# *The Premise*

*“The earth we abuse and living things we kill, in the end, take their revenge; for in exploiting their presence, we are diminishing our future.”*—Marya Mannes

*“The shining water that moves in the streams and rivers is not just water, but the blood of our ancestors . . . The rivers are our brothers, they quench our thirst. The air is precious to the red man, for all things share the same breath—the beast, the tree, the man, they all share the same breath . . . The earth does not belong to man: man belongs to the earth . . . All things are connected like the blood which unites one family . . . Whatever befalls the earth, befalls the sons of the earth. Man did not weave the web of life; he is merely a strand in it. Whatever he does to the web, he does to himself.”*—Native American Chief, Seattle

CHAPTER 1

# Understanding Forest Fires—The Global Fire Scene

*[This chapter discusses the increasing incidence and intensity of forest fires and associated haze in recent years, while underlining the uses of fires as an ecological agent and tool in land and forest management. The major causes of forest fires are analyzed, and the development of fire science and technology as a means of addressing devastating fires is traced. A brief account of international action in the field of forest fires and haze is also provided.]*

## The Burning Issue

The Report on Global Environmental Outlook 2000 prepared by the United Nations Environment Programme (UNEP) paints a devastating picture of the earth's health at the dawn of the new millennium. The planet is undergoing an unsustainable course of development, fueled by a relentless decline in the environment and degradation of natural resources.

Contributing to this decline are the uncontrolled and wildfires rampaging through lands and forests, affecting the environmental quality and ecological resilience of our habitat. Occurring in agricultural land, forests, and rural areas, spreading from one area to another, burning furiously, and causing heavy and suffocating haze, the fires that ravaged the Association of Southeast Asian Nations (ASEAN) region in 1997-1998 reached disastrous proportions. The environmental, economic, and social dimensions and impact of the catastrophic fires, and the associated transboundary atmospheric haze pollution, were profound. The haze caused by the conflagration in the ASEAN region and elsewhere was directly linked to important issues of land use and abuse, toxic contamination, biodiversity conservation, greenhouse gas emissions, and particularly to the importance of fire management within an overall regime of land resource management.

Experience indicates that the underlying causes of fires cannot be fully removed and there is no easy remedy. Hence, abatement through effective and integrated fire management assumes great relevance and urgency.

**Forest fires extending to the roadsides, Indonesia, 1997**

**Photo:** Anonymous

## Global Fire Occurrences

The annual rate of deforestation in developing countries during the 1980s was 16.3 million hectares (ha), while the corresponding figure for the developing countries of the Asian and Pacific region was 4.3 million ha. During the period 1990-1995, there was not much change in the rate of deforestation, standing at 13.7 million ha for all developing countries, and 4.2 million ha for forests of the Asian and Pacific region (FAO 1997). While several causes have been attributed to the alarming rate of deforestation, in the majority of cases, fire has played a decisive role (Mol et al. 1997).

Every year, millions of hectares of the world's forests are being consumed by fires, big and small, resulting in billions of dollars in suppression costs and causing tremendous damage in lost timber, falls in real estate and recreational values, property losses, and deaths. Wildfire is influencing many aspects of our life: the flow of commodities on which we depend, the health and safety of the communities in which we live, and the health and resilience of wildland ecosystems.

There are many forests seldom affected by fire, while others regenerate easily after burning. Some forests are subjected to high fire frequencies and heavy destructive impact. It is difficult to estimate the number and extent of forest fires and related annual losses. Comprehensive reports on losses are not available and forest fire statistics are often deficient (Goldammer 1997e).

## Prehistory of Fires

Wildfires have been present on the earth since the development of terrestrial vegetation and the evolution of the atmosphere. Lightning, sparks generated by swaying bamboos, and volcanoes have been some of nature's ways of igniting forests and keeping the plant environment dynamic. As a perfect relationship existed between fire and the ecosystem (Soares 1991), such natural wildfires occurred at long intervals.

Taking a cue from nature, early humans used fire as a tool to alter their surroundings and later to prepare land for cultivation. There is paleontological evidence to show that fires occurred in the prehistoric past. The mythology of many countries features accounts of fires dating back to several thousands of years.

