES, AND RECOMMENDATIONS

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I. ROLE OF AQUACULTURE IN ASIA

A. Overview

Fish and seafood have been regarded as an important part of the traditional cuisine for people in many parts of Asia and the Pacific. Traditionally, the majority of produced fish and seafood come from capture fishing, either in the ocean or freshwater rivers, along with some forms of fish farming in extensively used ponds. Fishing and fish farming not only provide food and nutrition to people, but also offer important sources of livelihood for many people (Dey and Ahmed 2005).

However, this scenario has been changing rapidly in recent years. Figure 1 shows fish and seafood production by capture and aquaculture worldwide between 1950 and 2018. This figure shows that, while capture fisheries have been the major source of fish and seafood production in the early years, the proportion of aquaculture started increasing in the later part of the 1990s and continues to grow until today. According to the Food and Agriculture Organization (FAO 2020d), 46% of the total fish production and 52% of the total human consumption were from aquaculture in 2018. Figure 2 shows how the contribution of aquaculture production to human consumption reversed its role relative to capture production.

Asia has been the major producer of fish and seafood, and is also where the remarkable growth in aquaculture has been observed (Figure 3). Among the Asian countries, the People's Republic of China (PRC), by far, is the largest producer of farmed fish, producing more than the total amount produced by the rest of the world since 1991 (FAO 2020d).

Figure 4 shows the production trends particularly for Asia and Oceania. The growth of aquaculture fish production has accelerated recently, reaching 48.3% of the total fish production in 2018 (FAO 2020d). Among the aquaculture production, Asia has been dominating in the world, with a proportion of 87.9% in 2018 (Figure 5). The continent has been the major producer since 1995,

but the proportion has increased even more at present. The volume of production has expanded owing to the conversion of agricultural land to aquaculture ponds, improvement of fish farming technologies, and intensification of production. Traditionally, fish farming took the form of extensive farming in many parts of Asia, which often does not accompany intentional feeding of fish or use of inputs. In particular, fish are raised in a rather natural way and harvested when they mature. However, more improved and integrated farming technologies have been adopted in many parts of Asia, leading to higher productivity, higher resource-use efficiency, and less impact on the environment (FAO 2020d). Figure 6 shows the declining proportion of non-fed aquaculture over the years in Asia and Oceania, which is consistent with the global trend.

B. Regional Trend

1. Production

While Asia has been the dominant producer of farmed fish, the growth of aquaculture is not homogeneous across this continent. Figure 7 shows the regional production trends. We observed that the rapid growth occurred mostly in East Asia, Southeast Asia, and South Asia. Further, if we exclude the PRC from East Asia, the proportion of aquaculture to the total fish and seafood production is small, reflecting the continued importance of capture fisheries in Japan and the Republic of Korea.

Figure 8 further breaks down these figures country-wise, depicting five major producers in the region in terms of aquaculture production volume in 2018. Although the PRC is the largest producer of fish and seafood and its proportion of the aquaculture is the highest, we observe a rapid increase in the proportion of aquaculture in India, Viet Nam, and Bangladesh. We also notice that the aquaculture production in the PRC declined slightly from 2016 since the Government of the PRC's implementation of a policy that promotes sustainable aquaculture in the same year. Thus, a further decline is expected in a few more years (FAO 2020d).

In terms of farmed species, the proportion of freshwater fish was the greatest, followed by crustaceans and diadromous fish (Figure 9). Among finfish produced worldwide in 2018, in terms of volume, various types of carp accounted for 48.5%, followed by tilapia (10.2%), catfish (7.5%), and salmon (4.5%). Among crustaceans produced worldwide in 2018, in terms of volume, the

proportion of whiteleg shrimp (Penaeus vannamei) is 52.9%, followed by red swamp crawfish (18.2%), Chinese mitten crab (8.1%), and giant tiger prawn (Penaeus monodon) 8% (FAO 2020d).

2. Fish Balance Sheet

Figure 10 presents the "Balance Sheet" of fish production and consumption in Asia and in each country, constructed using the FAO's World Aquaculture Performance Indicators – Fish Consumption Module (FAO 2018). The figure also shows the proportion of fish and seafood production, imports, consumption, and exports within one area. Note that these figures include both capture and aquaculture production as trade data do not disaggregate the fish origin. Figure 10a presents the "Balance Sheet" of fish production and consumption in Asia. Although Asia is the major producer of fish and seafood, we observe that it is also a major consumer. Country-level figures present different structures among the countries. The proportion of domestic consumption is also high in countries such as Bangladesh, the PRC, India, and Indonesia. On the other hand, in countries such as Viet Nam and Thailand, the proportion of domestic consumption stagnates after around the 2000s with the rising proportion of exports. These countries produce shrimp, which is the most widely traded aquatic animal. Although the shrimp production of Thailand declined, its imports increased from the mid-2000s. These show that, although aquaculture has grown steadily in many countries in Asia, some countries mainly cater to domestic consumption, while others actively send their products to export markets.

Figure 11 shows the trend of export quantity and values by region and by the top 10 exporters. Note that these figures include both capture and aquaculture fish production as the data that disaggregate them do not exist. East Asia and Southeast Asia are the dominant foreign currency earners in fish and seafood. At the country level, we observe that, while the PRC is growing rapidly both in export volume and value, Japan's export proportion has declined over the years. Viet Nam, Thailand, and India are also on the rise, reflecting their contribution to the shrimp sector. Figure 12 particularly presents the types of fish that are exported in South Asia, Southeast Asia, and East Asia. We observe that, while the contribution from marine fish is the greatest in terms of volume, crustaceans dominate the proportion in terms of value in South Asia and Southeast Asia.

3. Contribution to Nutrition

The fish and seafood sectors have also contributed to better nutrition for the people in the region. Figure 13 shows the relationship between animal protein intake and the proportion of fish in the total animal protein consumed worldwide. We observed that, while Asian countries consume relatively less animal protein, the proportion of protein originating from fish tends to be greater, particularly in Southeast Asia and East Asia. It is also notable that many African countries have a relatively higher proportion of fish protein from the total animal protein intake. Ahmed and Lorica (2002) examine data from various countries in Asia and conclude that aquaculture growth positively contributed to raising income and consumption. These show the importance of the fish and seafood sector in improving the livelihood of people in developing countries.

4. Contribution to Employment

We also examine the contribution of fish and seafood sectors to job generation. According to the FAO, about 59.51 million people are engaged in the primary industry of the fish and seafood sector in the world, among which 20.53 million (34.5%) are in aquaculture and 38.98 million (65.5%) are in capture fisheries. Further, the FAO reports that the proportion of women in aquaculture is higher (19%) than that in the fisheries sector (12%) in 2018.

Figure 14 shows the number of fish farmers (those who engage in aquaculture only) by region. Asia has, by far, the greatest number of fish farmers, and this number has been increasing over the years. In the figure, we also plotted the changes in the number of fish farmers and fishers in Asia between 1995 and 2018. We observed an increasing trend for fish farmers, reaching a proportion of 0.389 in 2018. In 2018, the proportion of women fish farmers in aquaculture in Asia was about 19%, while that in fisheries was about 10% (FAO 2020d). Note that this figure only includes those in the primary industry. Hence, the contribution is much greater than these figures if we include those who are hired in processing sectors, trading, feed mills, and input dealing. As many women tend to work at the post-harvest stages, we expect an even higher proportion of women in the labor force.

II. CURRENT STATUS AND ISSUES WITH SUSTAINABLE AQUACULTURE PRODUCTION

A. History of Environmental Degradation and International Code of Conduct

Although section I showed the increasing importance of aquaculture in the world, notably in Asia, the sector has also faced many environmental issues. The practice of fish farming has existed for many decades in many Asian countries and constitutes an important part of their people's livelihood as well as their cultures. While the negative impacts on the environment were not so prevalent with extensive fish farming, these became known when modern aquaculture was still in its early stages.

In the 1970s, shrimp were mainly caught in the ocean by trawler vessels (Murai 1988). However, because of the risk of depleting marine resources with this untargeted fishing, many governments placed bans and restrictions on trawling methods in the 1980s. Around the same time, a researcher from Taipei,China succeeded in artificial spawning of black tiger shrimp in 1983, which resulted in the rapid growth of shrimp farming in Taipei,China (Murai 1988). Taipei,China was able to achieve high growth in this sector because it has a long tradition of fish culture, flat coastal land, and appropriate climate, as well as advanced aquaculture technologies, such as mass propagation and disease diagnostics and prevention (Chen and Qiu 2014). Their innovations in shrimp farming technologies were also supported by the foundational works of Japanese researchers and amplified by the strong demand for shrimp imports from Japan (Murai 1988). Although the development of shrimp farming was one step forward in reducing the negative impacts on marine resources, in the 1990s many environmental issues related to aquaculture emerged, such as land subsidence because of pumping too much groundwater, frequent disease outbreaks, and destruction of biodiversity in the coastal areas (Chen and Qiu 2014).

These issues, combined with the depletion of marine resources because of capture fisheries, led to the launch of the Code of Conduct for Responsible Fisheries, which was endorsed by all the FAO member countries. This code outlines the importance of managing fisheries and aquaculture sustainably, and many technical guidelines and instruments have been developed to realize the principles of this code. Thus, many international organizations, namely the FAO, the Network of Aquaculture Centres in Asia-Pacific (NACA), the Global Programme of Action for the Protection

of the Marine Environment from Land-based Activities of the United Nations Environmental Programme (UNEP/GPA), the World Bank, and the World Wildlife Fund (WWF), joined together to form a consortium to prepare specific guidelines on shrimp farming. After many years of careful research and discussions, the International Principles for Responsible Shrimp Farming (FAO, NACA, UNEP, World Bank, and WWF 2006) was launched in 2006 and endorsed internationally (Corsin et al. 2008). Further, more detailed guidelines for actual practices that are effective to implement these principles were developed in many countries (e.g., Viet Nam, India, and Thailand) and are referred to as Better Management Practices and Good Aquaculture Practices (Corsin et al. 2008). These are translated into local languages and disseminated to shrimp farmers via their agricultural extension officers.

In addition to these foundational efforts, there have been many international guidelines, standards, and certifications to minimize the adverse effects of the environment. The major examples are GlobalG.A.P. and certifications by the Aquaculture Stewardship Council. Some are private standards, whereas others are public ones. Many countries have also adopted national certifications in the aquaculture sector. For example, there are three national certification standards in Thailand: good aquaculture practice, code of conduct, and TAS-7401 (Samerwong et al. 2018). The Government of Thailand also requires traceability from hatcheries to the export and registration of shrimp farmers (Suzuki and Nam 2018). Meanwhile, in Viet Nam, the government has developed VietGAP, which is a national standard that encompasses various international standards (Nguyen and Jolly 2020).

However, despite all these international efforts to minimize adverse effects, issues associated with sustainable fish farming remain in many countries. First, this may be caused by the diversity of the countries involved in modern aquaculture at present, as discussed in section I, and by the location specificness of aquaculture, similar to that of agriculture. Second, the majority of the primary fish farmers in Asia are small-scale farmers who are operating in ponds of less than 1 hectare (ha) (Hall 2004). Owing to this scale, the number of farmers involved, and the decentralized system involved, controlling all fish farming practices on the ground is extremely difficult. Third, according to Bush et al. (2019), the aquaculture sector has transformed itself from a “South–North” trade driven by the North lead firms to “‘multi-polarity’ driven by competing producers, traders and consumers across, within, and between Southern and Northern countries” (p. 428) in the recent years. This

structure makes it difficult to manage good practices.

B. Forms of Fish Farming

In general, the more extensive the production method, the less adverse its environmental effects. Stocking fish at a low density leads to less stress for the fish and less waste generated from fish. Thus, cleaner water leads to a lower probability of disease, thus reducing the risk for farmers. However, the productivity in an extensive production system is low, and harvesting cannot be scheduled precisely. Thus, it may not be reliable as a major source of income. To adopt intensive farming methods, farmers need to incur more initial costs (pond preparation and aeration equipment) as well as operating costs (e.g., seed, feed, electricity, and labor). They also need to manage their feeding schedules and pay attention to fish health and water quality. If these factors are not controlled well, fish may catch disease, and farmers may lose all their investment. Regarding the difference between brackish water and freshwater fish farming, brackish water fish farming is associated more with the destruction of mangrove forests and the adverse effects of coastal biodiversity. Meanwhile, in freshwater fish farming, pumping too much groundwater may lead to land subsidence. Thus, it is important to consider the conditions and requirements that are appropriate for farmers, depending on the area. Dey et al. (2005) conclude that semi-intensive freshwater fishing is suitable for resource-poor farmers, while shrimp may be too expensive or risky for these farmers.

While various species are cultured in inland waters using various methods, freshwater finfish aquaculture and shrimp aquaculture based on brackish water are two major forms of fish farming in Asian countries. Various types of carp, tilapia, and catfish are the major species produced in the former, whereas whiteleg shrimp (P. vannamei) are becoming the second dominant in the world after the black tiger prawn.

1. Freshwater Aquaculture for Domestic Market

Freshwater finfish aquaculture is mainly produced for domestic markets in many countries and dominates inland aquaculture in all regions of Asia (Figure 9). While growth driven by domestic demand is often overlooked in the English literature, its growth tends to be more stable and may even be more beneficial to stakeholders involved than the one driven by the export market (Belton

and Little 2008 and Belton et al. 2017). Bangladesh is a typical example of a country that has a remarkable growth of aquaculture relying on this path, and the benefit from the sector was indeed the poorest (Dey and Ahmed 2005; and Murshed-e-Jahan, Ahmed, and Belton 2010). While the Green Revolution dramatically increased rice production and reduced rice prices in the 1980s, and the country continued economic growth, it was also found that an increase in income did not translate into higher nutritional values (Rashid and Zhang 2019). Behrman and Dolalikar's (1987) seminal paper on this topic found that a 10% increase in income is associated with only a 1.7% increase in calorie consumption in India. As fish contribute to more than 60% of protein sourced from animals in Bangladesh, there are expectations to increase fish production and to reduce fish prices (Rashid and Zhang 2019). Fish production in Bangladesh consists of inland capture, inland aquaculture, and marine capture. Between 1983 and 2006, inland aquaculture grew at an average annual growth rate of 9.47%, whereas inland capture grew by 3.24% and marine capture by 4.84% (Murshed-e-Jahan et al. 2010). This translated into declining fish prices based on aquaculture by 12% between 2000 and 2010, while the fish prices based on inland capture increased by 39% and marine capture by 44% (Rashid and Zhang 2019). It was also shown that the change in fish consumption sourced from inland aquaculture between 2000 and 2010 was the highest for the extreme poor at 152.1%, followed by the moderately poor (114%) and non-poor (88.2%) (Toufigue and Belton 2014). The per capita annual fish consumption grew from 7.7 kilograms (kg) in 1980, 13 kg in 2000, to 18 kg in 2010 (Rashid and Zhang 2019).

Overall, the total fishpond area grew by 31% between 2007 and 2016, while the fish production volume from inland farming grew faster by 117.4% in the same period (Rashid and Zhang 2019). This suggests that the intensification of production, rather than the expansion of land is primarily the cause of aquaculture growth. The average pond size for aquaculture farmer did not change much over time from 0.29 ha in 2008 to 0.31 ha in 2013. Meanwhile, the average productivity was 3.35 metric tons per ha in 2013 in Bangladesh, with a wide regional variation ranging from 0.8 metric tons in Southwest to 10.02 metric tons per ha in the North (Rashid and Zhang 2019). As the yield in aquaculture is strongly associated with the intensity of farming practices, it shows that fish are farmed in more capital-intensive methods at a higher density and with more inputs in the north. In terms of production distribution, 89% of aquaculture households contributed only 25% of the total production, while the top 2.4% contributed 50% of the total production in Bangladesh, showing a skewed distribution of benefits across fish farmers (Rashid and Zhang 2019). It is

estimated that aquaculture in Bangladesh contributed to 2.11% of income growth between 2000 and 2010 and poverty reduction of 1.7%, which is 10% of the poverty reduction occurring within the same period (Rashid and Zhang 2019). They concluded that the development of the aquaculture sector was largely led by increasing domestic demand, fueled by stable economic development. Further, the number of workers involved in feed mills, hatcheries, feed dealing, and fish trading more than doubled, and that of fish farmers increased by 63% between 2004 and 2014. While it was a remarkable successful growth, the major challenges faced by the sector are low yields, as Bangladesh has yields less than one-third of Viet Nam and Thailand (Rashid and Zhang 2019). To intensify fish farming, the use of fish feed and improving feed quality are crucial, and it is also important to ease access to credit to finance these inputs for small-scale fish farmers.

2. Shrimp Aquaculture for Export Market

Another major fish farming in Asia is shrimp aquaculture, which is mainly used for export markets. Technology developed in Taipei,China and Japan spread to other countries in Southeast Asia in the 1980s, and black tiger production started in Indonesia, the Philippines, and Thailand (Belton and Little 2008 and Yi et al. 2018). In the Philippines, the San Miguel Corporation played a key role in converting sugar land to shrimp ponds, responding to the depressed sugar sector. Meanwhile, government support was more apparent in Thailand and Indonesia. The Government of Thailand started supporting the sector in the early 1970s, and the growth in intensive production started in the late 1970s and early 1980s. The Asian Development Bank had a large project on this sector in 1981, and a joint venture between the largest Thai conglomerate, the Charoen Pokphanand Group (CP group), and the Japanese conglomerate Mitsubishi was established in 1986 (Hall 2004). In Indonesia, the government promoted shrimp aquaculture after the ban on trawler shipping, which was the major form of shrimp production at that time, and declining oil prices in the export market.

While the shrimp sector in all the countries was hit by disease in the 1990s, the Thai shrimp sector was more resilient than others in that the sector of the former was able to sustain by shifting the major production area to the south from the Gulf of Thailand and by applying various innovations in farming techniques. Hall (2004) suspects that the relative success was mainly because of the following: (i) farmers changing their risky production practices; (ii) government support, including

investment in infrastructure and the establishment of a water treatment center; and (iii) various farming innovations developed in Thailand by both the CP group and small-scale farmers. The CP group is operated at every stage of the shrimp supply chain, from hatcheries, feed mills, shrimp ponds, laboratories, research institutes, and marketing stages, and it plays an important role in educating independent small-scale farmers on farming techniques (Goss et al. 2000). Hall (2004) also notes that feed mills in Thailand have incentives to teach farmers good practices as receiving returns on their investment in feed manufacturing takes time. Moreover, small-scale farmers have been active in developing on-farm innovation technologies in Thailand. Conversely, the separation of landowners and farm managers in the Philippines was not conducive to promoting on-farm innovations. The CP group also had a great influence on shrimp farming in other parts of Asia via their subsidiaries or joint ventures in Indonesia, Cambodia, Viet Nam, and India (Goss et al. 2000). In Indonesia, the response to the disease outbreak by small-scale shrimp farmers was either to exit production or move under the control of large-scale corporations. The government also promoted relocating shrimp ponds to other regions through their transmigration programs, which assisted farmers with pond infrastructure and credits. The largest of this corporative complex became as large as the size of Hong Kong, China with 1,600 kilometers of canals and 18,000 ponds (Hall 2004). Indonesia attempted to address this problem by centralizing the water control system.

Viet Nam was one of the newly emerging shrimp exporters in the 2000s. The country's rapid growth of shrimp production and exports started when the government issued a decree that allowed farmers to convert their rice farms to shrimp ponds in 2000. This decree was highly appreciated by people in the coastal areas in the south because their rice yields were not as high as in other parts of the country because of the saltiness of their water. In Ca Mau, which is located in the southernmost part of the country and produces the largest proportion of farmed shrimp (22%) and 4% of farmed fish in the country by volume in 2018 (General Statistics Office of Vietnam 2020), the areas for aquaculture ponds and production volume proliferated after 2000. This was accompanied by a significant decline in paddy production from the same province (Figure 15).

Although the profitability of shrimp farming depends on the farming methods adopted, it is reported that farmers may earn returns that are 10 times more than those in rice farming (Belton and Little 2008). Figure 16 shows that the gross output of product per hectare is higher for the aquaculture surface area than the cultivated area in Viet Nam, and the growth of the former has

been exponential. Black tiger prawn, which was originally popular in the area, was cultured twice a year, while vannamei shrimp, which is currently dominant, can be cultured three times a year as their production cycle is only for 3 months. Over time, shrimp production in Ca Mau became more intensive and, since 2017, a new farming method called "super-intensive" farmers emerged (Nguyen et al. 2019). The required capital differs across farming methods adopted. While extensive farming does not require feed, intensive production requires capital inputs such as aerators, electricity, pumps to remove waste from the pond floor, automatic feeding machines, shade, and water reservoirs. Shrimp needs to be fed 4–5 times a day, and as shrimp are nocturnal, farmers also feed shrimp during the night. Further, farmers need to maintain the water quality in the pond. This high-risk high-return nature of intensive farming makes it unsuitable for all farmers, even if they have suitable land. In Indonesia, Yi et al. (2018) provides quantitative evidence that, while there is no barrier to entry for vannamei shrimp farming, there are barriers to starting intensive farming methods largely because of capital constraints.

C. Current Issues with Sustainable Aquaculture

The typical structure of the fish farming market and associated problems with sustainable aquaculture are shown in Figure 12. The problems can be largely categorized into those affecting the (i) surrounding environment, (ii) coastal land and marine resources, (iii) fish farmers' own and neighborhood ponds, (iv) final consumers' health, and (v) processing factory workers.

Environmental problems in the surrounding environment have long been identified as issues associated with shrimp farming in many countries since the beginning of modern aquaculture in Taipei,China in the 1970s. Pumping too much groundwater led to ground subsidence (Chen and Qiu, 2014). Sourcing brackish water to ponds also affected the salinity of the surrounding land and water, which lowered the yields of other agricultural crops produced in the area (Páez-Osuna 2001). Further, Klinger and Naylor (2012) note that effluents from shrimp ponds include "uneaten feeds, feces, and bacteria (particulate organic matter), excreted ammonia, nitrite, nitrate, and phosphorus compounds (dissolved inorganic nutrients)", and these are toxic to fish if not removed from the ponds and can also change aquatic ecosystems of surrounding environment if released from pond. Therefore, these effluents should be treated properly. Several alternatives have been developed such as "recirculating aquaculture system", "aquaponic systems," "integrated

multitrophic aquaculture", and finally moving aquaculture offshore (Klinger and Naylor 2012). Biofloc technology, which uses microbes to recycle waste in water, is another methodology developed and widely implemented (Stokstad 2010).

Coastal land and marine resources are also affected by inland fish farming directly because of the opening of coastal land and cutting mangrove forests to be used as ponds and changing coastal diversity and ecosystems (Murai 1988 and Páez-Osuna 2001). Mangrove forests function as nursery grounds and shelters for many aquatic species during the early stages of their lives, and their destruction severely affects the biodiversity of these areas. In addition, the development of intensive farming methods that rely on feed increases the depletion of wild fish captured by marine fisheries. The average rates of fishmeal inclusion in feed are 27% for shrimp, 6% for tilapia, and 3.2% for carp (Cao et al. 2015), and 60% of global fishmeal is estimated to be consumed by aquaculture in the world in 2008, which was twice as high as 10 years in the past (Klinger and Naylor 2012). As the development of fed-aquaculture increases the demand for fishmeal, prices of "trash fish," which are the fish caught by non-targeted fisheries and do not fetch high values for human consumption, used for fishmeal is increasing. Cao et al. (2015) warn that the rapid growth of fed-aquaculture and high prices of trash fish will encourage non-targeted fisheries, which have adverse effects on marine resources.

The two issues affecting (i) fish farmers' own and neighborhood ponds and (ii) final consumers' health are closely related and largely come down to two aspects of farmers' farming behavior: water treatment and use of inputs. As discussed previously, pond effluents must be treated before they are released into canals used by other farmers. As the water quality is not easily observable, there is a high chance that, if one farmer pollutes the water in his or her pond, this polluted water will flow into his or her neighboring farmer's pond, creating a negative spillover. The probability of disease occurrence is higher if farmers are practicing intensive fish farming. Thus, to prevent or treat diseases, some farmers use prohibited antibiotics. This residue may remain in the shrimp body and may become a threat to consumers' health. Moreover, uneaten feed, chemical residues, and antibiotics can cause negative externalities to other ponds if farmers do not treat the water properly before releasing it to canals.

Many factors exist at each stage of the supply chain that contribute to this situation. First, input

markets are not adequately monitored by authorities, and this creates room for uncertified seed and feed to stay on markets. Second, farmers often lack financial resources to purchase feed, which accounts for about 70%–80% of the total production costs. Thus, in many places, farmers purchase feed on credit from input sellers. This situation locks fish farmers into a rigid financial relationship with input sellers, giving them limited options for their purchases. In other agricultural crops, we often observe contract farming with crop buyers, who finance the inputs for farmers in advance with the promise to sell the produce to these buyers. However, this type of contract with buyers does not seem to be operating for fish farming in many parts of the world. Hall (2004) notes that contract farming was once adopted in Thailand, but the system collapsed, and this requires further investigation. Third, farmers often lack access to appropriate equipment to visualize the unobserved quality of water and fish health, which are vital for fish farming. Fourth, farmers may not possess appropriate knowledge of fish farming and water quality. They are reported to use prohibited antibiotics to prevent or treat diseases (Tu et al. 2008, Suzuki and Nam 2018, and Lee et al. 2019a). While training by public extension officers is offered in many countries, its ineffectiveness has been recognized as a persistent issue in policy discussions (Takahashi et al. 2019). Fifth, some collectors are found to mix the fish and shrimp from different farmers when they transport the fish to the next stage of processors or domestic market because one farmer's fish is often not enough to fill one container (Suzuki and Nam 2018). This case makes traceability impossible, and the farmers are left uninformed even if their fish are rejected for residues at a later stage.

Recently, various digital technologies have been introduced to address some of these issues, notably farmer-to-farmer knowledge sharing via social media groups. Further, although water discharge was a serious problem in the early days of modern aquaculture, it is also true that an increasing number of farmers are aware of this potential negative spillover. To mitigate spillover among farmers, centralization of the water management system or cooperation among farmers is necessary (Hall 2004). Although a large-scale shrimp complex in Indonesia is rare in other Asian countries, central control is one form of addressing the spillover problem. Collaborative management systems have also been introduced. For example, shrimp farmers in Sri Lanka voluntarily set rules on the timing of water intake and release, and this co-management system has worked successfully for them (Galappaththi and Berkes 2015).

Last, while the focus of this paper is on the issues that derive from fish farming stages, it is also important to mention that fish processing stages have often been criticized for the health and ethical problems of their workers. Long hours of work while standing in cold environments tend to degrade workers' health status (Tomita et al. 2010 and Soe et al. 2015). Ethical issues of child labor and migrants working in environments below labor standards are also reported in media and in academic papers (Warrier 2001 and Islam 2008). These issues need to be addressed fully to achieve the sustainable aquaculture sector.

III. POLICY RECOMMENDATIONS

Based on the above discussions, several policy recommendations are proposed:

A. Limit land use along coasts for aquaculture

The adverse effects of aquaculture on coastal biodiversity and the destruction of mangrove forests have long been reported and criticized. As restoring biodiversity is difficult once it is lost, it is important that governments place certain rules and restrictions on the use of land for these areas.

B. Promote feed that rely less on wild fish

To reduce the reliance of aquaculture on marine resources via feed, feed manufacturers should be encouraged to use resources in addition to wild fish. Naylor et al. (2009) reported that although the ratio of wild fish to farmed fish has declined over time owing to the efforts of feed manufacturers, the dramatic growth of aquaculture outpaced the ratio decline, which in turn increased the total use of wild fish. Various alternatives that rely on vegetable or animal proteins and fish processing waste are considered and should be promoted (Stokstad, 2010).

C. Control and monitor the input markets

Farmers use prohibited antibiotics because they are available in the market. Thus, governments should monitor and control the input markets more closely. Farmers are sometimes unaware of the components included in feeds and fertilizers, which may contain some of these prohibited elements. In fact, there was a case in which ethoxyquin was detected from Viet Nam shrimp exports at the ports of Japan originating in the imported shrimp feed (UNIDO-IDE 2013). Farmers

may use these devices without being aware of the content. Thus, governments should regularly check the input markets.

D. Ease credit constraint

Another important problem is the lack of credit for farmers to finance the cost of feed. As discussed previously, the input sellers often sell feeds to farmers on credit, and farmers repay these input sellers when they harvest the fish. This creates a vertical relationship between input sellers and farmers, which restricts farmers' choice of inputs for farming. Thus, governments should encourage banks and financial institutions to lend farmers the necessary credits. Further, new technologies may help bridge the difficulty of lending to small-scale farmers, such as digital creditability assurance systems based on farmers' previous production history.

E. Promote farmers' knowledge using digital technologies

Mobile phones and smartphones have changed the way farmers learn new technology dramatically. Farmers are known to rely on their social networks to obtain information (Conley and Udry 2010 and Lee et al. 2019b). In particular, it is now common for farmers to form a certain group to share information on prices, markets, farming techniques, type of inputs to use, what to do if you suspect disease occurrence, and so on (Lee and Suzuki 2020). These interactive and visual media provide timely and effective information for farmers to upgrade their knowledge. While this action is driven by private interests, it is also worth considering how public extension efforts can be improved further by benefiting from these digital technologies. Examples include providing platforms for farmers to connect with extension officers to seek information, connecting model farmers from distant provinces to provide advice to farmers, collecting water quality information of public canals and distributing it to farmers, or using satellite imageries or drone photos to analyze the situation of fishponds and water bodies in the surrounding areas. Hence, opportunities are widely available in this area.

F. Provide easy access to public laboratories

As discussed previously, the maintenance of water quality and fish health are two vital aspects of fish farming. However, these qualities were not observed, unless tested. Most farmers operate based on their experience or rely on simple kits to test water quality. Hence, providing an easy

access for farmers to public laboratories, which is implemented in Thailand, is expected to be an effective investment for the government to promote sustainable aquaculture (Suzuki and Nam 2018). Partial financial support to acquire small equipment to visualize quality, such as water quality testing meters, may also be a good option. If farmers have better information, they can act accordingly to maximize their performance and reduce negative spillover effects.

G. Assure traceability along the supply chain

The assurance of traceability is of utmost importance to compete in the global market. However, this is practically difficult in the fish farming sector in Asia because producers in the upstream of the supply chain are small-scale farmers, operating on small ponds of 0.2 ha–0.5 ha. Meanwhile, tracing which particular pond a piece of fish came from is expensive. Although some processors also own large-scale ponds and vertically integrate fish production, a proportion of fish sourced from its own ponds was as low as 20%, even for the largest processor in Viet Nam. While this is a difficult task, we have some promising digital technology that is already used to trace “farm to table” in other agricultural produce, such as the IBM Food Trust. Howson (2020) illustrates how blockchain technology can be used in the aquaculture sector. If governments can invest in establishing a firm traceability system from pond to port, it will surely bring a positive reputation among buyers in the global market.

H. Monitor working conditions at processing factories

Processing factories have often been criticized for the health and ethical issues of their workers. The governments need to monitor the working environments and conditions for these factories to ensure that labor standards are complied with in this sector.

REFERENCES

Ahmed, Mahfuzuddin and Mylene H. Lorica. 2002. Improving Developing Country Food Security through Aquaculture Development - Lessons from Asia. *Food Policy* 27: 125–141.

Behrman, Jere R. and Anil B. Deolalikar. 1987. Will Developing Country Nutrition Improve with Income? A Case Study from Rural South India. *Journal of Political Economy* 95(3): 492–507.

Belton, Ben and David Little. 2008. The Development of Aquaculture in Central Thailand: Domestic Demand versus Export-Led Production. *Journal of Agrarian Change* 8(1): 123–143.

Belton, Ben, Arun Padiyar, G. Ravibabu, and K. Gopal Rao. 2017. Boom and Bust in Andra Pradesh: Development and Transformation in India's Domestic Aquaculture Value Chain. *Aquaculture* 470: 196–206.

Bush, Simon R., Ben Belton, David C. Little, and Md. Saidul Islam. 2019. Emerging Trends in Aquaculture Value Chain Research. *Aquaculture* 498: 428–434.

Cao, Ling, Rosamond Naylor, Patrik Henriksson, Duncan Leadbitter, Marc Metian, Max Troell, and Wenbo Zhang. 2015. (People's Republic of) China's Aquaculture and the World's Wild Fisheries. *Science* 347(6218): 133–135.

Chen, Chung-Ling and Guo-Hao Qiu. 2014. The long and bumpy journey: (Taipei,China)'s aquaculture development and management. *Marine Policy* 48: 152–161.

Conley, T.G. and C. R. Udry. 2010. Learning about a New Technology: Pineapple in Ghana. *American Economic Review* 100(1): 35–69.