The climate in the tropical Amazonian region is too moist to allow a forest fire to burn as long as the forests are in an undisturbed state. There is, however, evidence that in the remote past, forest fires did occur in the region. For example, Saldarrioga and West (1986) determined that the ages of charcoal fragments collected from the Venezuelan part of the Amazon ranged from 250 to 6,260 years old. Those fires were most likely associated with extremely dry periods or human disturbances (Reis 1996).

## Recent History of Fires

Since the 1960s, several fires have attracted world attention. The Parana fire in Brazil in 1963 burned 2 million ha, destroyed more than 5,000 houses, and claimed 110 lives (Reis 1996). With this started the new history of wildfires in Brazil, and a permanent worry, mainly with regard to the damage that fire can cause to forest plantations. The effect of fire on vegetation became an issue in 1988 following devastation to some parts of the Amazon forests. According to the World Wide Fund for Nature (WWF), large-scale logging and forest fires have contributed to the wiping out of some 12-15 percent of the Amazon rain forest. Satellite imagery from the Advanced Very High Resolution Radiometer (AVHRR) satellite, interpreted by the Brazilian National Institute for Space Studies, indicated that 20.5 million ha of Brazil's Legal Amazon (which covers an area of 500 million ha) was burned in 1987, of which about 8 million ha was considered to be

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Each year, fires in the Brazilian Amazon burn an area larger than Rio de Janeiro state. Ranchers and subsistence farmers ignite their lands in an attempt to convert forests into fields and to reclaim pastures from invading weeds. Subsistence farmers have migrated from all parts of Brazil to the fringes of the rain forest, lured by government promises of free land and a better life. But despite the lushness of the nearby forest, the soil is too poor to support intensive agriculture. They arrive armed with hope and chainsaws, clearing and burning land to farm the poor soil.

The fires set by ranchers and subsistence farmers often get out of hand, inadvertently burning forests, pastures, and plantations (WCFSD 1999).

The results of a seven-year study conducted by the Woods Hole Research Center in Massachusetts, US, suggest that the Amazon rain forest is experiencing an acute drying, leading to increased susceptibility to fire. Recent tests involving digging for water at many sites found dry ground, while similar tests seven years earlier revealed water close below the surface (Reis 1996, WCFSD 1999).

During the last four years, unusual weather conditions (and global weather changes) have led to fires in several parts of the world

Statistics in the People's Republic of China (PRC) reveal that between 1950 and 1990, 4,137 people were killed in forest fires (Goldammer 1994a). In the same period, information from satellites reveals that about 14.5 million ha of forest were affected by fires in the neighboring Soviet Union, predominantly burning in the Siberian boreal forests, which have a composition similar to the northeastern PRC (Cahoon et al. 1994).

The Kalimantan fire in Indonesia in 1982 burned about 5 million ha and caused losses amounting to $9.1 billion. Fires have swept through the forests of Kalimantan and Sumatra (also elsewhere) in Indonesia several times during the last two decades, engulfing millions of hectares and causing losses estimated at billions of dollars (Goldammer et al. 1996).

In 1983, the Ash Wednesday fire in Australia caused 76 deaths, killed 300,000 sheep and cattle, and burned more than 2,500 homes. The Great Black Dragon Fire of the northern PRC in 1987 burned around 1.3 million ha, destroyed more than 10,000 houses, and resulted in a death toll of about 200. The Yellowstone fire in the United States in 1988 almost completely burned out one of the world's most famous parks, costing about $160 million to suppress, and causing an estimated loss of $60 million in tourist revenues between 1988 and 1990 (Polzin et al. 1993). In the longer term, however, the increased biodiversity created by the fires in Yellowstone National Park may well yield benefits that outweigh these losses.

In 1982-1983, Cote d'lvoire in West Africa was swept by wildfires over a total area of about 12 million ha. The burning of some 40,000 ha of coffee plantations, 60,000 ha of cocoa plantations, and some 10,000 ha of other cultivated plantations had detrimental impacts on the local economy and left more than 100 people dead during this devastating fire period (Goldammer 1998b).