Corsin, F., C. V. Mohan, A. Padiyar, K. Yamamoto, P. Chanratchakool, and M. J. Phillips. 2008. Codes of practice and better management: a solution for shrimp health management?, pp. 419–432. In Bondad-Reantaso, M.G., C. V. Mohan, M. Crumlish, and R. P. Subasinghe, eds. *Diseases in Asian Aquaculture VI. Fish Health Section*, Manila: Asian Fisheries Society.

Dey, Madan Mohan and Mahfuzuddin Ahmed. 2005. Aquaculture- Food and Livelihoods for the Poor in Asia: A Brief Overview of the Issues. *Aquaculture Economics and Management* 9:1-2, 1–10.

Dey, Madan Mohan, Mohammed A. Rab, Ferdinand J. Paraguas, Ramachandra Bhatta, Md. Ferdous Alam, Sonny Koeshendrajana, and Mahfuzuddin Ahmed. 2005. Status and Economics of Freshwater Aquaculture in Selected Countries of Asia. *Aquaculture Economics and Management* 9:1-2, 11–37.

FAO, NACA, UNEP, World Bank, and WWF. 2006. *International principles for responsible shrimp farming.* Bangkok: Network of Aquaculture Centres in Asia-Pacific.

FAO. 2018. *World Aquaculture Performance Indicators (WAPI) – Fish Consumption Module (WAPI-FISHCSP v.2018.1).* In FAO Fisheries and Aquaculture Department [online] Rome. Updated 2018. http://www.fao.org/fishery/statistics/software/wapi/en.

_____. 2020a. *Fishery and Aquaculture Statistics. Global aquaculture production 1950–2018* (FishstatJ). In FAO Fisheries Division [online]. Rome. Updated 2020. www.fao.org/fishery/statistics/software/fishstatj/en.

_____. 2020b. *Fishery and Aquaculture Statistics. Global capture production 1950–2018 (FishstatJ)*. In FAO Fisheries Division [online]. Rome. Updated 2020. www.fao.org/fishery/statistics/software/fishstatj/en.

_____. 2020c. *Fishery and Aquaculture Statistics. Global Fisheries commodities production and trade 1976–2018* (FishstatJ). In FAO Fisheries Division [online]. Rome. Updated 2020. www.fao.org/fishery/statistics/software/fishstatj/en.

_____. 2020d. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome.

_____. 2020e. *Aquaculture Growth Potential in Asia: WAPI Factsheet to Facilitate Evidence-based Policy Making and Sector Management in Aquaculture*. In FAO Fisheries Division [online]. Rome. http://www.fao.org/fishery/statistics/software/wapi/en.

Galappaththi, Eranga K. and Fikret Berkes. 2015. Can co-management emerge spontaneously? Collaborative Management in Sri Lankan Shrimp Aquaculture. *Marine Policy* 60: 1–8.

General Statistics Office of Viet Nam. 2020. Agriculture, Forestry and Fishery. [online]. Ha Noi. https://www.gso.gov.vn/en/agriculture-forestry-and-fishery/.

Goss, Jasper, David Burch, and Roy E. Rickson. 2000. Agri-Food Restructuring and Third World Transnationals: Thailand, the CP Group and the Global Shrimp Industry. *World Development* 28 (3): 513–530..

Hall, Derek. 2004. Explaining the Diversity of Southeast Asian Shrimp Aquaculture. *Journal of Agrarian Change* 4(3): 315–335.

Howson, Peter. 2020 Building Trust and Equity in Marine Conservation and Fisheries Supply Chain Management with Blockchain. *Marine Policy* 115: 103873.

Islam, Saidul. 2008. From Sea to Shrimp Processing Factories in Bangladesh: Gender and Employment at the Bottom of a Global Commodity Chain. *Journal of South Asian Development* 3(2): 211–236.

Klinger, Dane and Rosamond Naylor. 2012. Searching for Solutions in Aquaculture: Changing a Sustainable Course. *Annual Review on Environmental Resources* 37: 247–276.

Lee, Guenwoo, Aya Suzuki, and Vu Hoang Nam. 2019a. The determinants of detecting veterinary drug residues: Evidence from shrimp farmers in southern Viet Nam. *Aquaculture Economics and Management* 23(2): 135–157.

_____. 2019b. Effect of network-based targeting on the diffusion of good aquaculture practices among shrimp producers in Vietnam. *World Development* 124: 104641.

Lee, Guenwoo, and Aya Suzuki. 2020. Motivation for information exchange in a virtual community of practice: Evidence from a Facebook group for shrimp farmers. *World Development* 125: 104698.

Murshed-e-Jahan, Khondker, Mahfuzuddin Ahmed, and Ben Belton. 2010. The Impacts of Aquaculture Development on Food Security: Lessons from Bangladesh. *Aquaculture Research* 41: 481–495.

Murai, Yoshinori. 1988. *Ebi to Nihon Jin (Shrimp and the Japanese).* Tokyo: Iwanami Shoten.

Naylor, Rosamond L., Ronald W. Hardy, Dominique P. Bureau, Alice Chiu, Matthew Elliot, Anthony P. Farrell, Ian Forster, Delbert M. Gatlin, Rebecca J. Goldburg, Katheline Hua, and Peter D. Nichols. 2009. Feeding Aquaculture in an Era of Finite Resources. *PNAS* 106 (36): 15103–15110.

Nguyen, Tram Anh Thi, Kim Anh Thi Nguyen, and Curtis Jolly. 2019. Is Super-Intensification the Solution to Shrimp Production and Export Sustainability? *Sustainability* 11, 5277.

Nguyen, Tram Anh Ti and Curtis M. Jolly. 2020. Global Value Chain and Food Safety and Quality Standards of Vietnam Pangasius Exports. *Aquaculture Reports* 16(100256): 1–12.

Páez-Osuna, Federico. 2001. The Environmental Impact of Shrimp Aquaculture: Causes, Effects, and Mitigating Alternatives. *Environmental Management* 28(1): 131–140.

Rashid, Shahidur and Xiaobo Zhang. 2019. *The Making of a Blue Revolution in Bangladesh: Enablers, Impacts, and the Path Ahead for Aquaculture*. Washington, DC: International Food Policy Research Institute.

Samerwong, Phatra, Simon R. Bush, and Peter Oosterveer. 2018. Implications of Multiple National Certification Standards for Thai Shrimp Aquaculture. *Aquaculture* 493: 319–327.

Soe, Kyaw Thu, Orapin Laosse, Suwassa Limsatchapanich, and Cheerawit Rattanapan. 2015. Prevalence and Risk Factors of Musculoskeletal Disorders among Myanmar Migrant Workers in Thai Seafood Industries. *International Journal of Occupational Safety and Ergonomics* 21(4): 539–546.

Stokstad, Erik. 2010. Down on the Shrimp Farm. *Science* 328(5985): 1504–1505.

Suzuki, Aya and Vu Hoang Nam. 2018. Better management practices and their outcomes in shrimp farming: evidence from small-scale shrimp farmers in Southern Vietnam. *Aquaculture International* 26: 469–486.

_____. 2019. Marketing Risks and Standards Compliance: Challenges in Accessing the Global Market for High-value Agricultural and Aquacultural Industries. In Tsunekawa, K. and Y. Todo, eds. *Emerging States at Crossroads.* Springer: 163–184.

Takahashi, Kazushi, Rie Muraoka, and Keijiro Otsuka. 2019. Technology Adoption, Impact, and Extension in Developing Countries' Agriculture: A Review of the Recent Literature. *Agricultural Economics* 51: 31–45.

Tomita, Shigeru, Sara Arphorn, Takashi Muto, Kanatid Koetkhlai, Saw Sandy Naing, and Chalermchai Chaikittiportn. 2010. Prevalence and Risk Factors of Low Back Pain among Thai and Myanmar Migrant Seafood Processing Factory Workers in Samut Sakorn Province, Thailand. *Industrial Health* 48: 283–291.

Tu, Huynh Thi, Fédéric Silvestre, Amandine Bernard, Caroline Douny, Nguyen Thanh Phuong, Chau Tai Tao, Guy Maghuin-Rogister, and Patrick Kestemont. 2008 Oxidative Stress Response of Black Tiger Shrimp (*Penaeus monodon*) to Enrofloxacin and to Culture System. *Aquaculture* 285: 244–248.

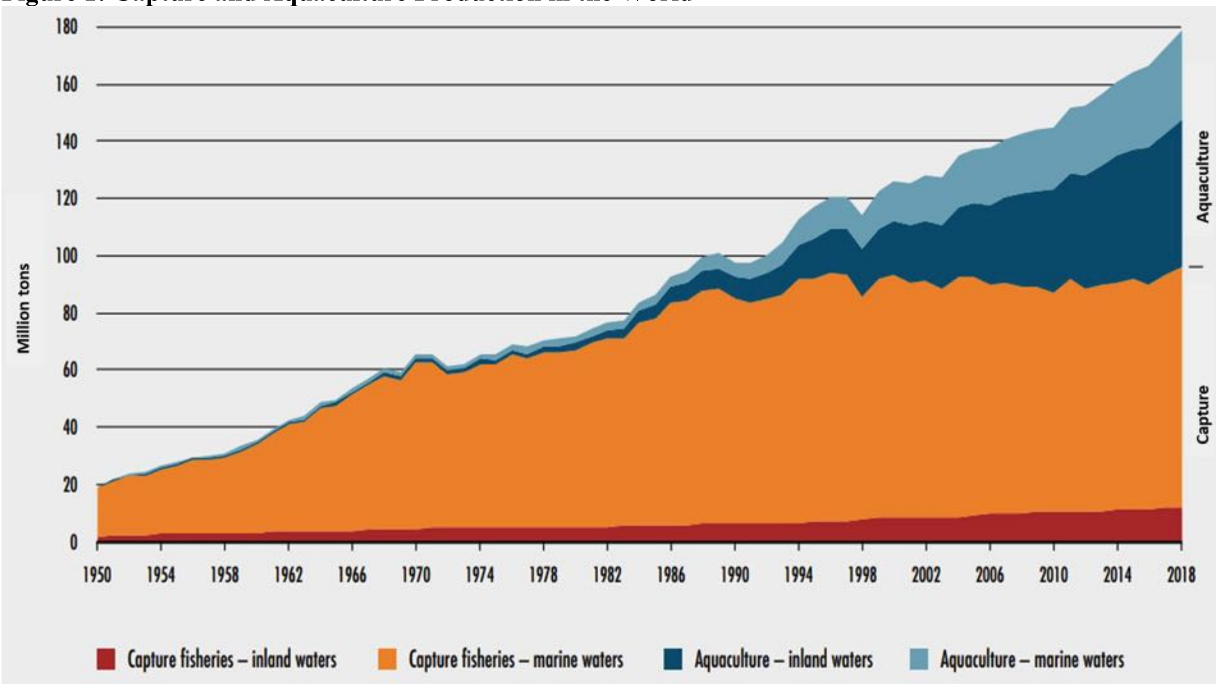
UNIDO and Institute of Developing Economies. 2013. *Meeting standards, winning markets regional trade standards compliance report East Asia 2013*. Vienna: United Nations Industrial Development Organization.

Warrier, M.V. Shobhana. 2001. Women at Work: Migrant Women in Fish Processing Industry. *Economic and Political Weekly* 36(37): 3554–3562.

Yi, Dale, Thomas Reardon, and Randy Stringer. 2018. Shrimp Aquaculture Technology Change in Indonesia: Are Small Farmers Included? *Aquaculture* 493: 436–445.

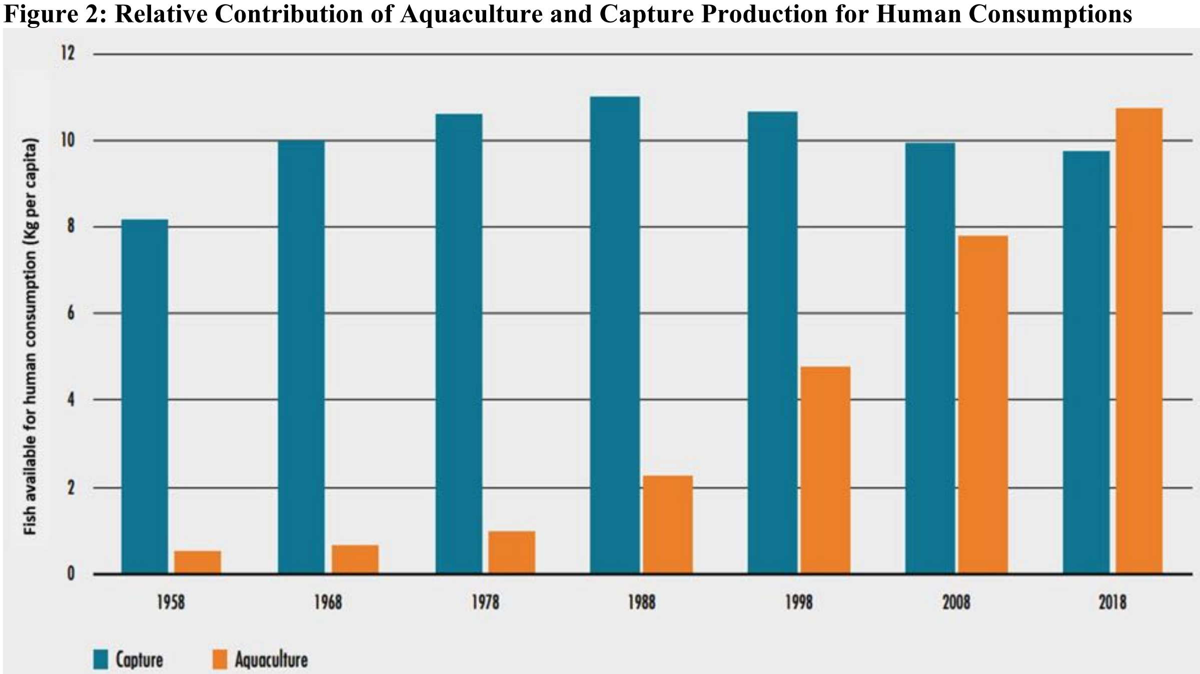
Tables and Figures

Figure 1: Capture and Aquaculture Production in the World



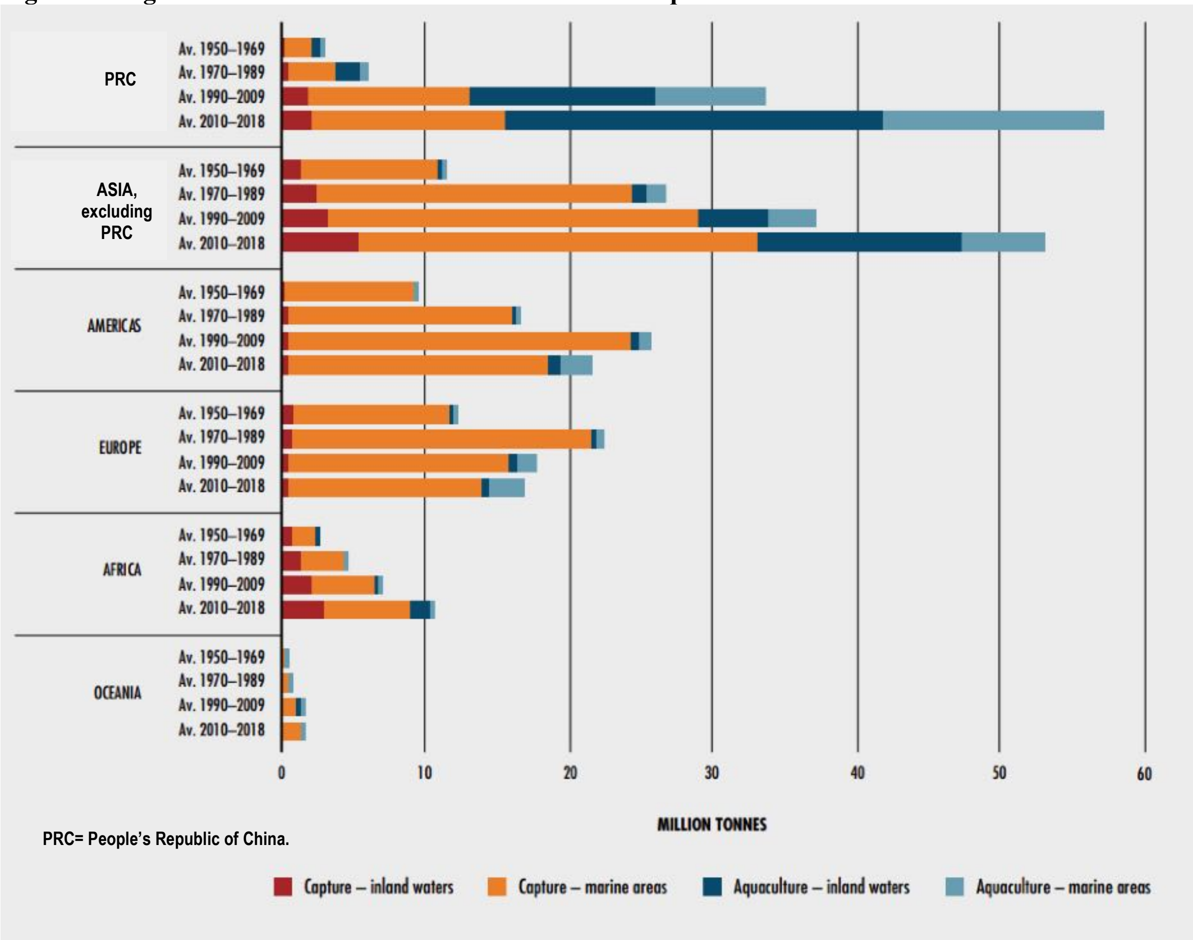
Source: Adapted from FAO. 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome: Food and Agriculture Organization of the United Nations (p. 4, figure 1).

Figure 2: Relative Contribution of Aquaculture and Capture Production for Human Consumptions



Source: Adapted from FAO. 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome: Food and Agriculture Organization of the United Nations (p. 72, figure 27).

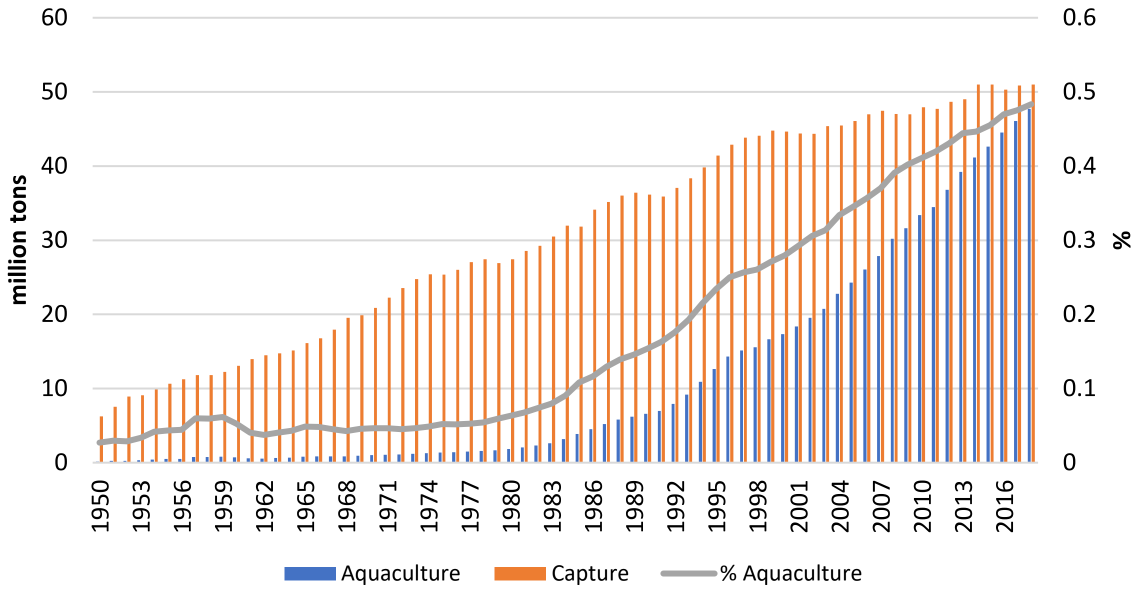
Figure 3: Regional Contribution to World Fisheries and Aquaculture



NOTE: Excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants. Europe includes data for the Union of Soviet Socialist Republics for the years 1950–1987. Av. = Average per year.

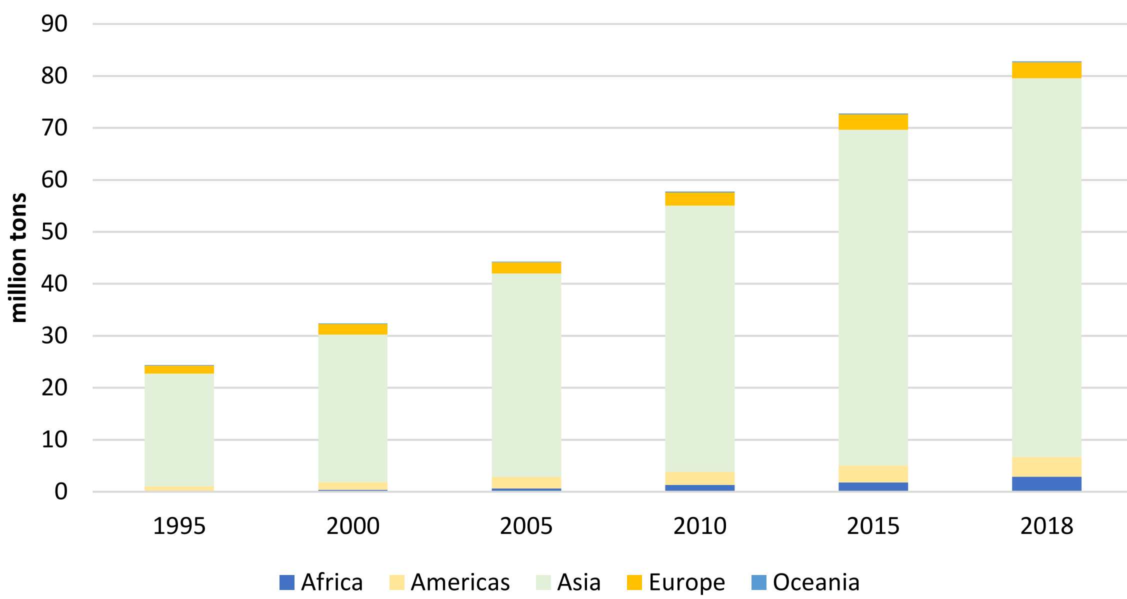
Source: Adapted from FAO. 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome: Food and Agriculture Organization of the United Nations (p. 5, figure 3).

Figure 4: Capture and Aquaculture Production in Asia and Oceania



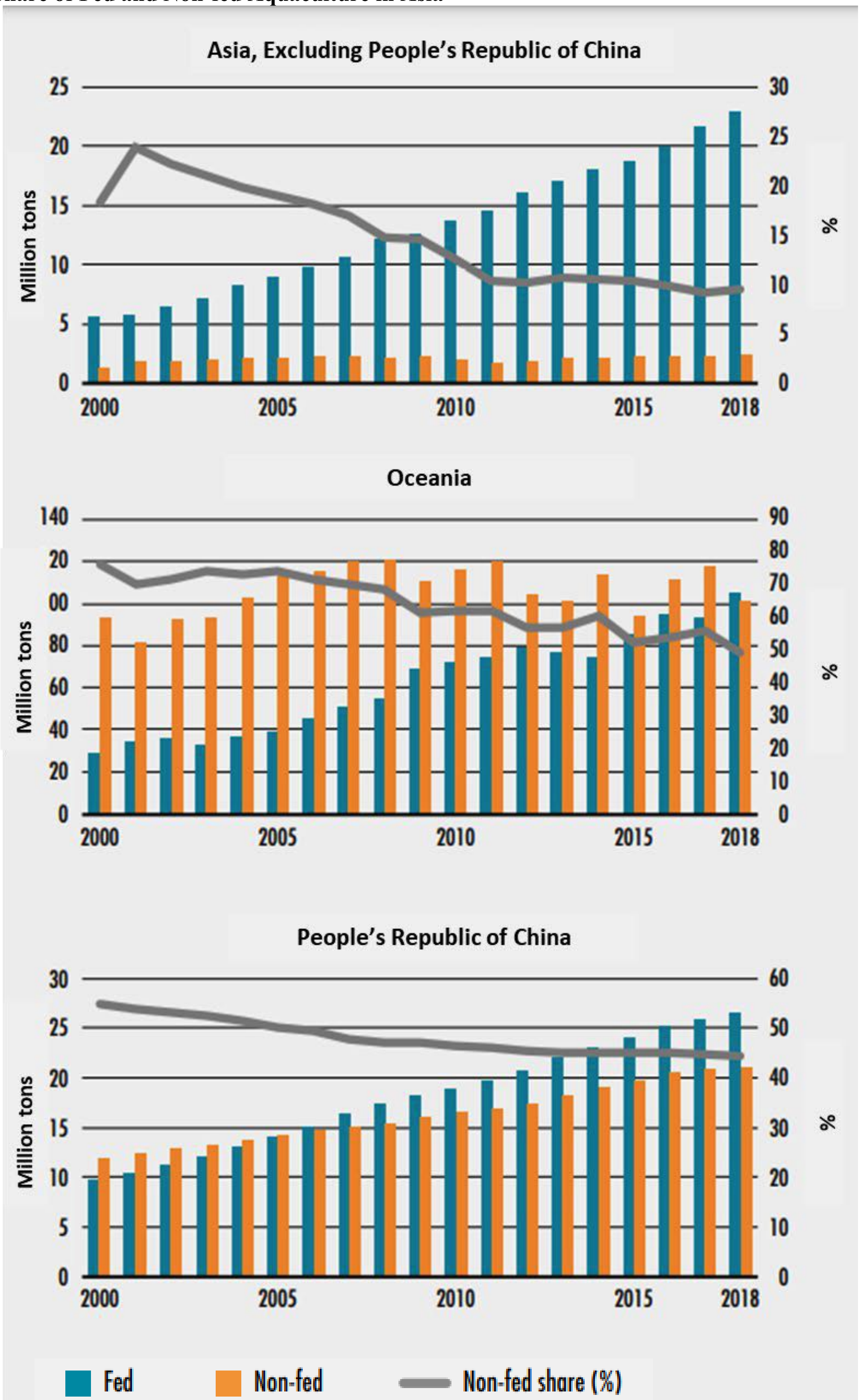
Source: FAO. FishStatJ. http://www.fao.org/fishery/statistics/software/fishstatj/en (accessed 30 August 2021).

Figure 5: Aquaculture Fish Production by Regions



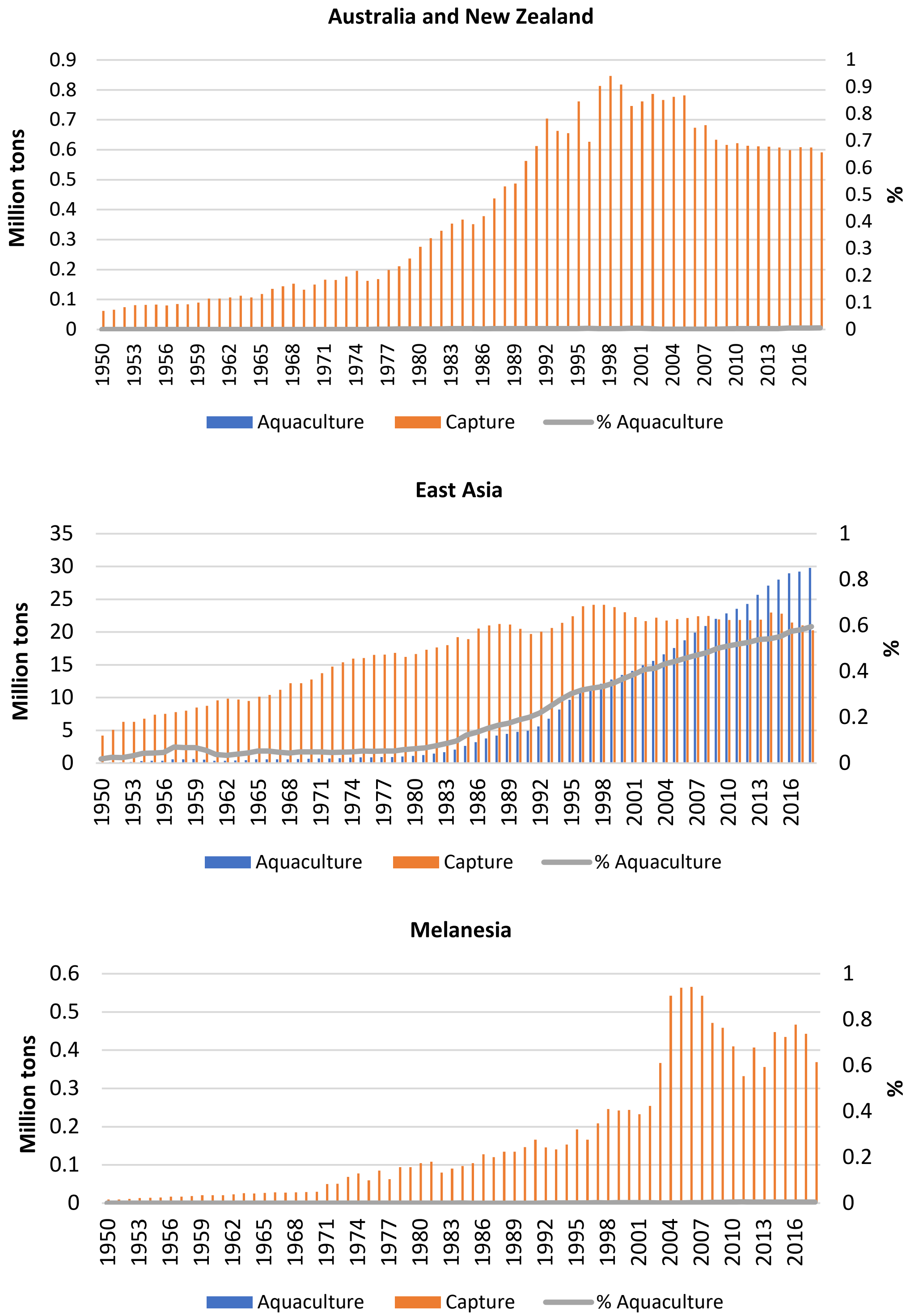
Source: FAO. 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome: Food and Agriculture Organization of the United Nations (p. 33).