In the last four years, unusual weather conditions (and global weather changes) have led to fires in several parts of the world. Some of the conflagrations during 1996-1998 have been particularly damaging, as fires swept across the fragile rain forests of South America and two waves of forest fires gripped Indonesia, causing a national disaster.

Fires in Mexico and Central America have burned a reported 1.5 million ha. These have generated large quantities of smoke, which have blanketed the region and spread into the United States as far north as Chicago. From January to June 1998, about 13,000 fires burned in Mexico alone. Figures released by Mexican authorities in May 1998 indicated that a reduction of industrial production in Mexico City, which was imposed in order to mitigate the additional smog caused by forest fires, involved daily losses of $8 million.

Between December 1997 and April 1988, more than 13,000 fires burned in Nicaragua, the most in any Central American country, destroying vegetation on more than 800,000 ha of land. The Nicaraguan Ministry of Environment and Natural Resources recorded more than 11,000 fires in the month of April 1998 alone.

In July 1998, devastating forest fires affected more than 100,000 ha in eastern Russia. Coniferous forests burned in more than 150 locations around Vladivostok, Sakhalin, and Kamchatka peninsula. In Russia's Pacific island of Sakhalin alone, more than 25,000 ha of forest were consumed by fire during September 1998. The same year, forest fires in Florida, in the United States, burned an area of some 100,000 ha (Goldammer 1998b).

Fires burned the forests and pastures of Mongolia consecutively in each of the years between 1996 and 1998. The 1996 fires affected an area of 10.2 million ha, including 2.4 million ha of forests, in which 22 million cubic meters ($m^3$) of forest growing stock were lost. The 1997 fires affected more than 12.4 million ha, of which forests accounted for 2.7 million ha. This fire killed some 600,000 livestock while damage to the Mongolian economy was estimated at $1.9 billion (Chandrasekharan 1998a).

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### Fire Data

Reliable data on the occurrence of wildland fires, areas burned, and losses are available for only a limited number of nations and regions. Within the northern hemisphere, the most complete data set on forest fires is periodically collected and published for the member states of the Economic Commission for Europe, covering Canada, all western and eastern European countries, countries of the former Soviet Union, and the US. The last data set covers the period 1994-1996 (ECE/FAO 1997). In the European Union (EU), a Community Information System on Forest Fires has been created on the basis of information collected on every fire in national databases. The collection of data on forest fires (the common core) has become systematic with the adoption of a Commission Regulation in 1994.

The Community Information System on Forest Fires covers 319 provinces (departments, states) of France, Germany, Greece, Italy, Portugal, and Spain (European Commission 1996, Lemasson 1997). It contains information on 460,000 fires recorded between 1 January and 31 December 1995, involving a total of 6 million ha.

A global data set has been developed on the basis of active fires detected by the National Oceanic and Atmospheric Administration (NOAA) AVHRR sensor—the "Global Fire Product" of the International Geosphere-Biosphere Program under its subcomponent of Global Vegetation Fire Information (GVFI) System.

The fire data set includes all free-burning vegetation fires (wildfires in forests, savannahs, and other vegetation; prescribed burning), use of fire in agricultural systems (e.g., burning of

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agricultural residues, prescribed burning) and burning of plant biomass in households (fuelwood, charcoal, etc.).

## Fire Type Classification

Forest fire type classification is important in designing and implementing appropriate control measures. Forest fires are variously classified, based on:

- source of ignition: natural and human-made fires, which may result from carelessness and accident, or may be incendiary in nature (often using fire as a weapon instead of as a tool);
- size of area affected: large (e.g., more than 50,000 ha), medium, and small fires (irrespective of the nature of damage);
- intensity of burn and damage: very heavy, heavy, medium, and light fires (depending on fuel load and other factors [e.g., duration]); and
- nature of burn: underground fire (e.g., coal seams), ground fire (that consumes the organic materials beneath the surface litter), surface fire (that burns surface litter and other loose debris of the forest floor), creeping fire (that spreads overground), and crown fire (consuming the upper branches and foliage). Crown fires often burn the ground level vegetation and canopy of the forest, and are the most damaging.

Depending on the circumstances, weather, fuel load, undergrowth, etc., one form of fire may change into another or into a combination of different types. The impact of fire depends on the type.

## Fire Frequency and Intensity

Fire frequency and intensity are both a cause and an effect of ecosystem characteristics and are fundamental variables in the negative or beneficial effects of fire. However, every region has its own peculiarities and the role of fire varies not only between regions, but also within each region from habitat to habitat. A great deal has been learned from fire research and management in temperate and subtropical ecosystems. However, fire management practices found to be successful in these regions should not be applied automatically to the tropics.

### Fire Frequency

Fire frequency, measured as the return interval between fires, may be as short as one year or may extend into centuries. Fire frequency and intensity are not fully independent variables. Areas with short return interval fires tend to have less intense fires than areas with long return interval fires. Moreover, many ecosystems are subjected to low-intensity, short return interval fires as well as less frequent, high intensity fires. The relationship between frequency and intensity is complicated by a variety of factors such as vegetation structure, productivity, weather, and topography. Grasslands, for example, can support high intensity fires that burn annually.

A distinction is often made between fire frequency and fire incidence. Fire frequency is used to refer to the fire return interval at a particular location, whereas fire incidence is used to refer to the interval between fires that burn within a specified land unit, but not necessarily at the same point.

### Fire Intensity

It is difficult to provide a conventional definition for fire intensity. If the focus is on energetics or fire behavior, then fire intensity is best defined in terms of energy released per unit time per unit of fire front. If it is on carbon or nutrient cycling, or fuel reduction, then fire intensity is the energy or biomass consumed per unit area. These measures may or may not be of use to measure the impact of fires on ecosystem biota. For example, low intensity surface fires in ecosystems composed of vulnerable species result in substantial changes. In contrast, high intensity crown fires in savannahs or pine forests can simply stimulate reproduction of the same species, with little change in the overall composition of the ecosystem.

### Influencing Factors

A variety of environmental factors regulate fire frequency and intensity. Climate influences fire variations on a geographic scale. The frequency of lightning discharges and associated rainfall are the most important variables influencing ignition in some ecosystems. However, in others, humans have been able to and still do control the frequency of fire starts. In general, fire frequency increases inversely with moisture availability. On the other hand, in very dry areas, slow rates of biomass accumulation can result in longer fire return intervals.

Topographic diversity and vegetation patterns regulate fire frequencies in any given area. Vegetation also influences intensity. In many temperate ecosystems fuels tend to accumulate as vegetation ages. Such an accumulation is often associated with the production of hard and dense leaves and waste wood. Further, the quality and distribution of these fuels also change. In any case, such changes act as feedback mechanisms about the likelihood of ignitions.

Changes in vertical and horizontal fuel distribution associated with ecosystem development also affect fire frequency and intensity. Given sufficient time between fires, understory trees and debris form a vertical pathway, or "ladder," of fuels from the forest floor to the canopy along which fire may be carried into the crowns. Repeated burning tends to reduce fire intensity, though the long-term ecological consequences of such burning may vary.

Variations in fire behavior and frequency greatly influence post-fire vegetation development. In ecosystems with light to moderate intensity fires, and short return intervals, post-fire species composition may be quite similar to the pre-fire composition. In ecosystems with longer and perhaps less predictable return intervals, post-fire ecosystem response typically follows a classical species replacement series. The similarity between pre- and post-fire composition is also determined in some ecosystems by fire intensity.

Humans' historic role in changing fire frequency and intensity is variable. Human influence has generally resulted in an increase in fire frequency, but fire intensity increased or decreased in different vegetation types. In tropical regions, where human association with the vegetation has been more prolonged, this alteration of ecosystems from previously existing conditions may have been more dramatic. The growth of population and economic development have increased the damage caused by forest fires, and the fire cycle around the world has quickened—in some cases from more than 100 years to only three to four years, or even less. Also, in the West's coniferous forests and North's forests, fire suppression has resulted in substantial changes in fuel conditions. Although modern humans further increased the number of fire starts, the area burned by fires has declined in many vegetation types. Consequently, fuels have accumulated and fire intensities have risen. In the tropics, intentional burning for forest cultivation and agriculture has increased fire incidence (Goldammer and Odintsov 1998).