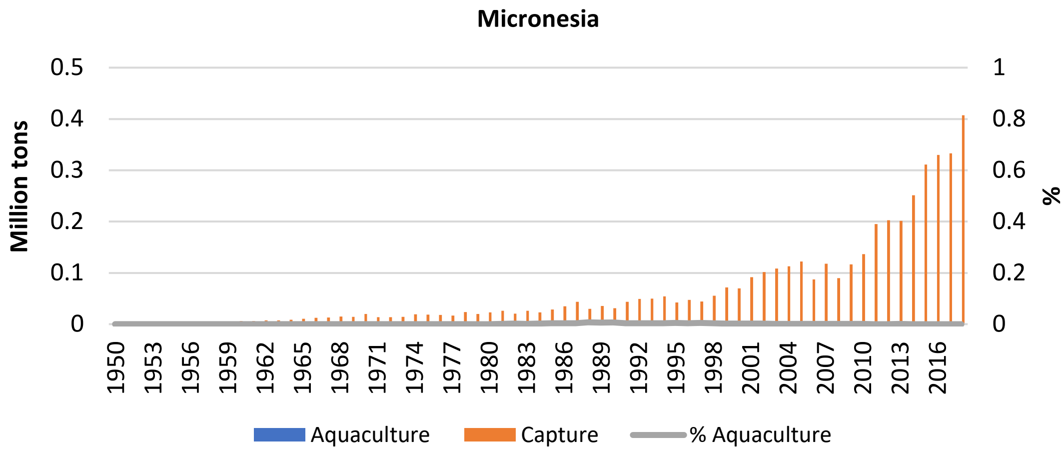
Figure 6: Share of Fed and Non-fed Aquaculture in Asia

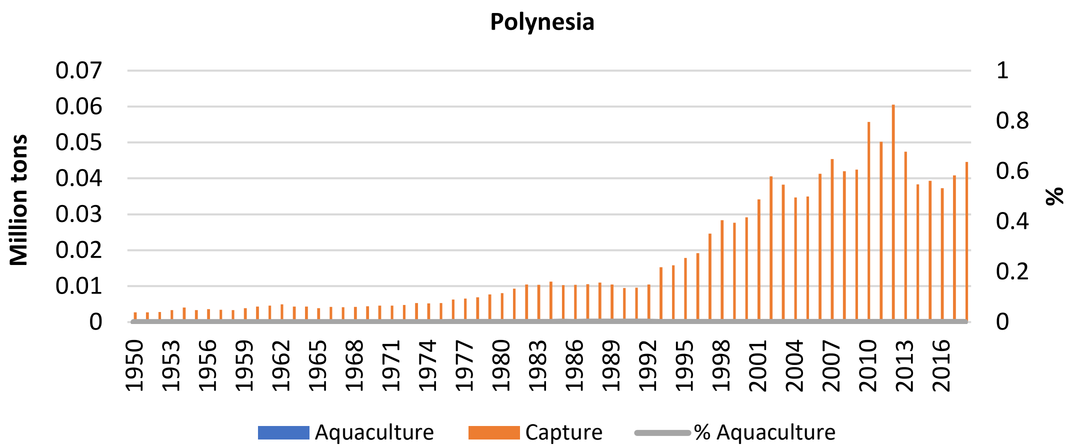


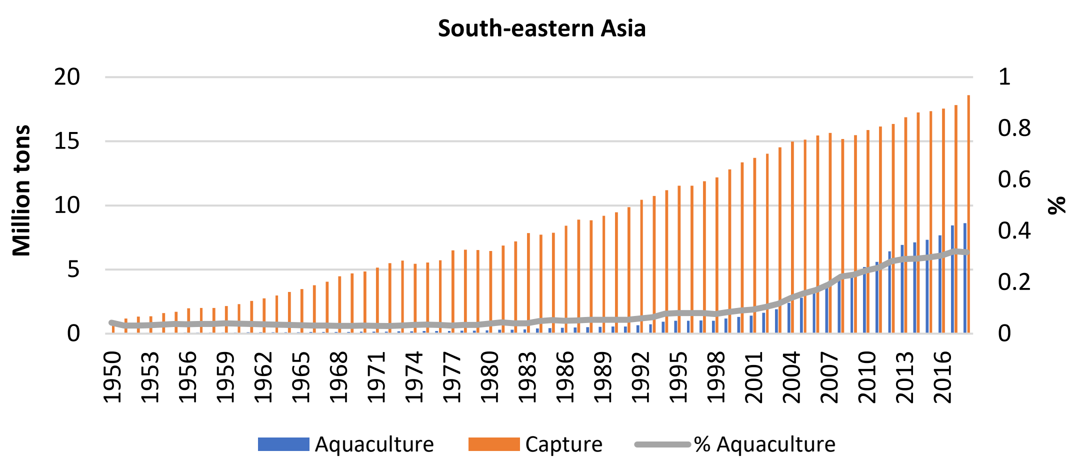
Source: Adapted from FAO. 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome: Food and Agriculture Organization of the United Nations (p. 28, figure 11).

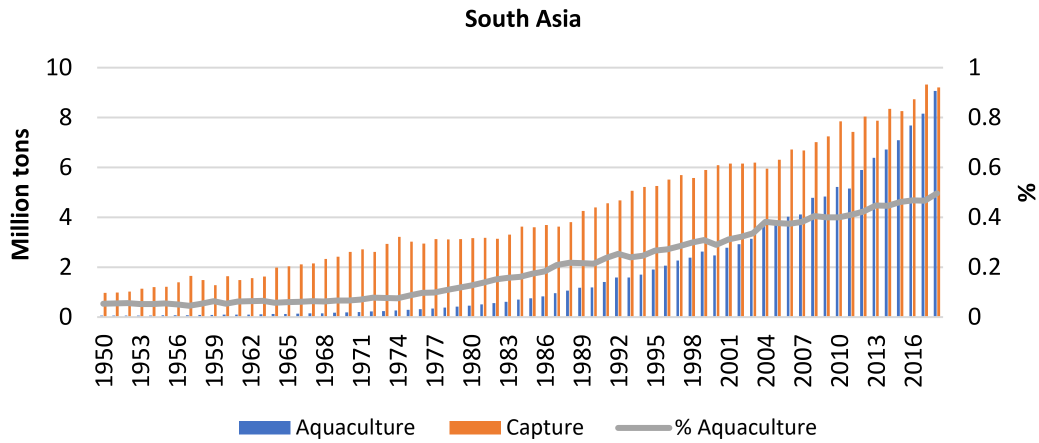
Figure 7: Capture and Aquaculture Fish Production by Regions

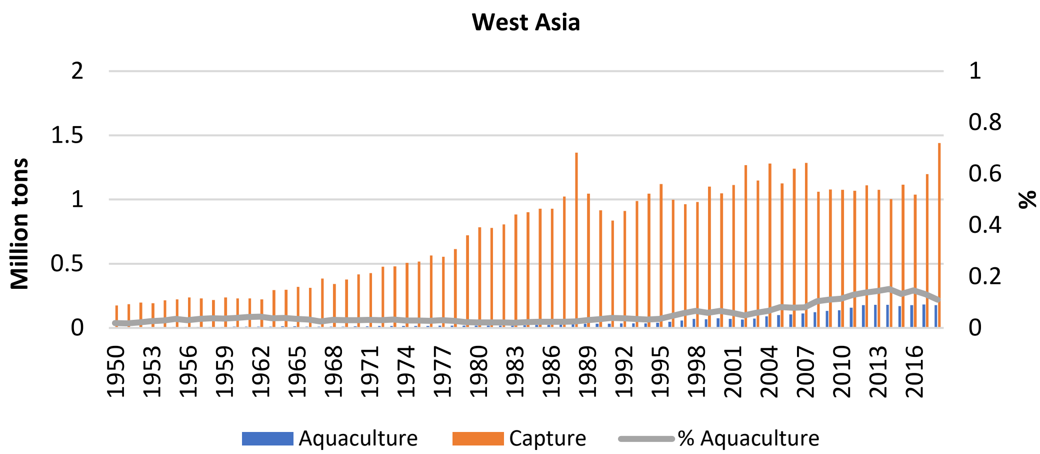


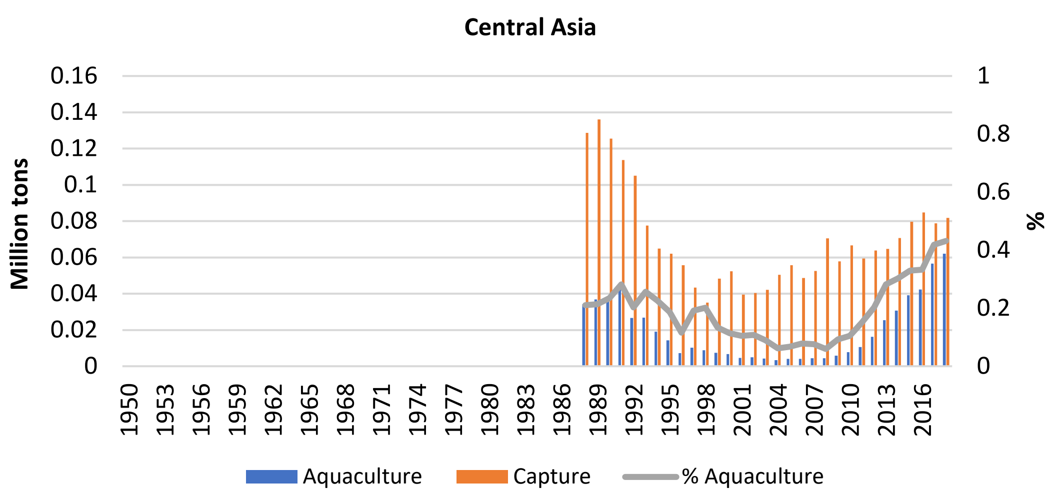

Micronesia
Million tons
%
Aquaculture
Capture
% Aquaculture

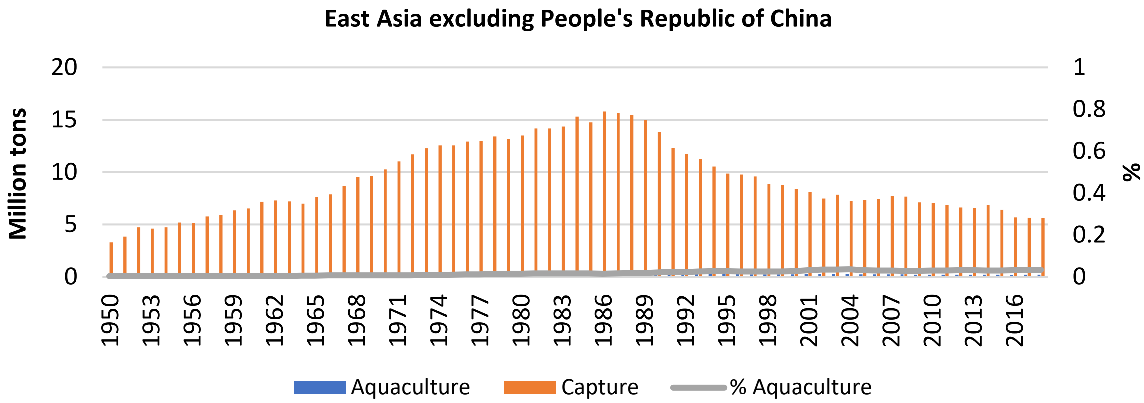

Polynesia
Million tons
%
Aquaculture
Capture
% Aquaculture


South-eastern Asia
Million tons
%
Aquaculture
Capture
% Aquaculture


South Asia
Million tons
%
Aquaculture
Capture
% Aquaculture


West Asia
Million tons
%
Aquaculture
Capture
% Aquaculture

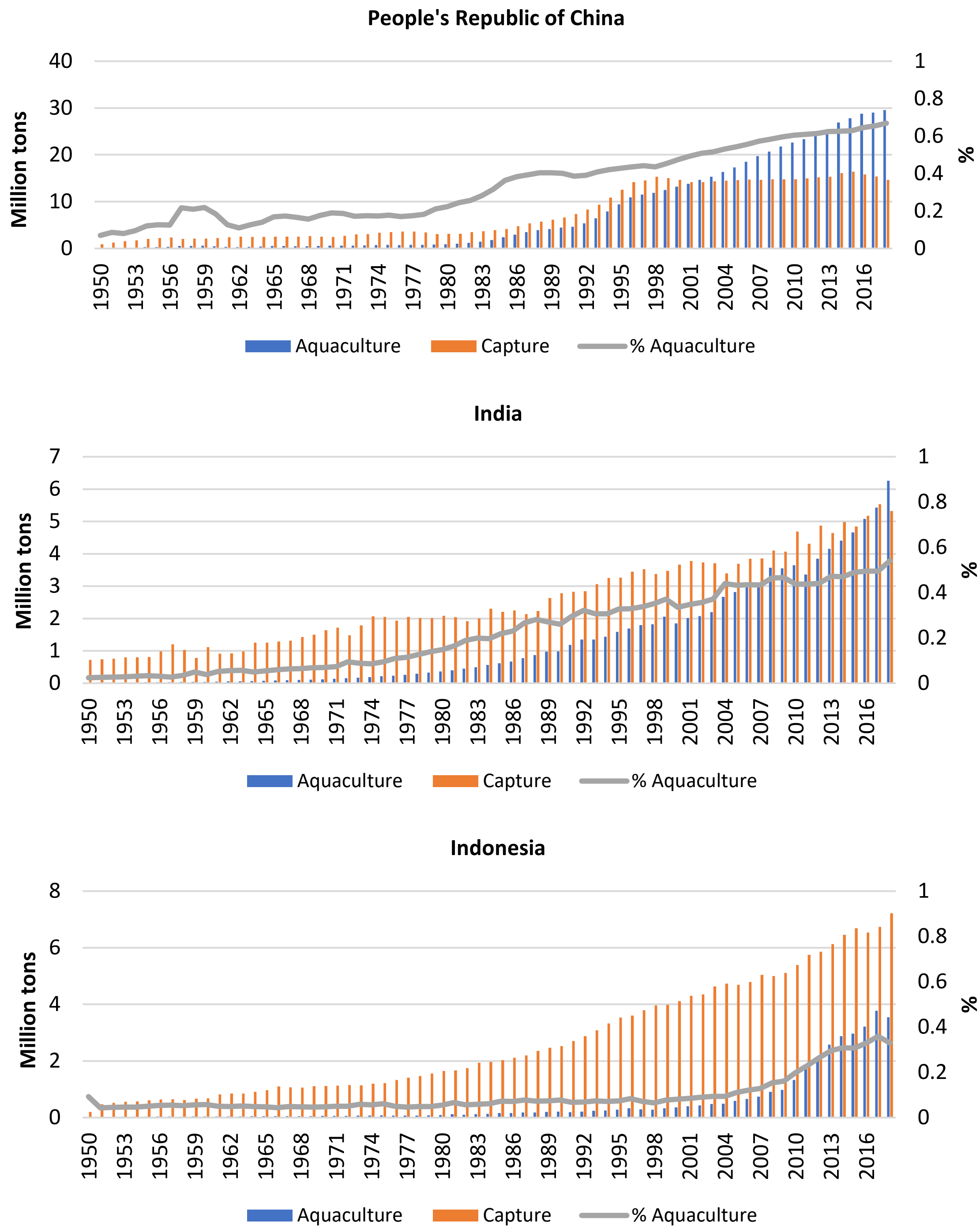

Central Asia
Million tons
%
Aquaculture
Capture
% Aquaculture

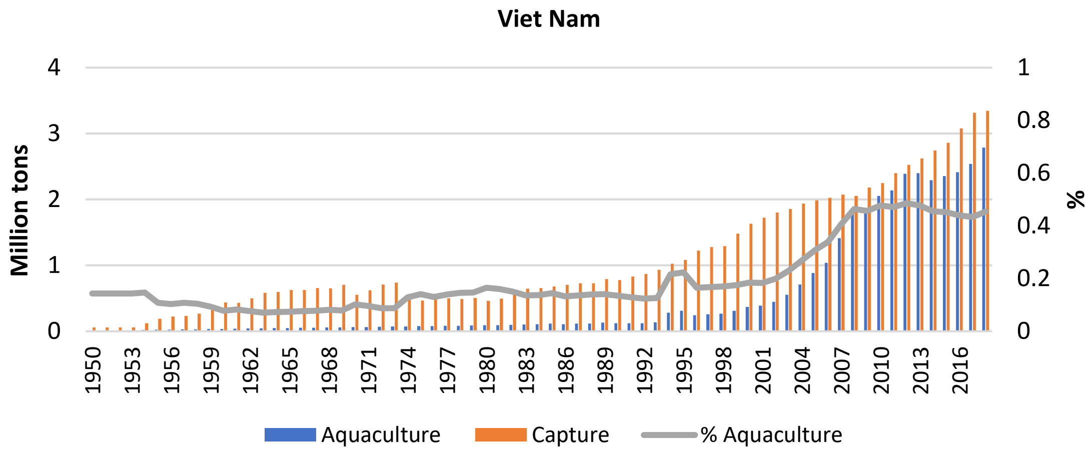


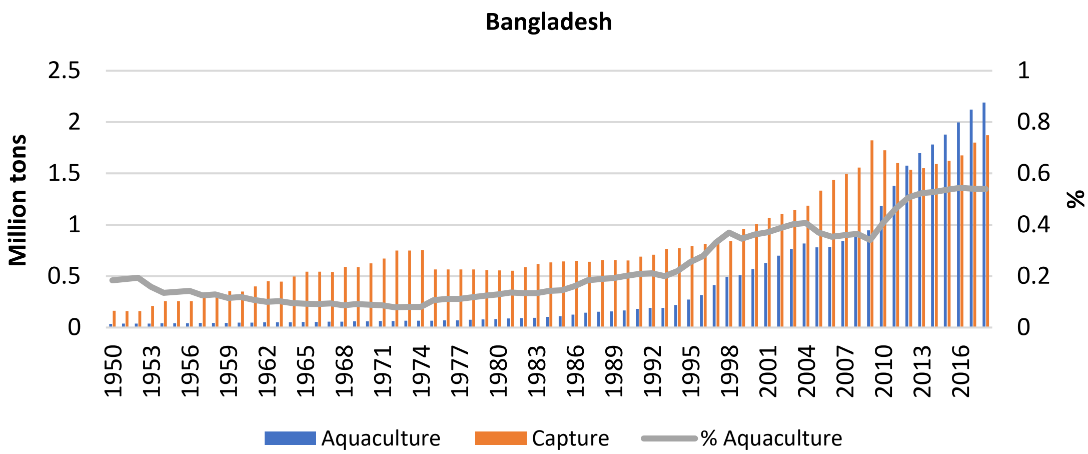
Note: Country groupings follow the definitions and standards used in FAOSTAT.