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## Factors Responsible

Analysis of causes is an important step toward designing control measures, management policies, and action. Historical perspectives provide an insight into future needs. There are predisposing factors or inherent conditions, as well as immediate causes that might result in wildfires and influence their frequency and intensity. These are often interrelated.

### Predisposing Factors

The predisposing factors are various and may include the following:

- economic (poverty and dependence of rural communities on forests for livelihood);
- demographic (increased population pressure on forests for their goods and services);
- meteorological (weather conditions including high temperature and lower atmospheric humidity);
- crop conditions (amount of canopy opening causing desiccation and water stress, nature and amount of ground vegetation, and fuel load);
- nature and condition of ecosystem (vegetational types, fire resistance level of component species, and locational topography);
- sociocultural (cultural significance of fire to the forest dwelling and rural communities); and
- institutional (lax environmental laws, inadequate enforcement capability, indifference of public administration to environmental matters, lack of dissemination of weather information and fire danger warnings, misuse of funds earmarked for fire protection, and management and policy weaknesses).

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### Immediate Causes

The contribution of natural fires to tropical wildland fires today is negligible. Most tropical fires are set or spread accidentally or intentionally by humans, and are related to several causative agents, some of them linked to subsistence livelihood, others to commercial activities (Goldammer 1997a, e). These include:

- deforestation (conversion of forests to other land uses, e.g., as agricultural land and pastures);
- land clearance and land preparation for agricultural crops;
- traditional slash-and-burn agriculture;
- grazing land management (fires set by graziers, mainly in savannahs and open forests with distinct grass strata);
- extraction of nonwood forest products (NWFPs) (using fires to facilitate harvests or improve the yield of plants, fruits, and other forest products, such as honey, resin, and antlers, predominantly in deciduous and semideciduous forests);
- wildland/residential area interface fires (fires from settlements, e.g., from cooking, torches, camp fires, etc.);
- other traditional fire uses (in the wake of religious, ethnic, and folk traditions; tribal warfare);
- socioeconomic and political conflicts over questions of land property and land-use rights, using arson;
- speculative burning to stake land claims; accidental fires (e.g., due to falling of dry leaves and twigs on high tension electricity lines); and
- fires introduced by design (e.g., prescribed fires) going out of control and becoming wildfires.

Another factor to be noted in this regard is the connection between population growth and deforestation. The 1995 world population stood at 5.7 billion, and is expected to grow to about 9.4 billion by 2050, with all the attendant impacts on natural resources.

How to obtain a respite from deforestation and forest fires and haze is a major management challenge.

### Fuel Loading

Air, temperature, and fuel are considered the three corners of a fire triangle. It is the volume, type, and condition of fuel that determine the rapidity and intensity of any fire. Moisture content in fuels could minimize the chances of a blaze, as moisture must evaporate to permit the temperature to rise to ignition point. The constant circulation of wind dries up the fuel, boosting chances of an outbreak and helping the blaze to spread.

The vegetation characteristics themselves are a major determinant of fire occurrences. Fuel-loading capacity in terms of plant density and plant lifeform combination (i.e., woody plants of various sizes and herbaceous plants, particularly grasses) determines the fire potential of vegetation. The soil substrate and its microorganism activity contribute to the fuel-loading capacity. If decomposition of the annually produced litter is slow, organic matter builds up at the soil surface. This is a leading cause of forest fires in temperate environments.

## Ignition Source

Fire in the tropical rain forests is often related to forest clearing for agriculture, industrial timber plantations, and other land-use changes, of which three broad types can be distinguished.

- Shifting cultivation where land is allowed to return to forest vegetation after a relatively short period of agricultural use. Traditionally, shifting cultivation provided a sustainable base of subsistence for indigenous forest inhabitants and had little impact on forest ecosystem stability. Today, shifting cultivation is practiced by some 500 million people on a land area of 300 million-500 million ha (Goldammer 1993a) and is often unsustainable due to the increase in size of individual plots and shorter fallow periods.
- Temporary complete removal of forest cover in preparation for industrial timber plantations.
- Permanent conversion of forests to grazing or cropland, as well as other nonforestry land uses.

In all cases, clearing and burning initially follow the same pattern; trees are felled at the end of the wet season and the slash is left to dry for some time. The efficiency of the first burning is variable; often not exceeding 10-30 percent of the ground biomass due to the large amount of forest biomass in tree trunks and stumps. The remainder is tackled by a second fire or left to decompose.

The burning of primary or secondary rain forest vegetation for conversion purposes has accelerated in recent years. Such forest-clearing fires often escape and have been shown to often lead to large-scale wildfires in undisturbed rain forests under the right climatic conditions.

While a land fire (e.g., in farmlands) may lead to a forest fire, a distinction is often made between the two in view of the differences in their causes, impacts, control measures, etc. Forest fires and associated haze have damaging impacts, but not designed and controlled burnings.

Some ecologists assert that fire is nothing more than a secondary factor in the destruction of dense and moist rain forests, which will not burn unless interference causes inflammable materials to be present or accumulated. Logging can increase the susceptibility of tropical rain forest to fire, particularly when carried out in

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an unnecessarily destructive and wasteful manner or resulting in large gaps in the forest canopy. Such practices can cause the accumulation of flammable biomass, invasion by weed species, and desiccation of soil organic matter—all factors that make forests susceptible to wildfire.

A series of disturbances may also increase the susceptibility of rain forests to fire. For instance, the extended rain forest fires of 1989 in Yucatan (Mexico) that burned some 90,000 ha were the result of a chain of disturbances. In 1987, Hurricane Gilbert damaged and opened the closed forests, leaving behind unusual amounts of downed woody fuels. These fuels were then desiccated by the drought of 1988-1989, and the whole forest area was finally ignited by escaped land-clearing fires. None of these three factors, the cyclonic storm, the drought, or the ignition source, if occurring alone, would have caused a disturbance of such severity (Goldammer 1992a).

### Climate—An Aggravating Factor

Climate is a crucial control factor in fire occurrence and frequency, since it determines not only the vegetation, but also influences soil microorganism activity, and thus litter decomposition. In tropical lowland environments, litter decomposition is generally fast, and organic matter accumulation is rarely an important factor. However, climatic seasonality in terms of wetness and dryness is the most important parameter related to fire occurrence. Thus, a climate and vegetation analysis is imperative for an assessment of fire occurrence and frequency. Climatic seasonality does not manifest itself only on a month-to-month basis, but also in year-to-year variation (Mueller-Dombois 1978).

If precipitation falls below 100 millimeters (mm) per month, and periods of two or more weeks without rain occur, the forest vegetation sheds leaves progressively. In addition, the moisture content of the surface fuels is lowered, while the downed woody material and loosely packed leaf-litter layer contribute to the buildup and spread of surface fires.

Aerial fuels such as desiccated climbers and lianas become fire ladders potentially resulting in crown fires or “torching” of single trees.

The occurrence of seasonal dry periods in the tropics increases with distance from the humid equatorial zone, leading to more open, semideciduous, and deciduous forest formations. Such forests are subject to frequent fires (often annual, but sometimes two or three times a year), and fire-tolerant species tend to dominate. The main fire-related characteristics of these formations are seasonally available flammable fuels (grass-herb layer, shed leaves). The most important adaptive traits that characterize the vegetation include thick bark, the ability to heal fire scars, resprouting ability, and seeds that feature fire adaptations.

#### *Weather Variability*

Meteorologists, based on available thermometric record, have determined that four of the hottest years in history occurred in the 1990s—1990, 1995, 1997, and 1998. The first five months of 1998 were the planet’s hottest on record according to the scientists of the US NOAA. The *El Niño* phenomenon is considered to be the main reason behind the mercury ascent and is frequently blamed for major forest fires. About 93 percent of all droughts in Indonesia have occurred during an *El Niño* (Goldammer and Manan 1996). *El Niño* affects the global weather pattern, resulting in extreme dry conditions, which in turn leave forests parched and open to fires. Thus, while *El Niño* is not a source of fire, it aggravates the danger of fires in places where negligence and management lapses can lead to severe conflagrations. Some point out that *El Niño* has always been in existence, without frequently causing major forest fires in the past. This may be due to the existence of relatively undisturbed forest cover with dense canopies in most tropical ecosystems that prevented drying of the lower vegetative strata, particularly the ground cover.