Source: FAO. FishStatJ. http://www.fao.org/fishery/statistics/software/fishstatj/en (accessed 30 August 2021).

Figure 8: Capture and Aquaculture Fish Production by Major Five Countries

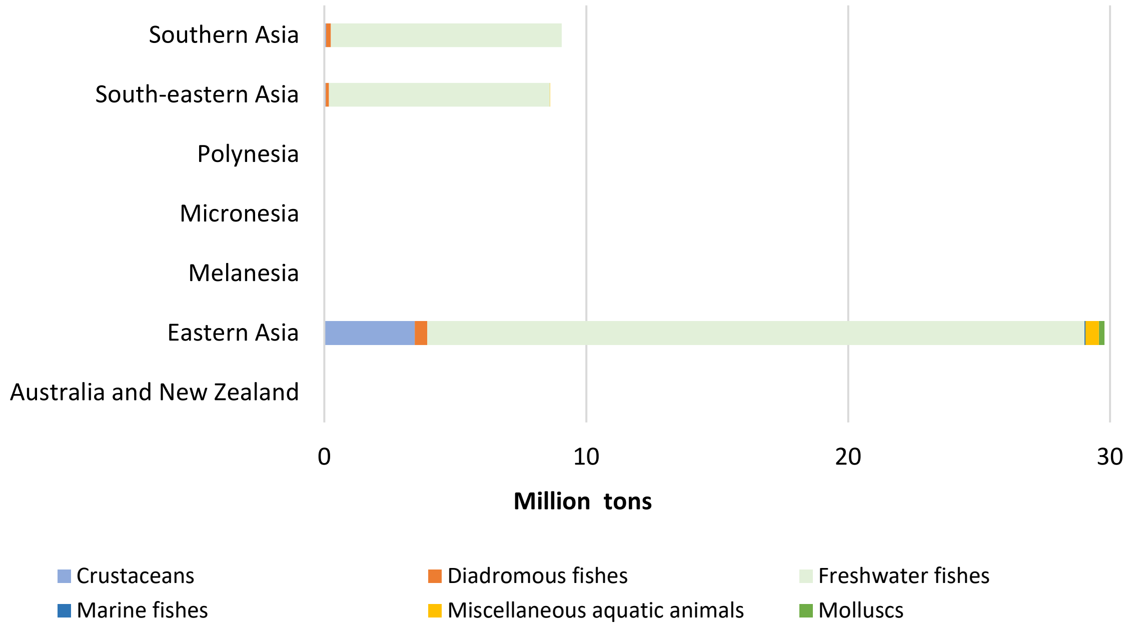






Source: FAO. FishStatJ. http://www.fao.org/fishery/statistics/software/fishstatj/en (accessed 30 August 2021).

Figure 9: Species Farmed on Inland Waters in Asia and Oceania in 2018

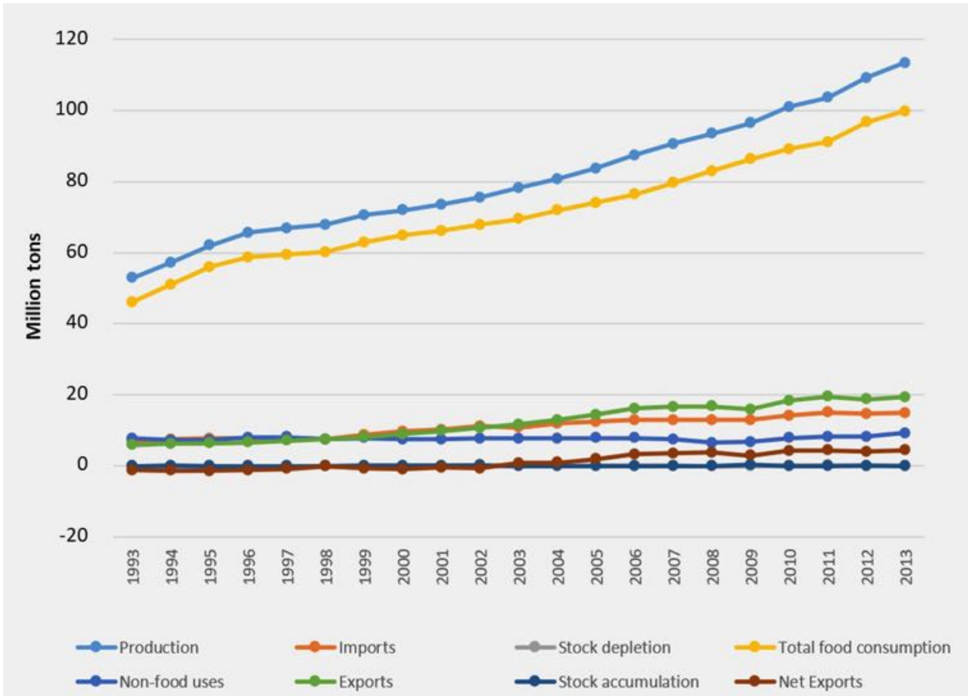


Note: Country groupings follow the definitions and standards used in FAOSTAT.

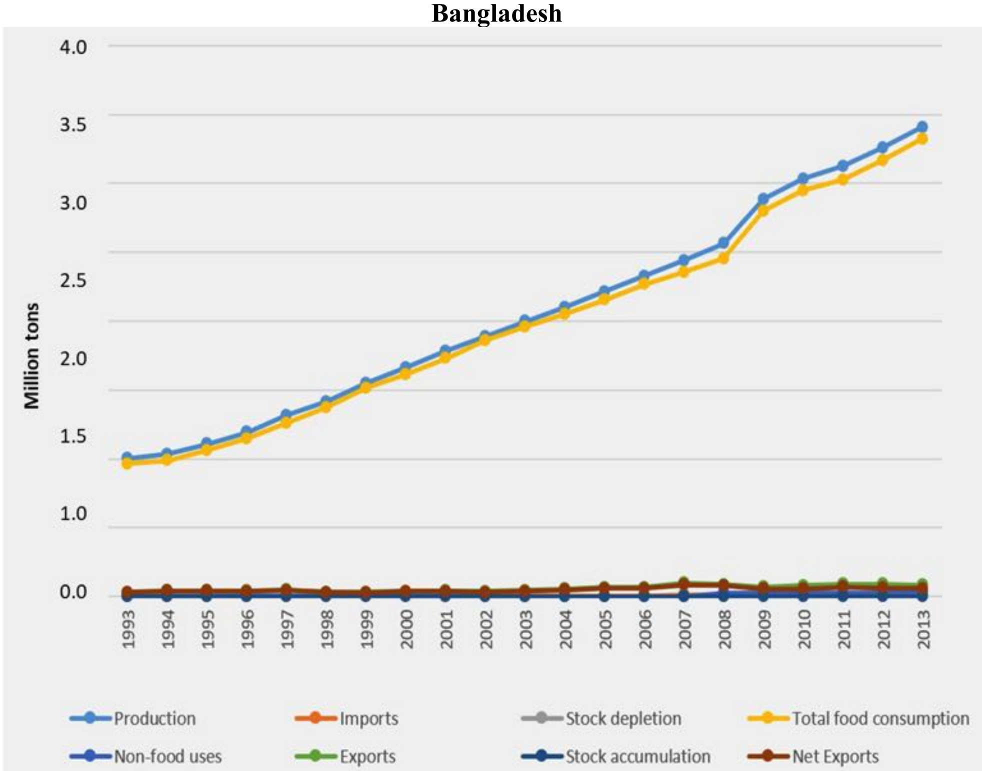
Source: FAO. FishStatJ. http://www.fao.org/fishery/statistics/software/fishstatj/en (accessed 30 August 2021).

Figure 10: Food Balance Sheet for Fish and Seafood for Asia and Major Producers

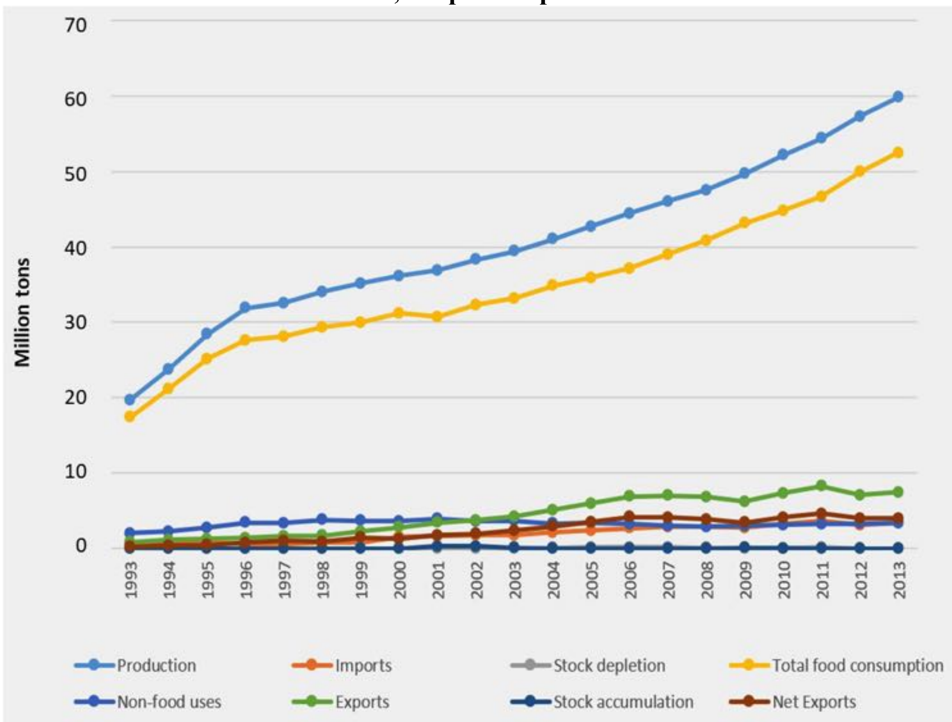
Asia



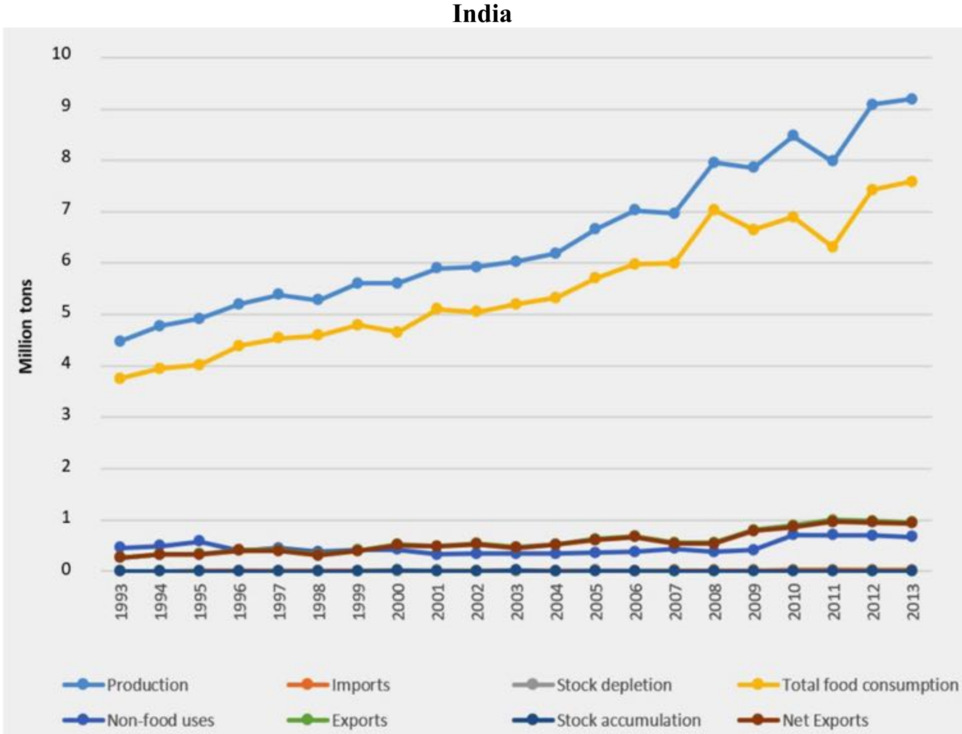
Bangladesh



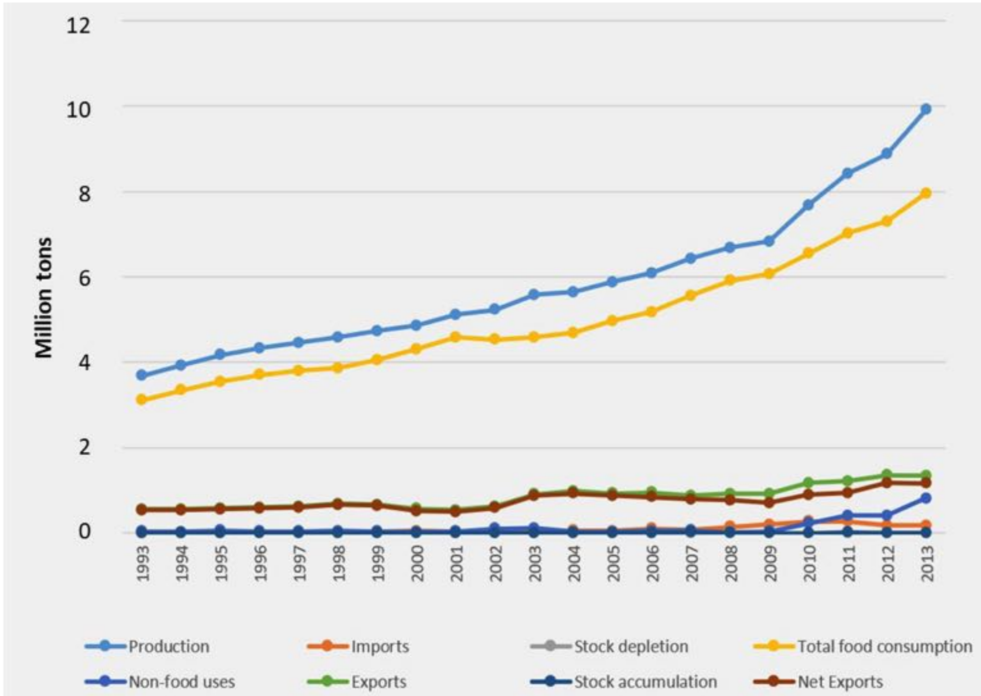
China, People's Republic of



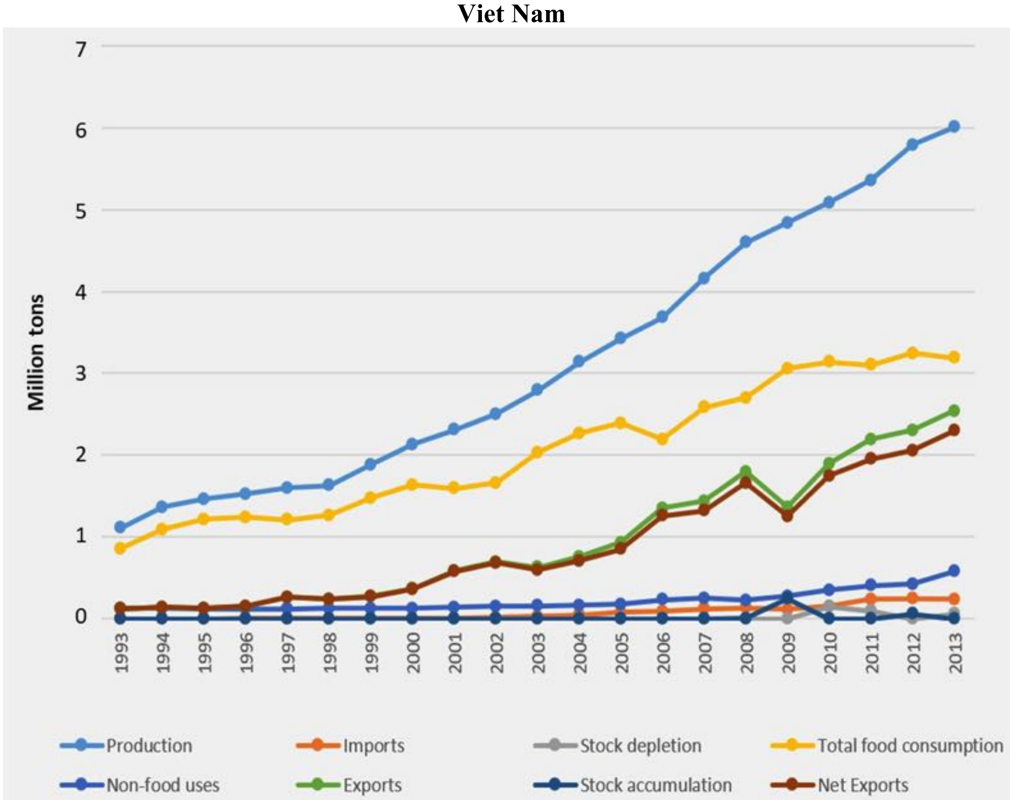
India



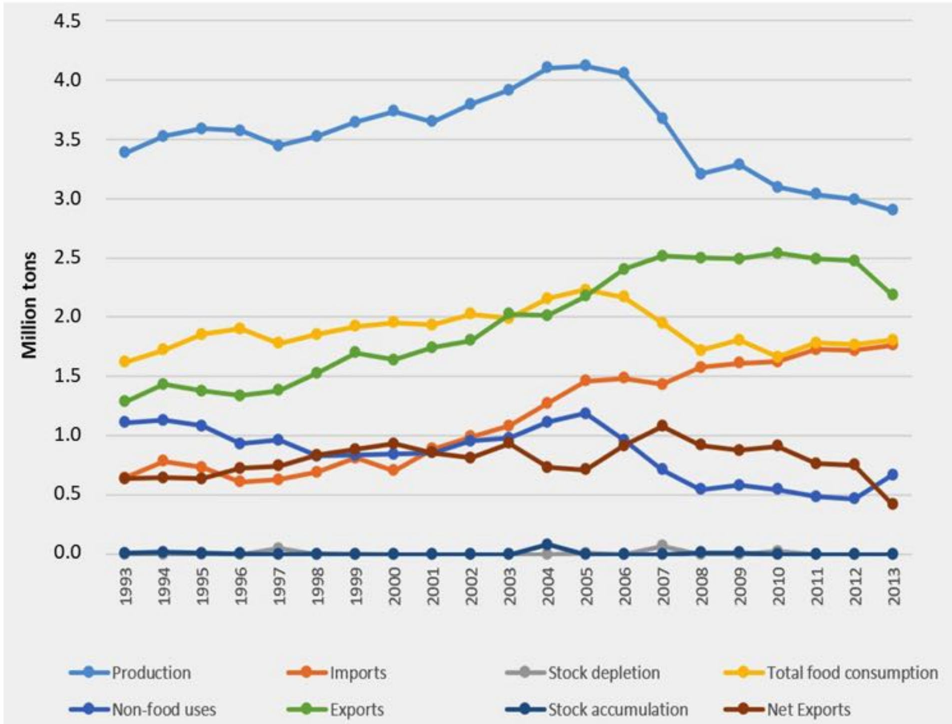
Indonesia



Viet Nam

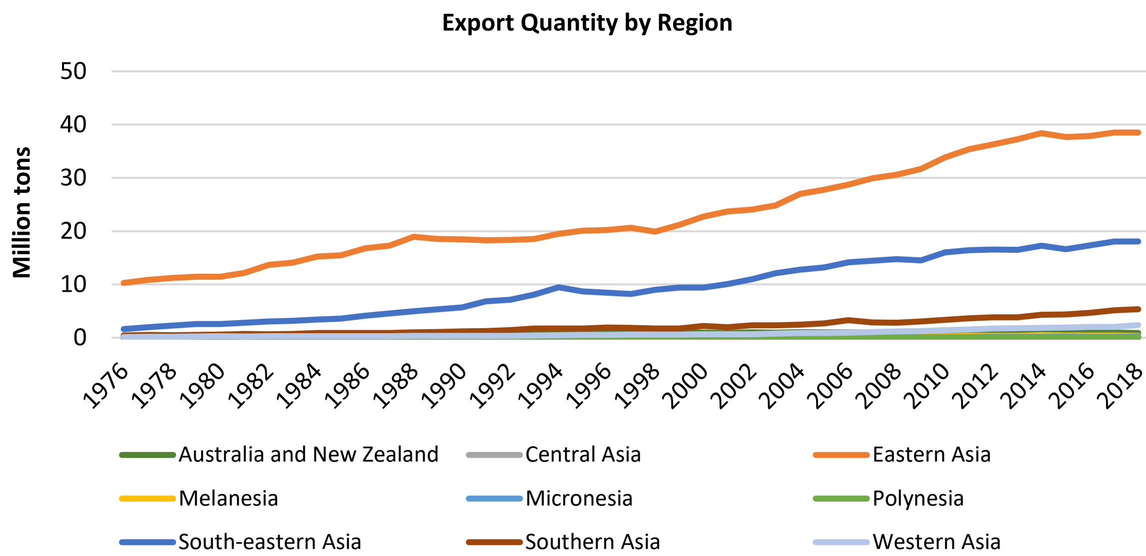


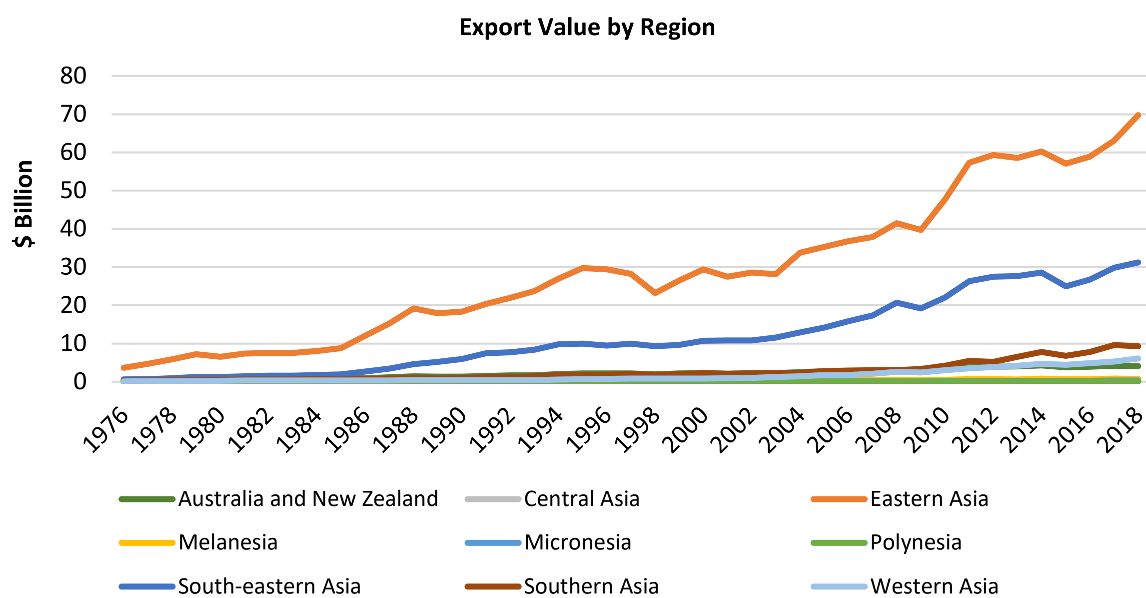
Thailand

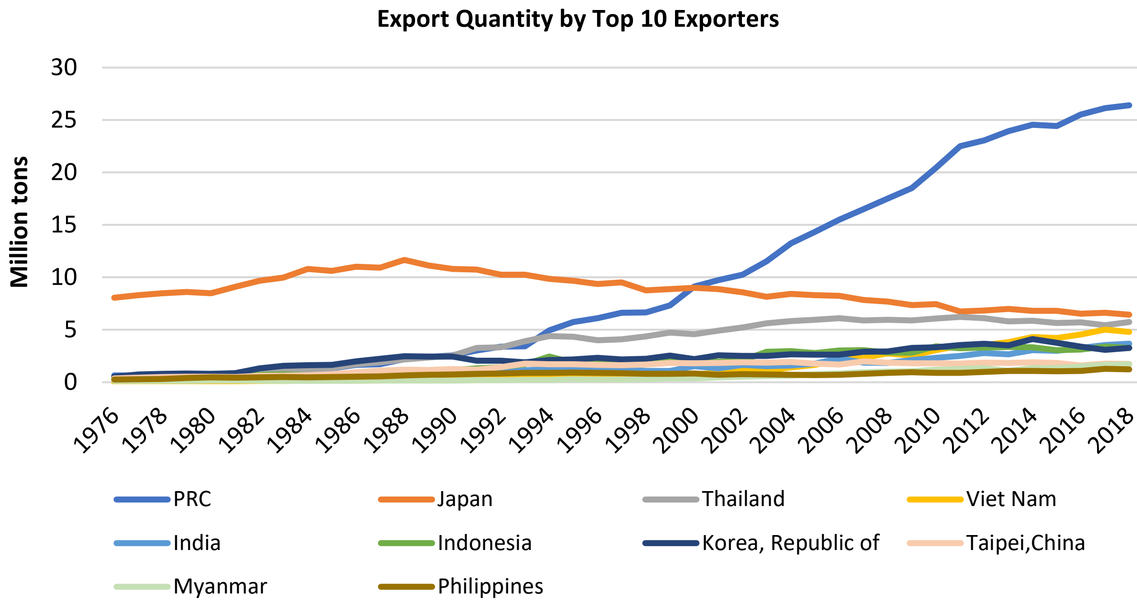


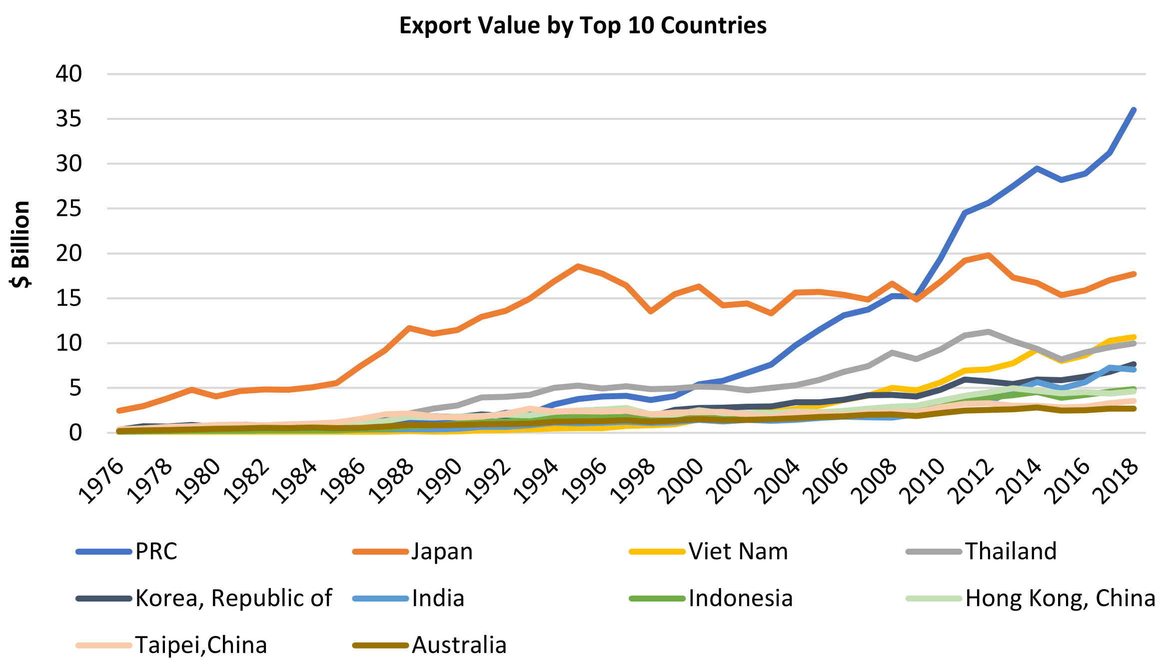
Source: FAO. WAPI-FISHCSP v.2018.1. http://www.fao.org/documents/card/en/c/CA0198EN/.

Figure 11: Export Volume and Value of Fish and Seafood by Region and by Top Ten Exporters





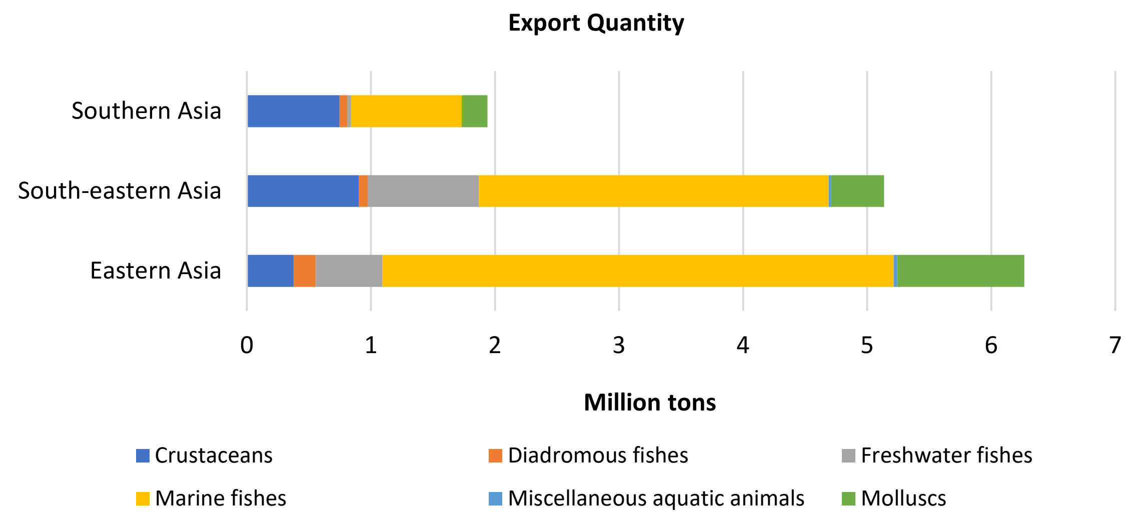


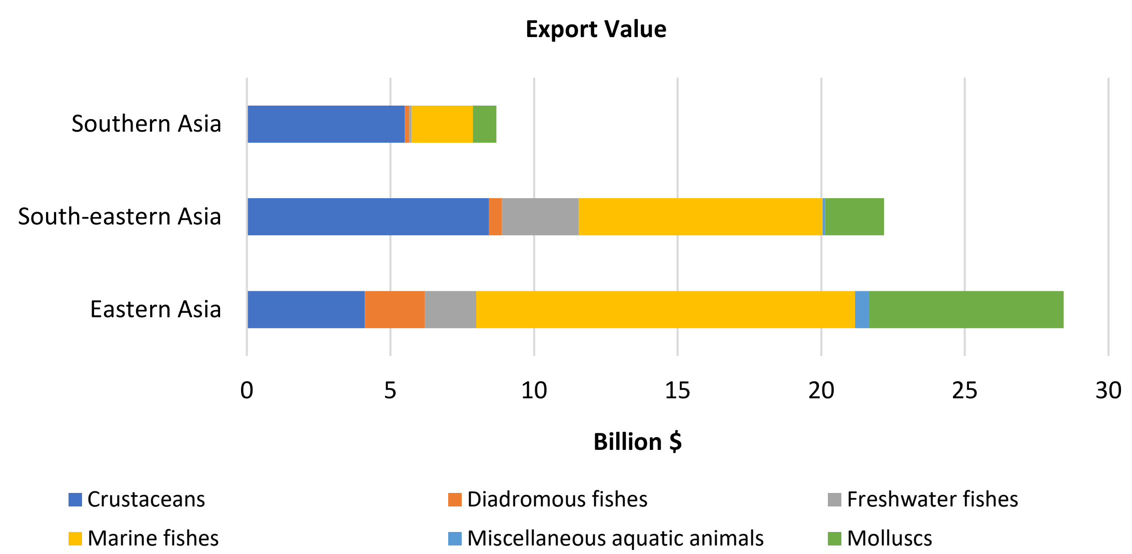


Note: Country groupings follow the definitions and standards used in FAOSTAT.

Source: FAO. FishStatJ. http://www.fao.org/fishery/statistics/software/fishstatj/en (accessed 30 August 2021).

Figure 12: Types of Fish Exported by Regions in 2018

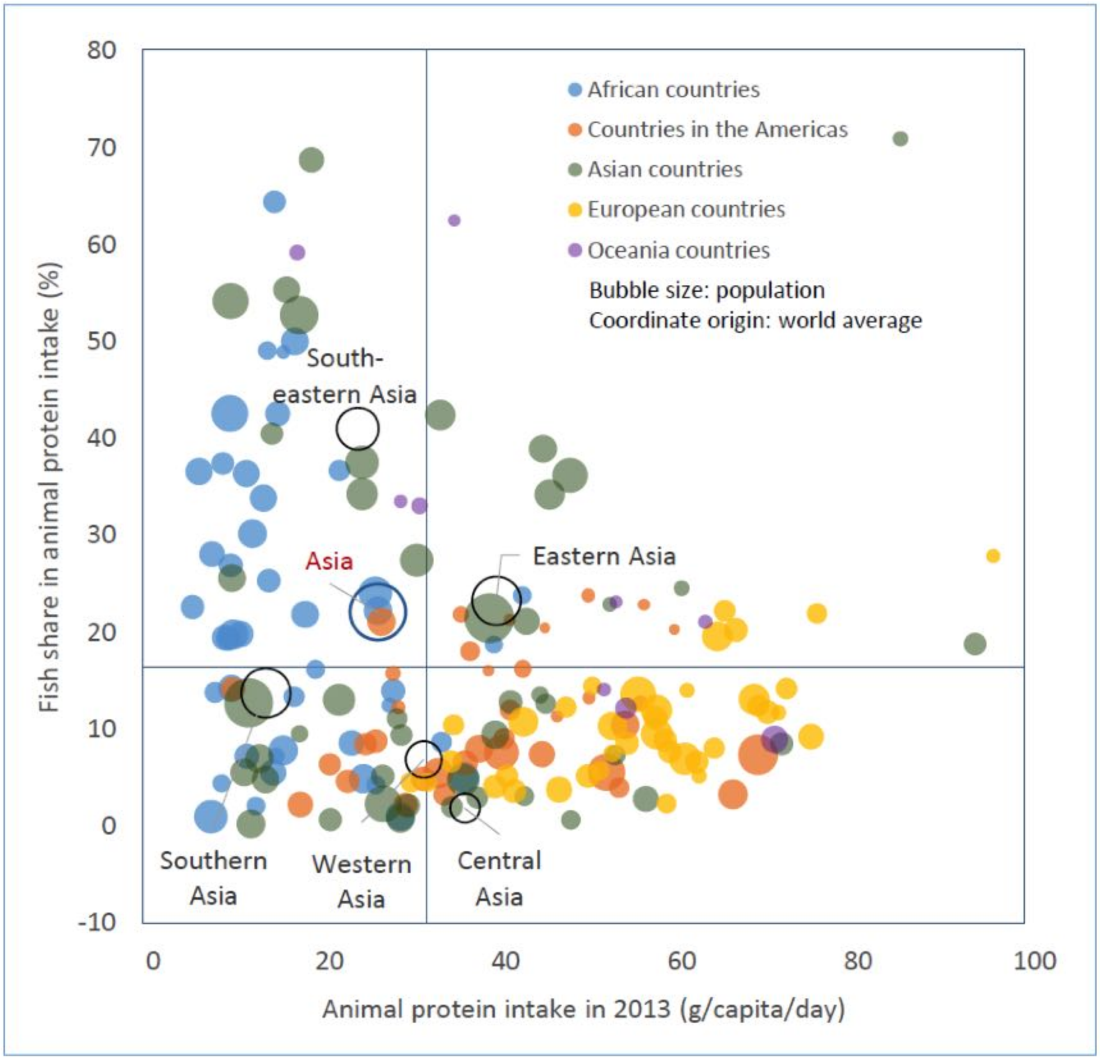




Note: Country groupings follow the definitions and standards used in FAOSTAT.

Source: FAO. FishStatJ. http://www.fao.org/fishery/statistics/software/fishstatj/en (accessed 30 August 2021).

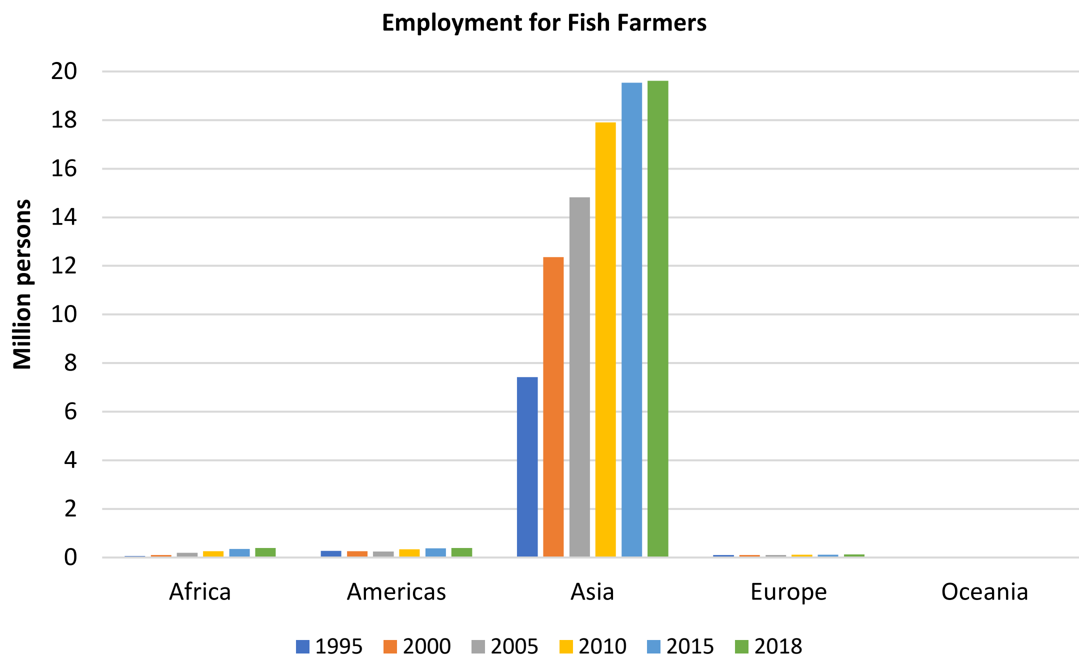
Figure 13: Share of Fish to Animal Protein Intake by Regions

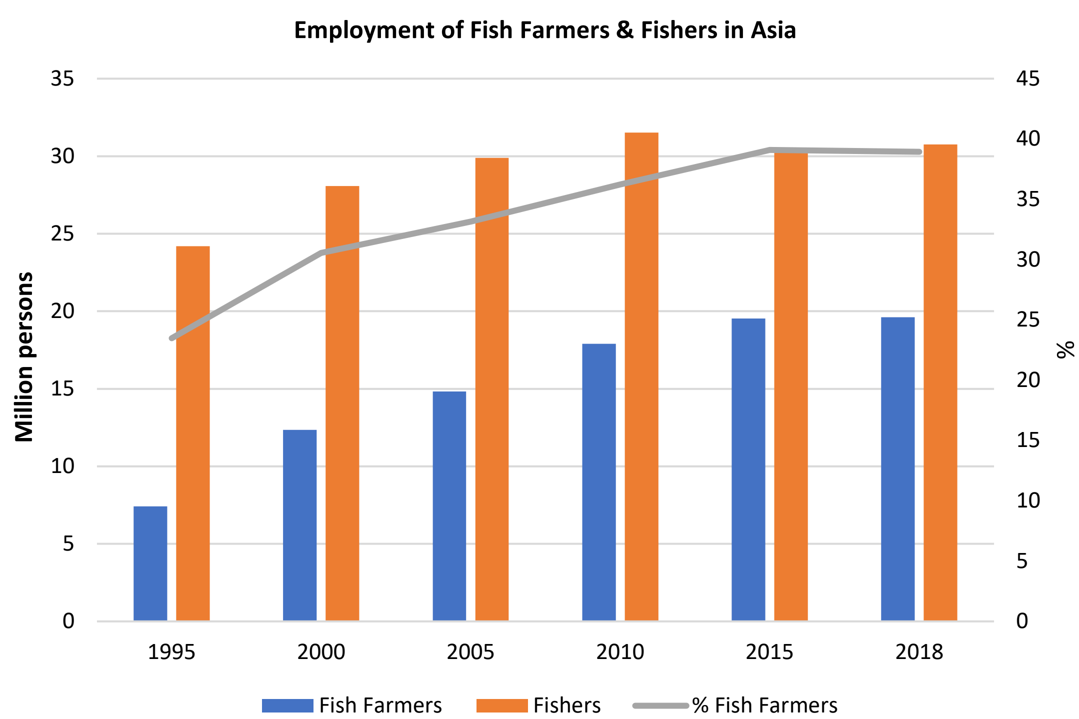


Note: Country groupings follow the definitions and standards used in FAOSTAT.

Source: FAO. Aquaculture Growth Potential in Asia: WAPI Factsheet to Facilitate Evidence-based Policy Making and Sector Management in Aquaculture. http://www.fao.org/fishery/statistics/software/wapi/en.

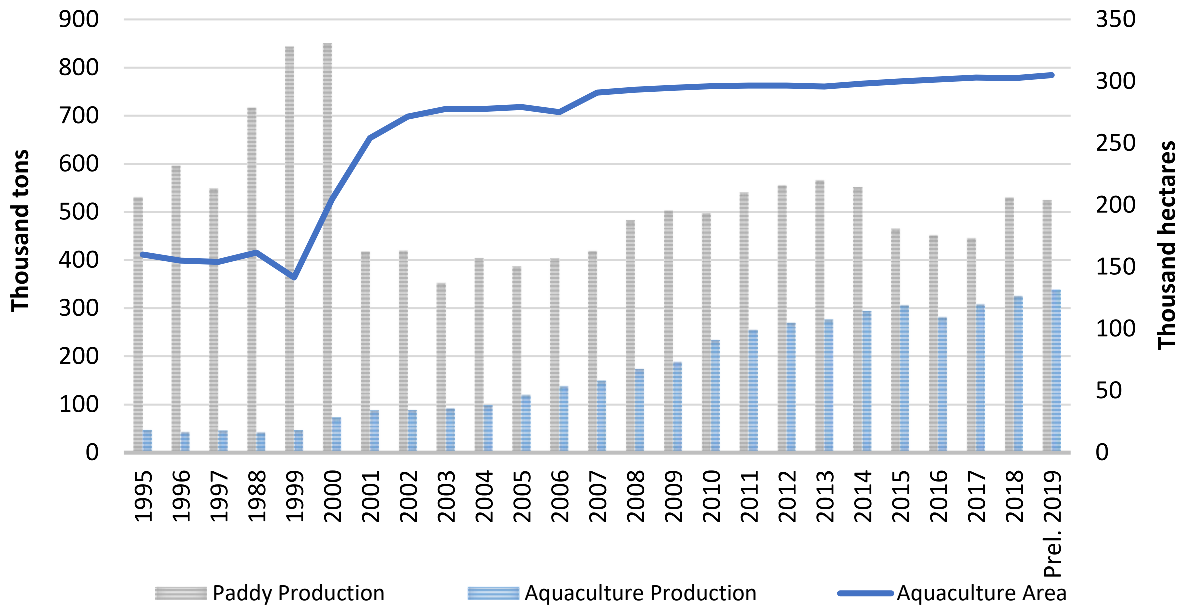
Figure 14: Employment Generated in Aquaculture Sector





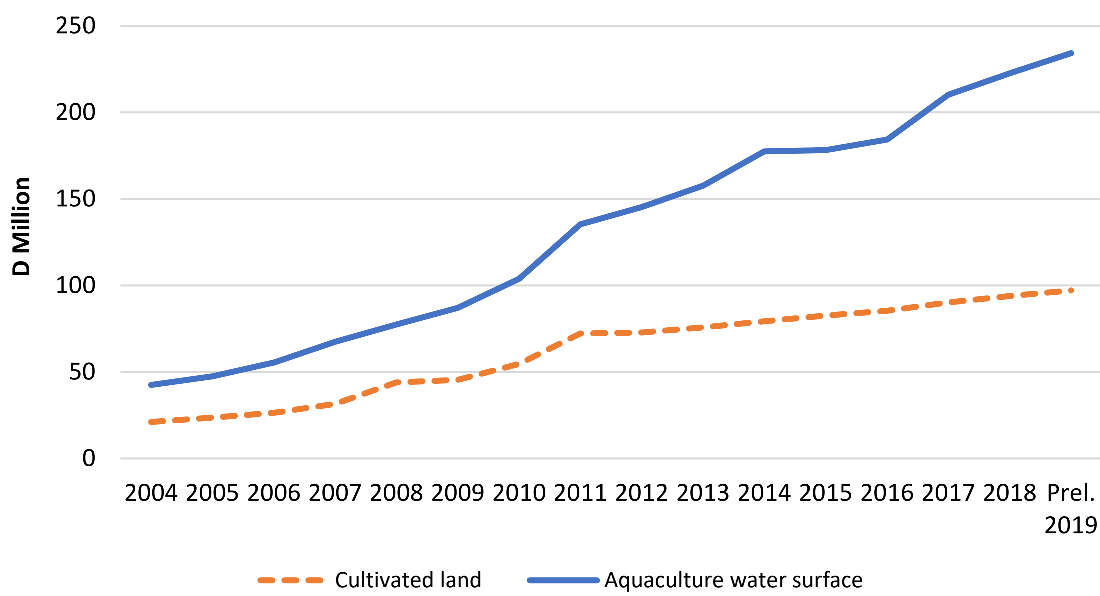
Source: FAO. 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Rome: Food and Agriculture Organization of the United Nations.

Figure 15: Production of Rice and Aquaculture and Aquaculture Area in Ca Mau, Viet Nam



Source: General Statistics Office of Viet Nam. 2020. Agriculture, Forestry and Fishery. https://www.gso.gov.vn/en/agriculture-forestry-and-fishery/.

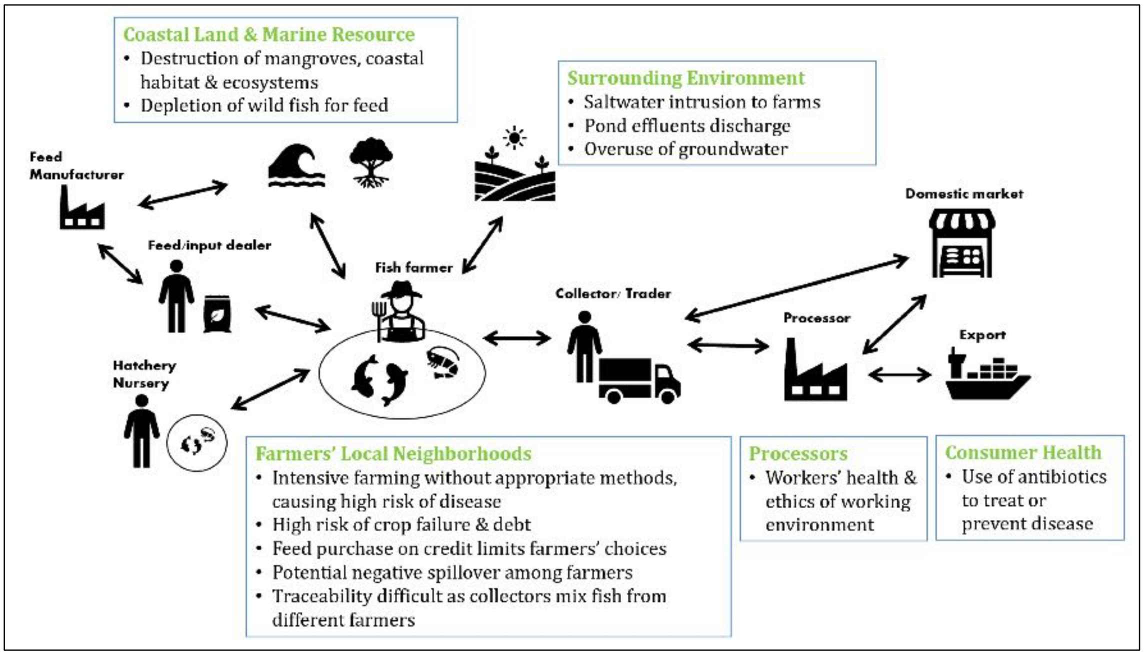
Figure 16: Gross Output of Product per Hectare in Viet Nam



D = dong.

Source: General Statistics Office of Viet Nam. 2020. Agriculture, Forestry and Fishery. https://www.gso.gov.vn/en/agriculture-forestry-and-fishery/.

Figure 17: Typical Market Structure of Fish Farming and Potential Effects on Surroundings



Source: Author.