### El Niño *Southern Oscillation and Global Weather*

*El Niño* is a periodic oceanographic phenomenon in which a strong and extensive warming occurs in the upper ocean in the tropical eastern Pacific, upsetting weather patterns globally. The *El Niño* effect leads to the strengthening of a warm ocean current called the equatorial countercurrent in the mid-Pacific, causing the entire weather mechanism to be disrupted. Rainfall is delayed, crops are adversely affected, and storms occur where they should not. Occurrence of *El Niño* is linked with a change in atmospheric pressure known as the Southern Oscillation, and the overall phenomenon is often called the *El Niño* Southern Oscillation (ENSO). ENSO consists of *El Niño*—a "warm phase" or a large warming in the equatorial Pacific Ocean—and *La Niña*—a "cool phase" in which surface waters of the central Pacific Ocean are colder than normal.

The typical global impact of ENSOs is the anomalous pattern of rainfall and temperature. The surface ocean in the central and eastern equatorial Pacific is normally colder than that in the western equatorial Pacific. In some years, however, the ocean is especially warm. This warming typically occurs around Christmas and lasts for several months. It is caused by a complicated atmospheric-oceanic coupling that is not yet entirely understood. During these warm intervals, fish are less plentiful (it was the fishers along the coasts of Ecuador and Peru that originally termed the phenomenon "*El Niño*" [Spanish for "the Christ child"]) (Goldammer 1997d).

In the eastern equatorial Pacific, the overlying air is heated by the warmer waters below, increasing the buoyancy of the lower atmosphere and fueling convective clouds and heavy rains. But the air over the cooler western equatorial Pacific becomes too dense to rise to produce clouds and rain—in other words, dry conditions result in Australia, Indonesia, and Philippines, while more flood-like conditions are caused in Ecuador and Peru. Over the past 50 years, 12 major *El Niños* have been recorded. The worst of these began in March 1997 and faded away in June 1998. Before this, the *El Niño* of 1982-1983 had been the most severe (See Box 1, and Figures 1 and 2).

According to scientists, the frequency and intensity of *El Niños* are on the increase. In the 19th century, *El Niño* appeared on average every seven-and-a-half years; now it comes at intervals of less than five years. The reasons for this increased frequency are not clear. There is a suggestion that the recent mood swings of *El Niño* have been due to climatic changes and global warming, with greenhouse gases, mainly carbon dioxide, the most dominant factor in the global weather changes (Goldammer 1997f and 1998a).

In contrast to *El Niño*, *La Niña* ("the girl child") is associated with unusually cool ocean temperatures across the central and eastern equatorial Pacific. This generally causes sharp reversals of weather patterns around the globe and occurs roughly half as often as does *El Niño* (only six major *La Niñas* have been recorded in the past 50 years). In *La Niña* years, monsoons are enhanced over Australia and Southeast Asia, but the central equatorial

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BOX 1

## Walker Circulation

In the 1920s, Sir Gilbert Walker made the seminal connection between barometer readings of air pressure at sea level at stations on the eastern and western sides of the Pacific Ocean. He observed that when pressure rises in the east, it usually falls in the west, and vice versa. This effect, which explains the *El Nińo* phenomenon, is referred to as the Walker Circulation. Walker and his team analyzed weather records until they found patterns of rainfall in Latin America that could be associated with changes in ocean water temperatures.

In the warm Indonesian archipelago, extensive burning of vegetation (from shifting cultivation, forest conversion, and other agricultural burnings) takes place. Although the impacts of these fires on atmospheric chemistry have not yet been explored, it is assumed that two major patterns of emission take place based on Walker Circulation. During the "high phase" (normal years) of the Walker Circulation, low pressure is centered over the Indonesian hot spots. Air masses with products from biomass burning (aerosols, trace gases) are carried to the high troposphere and exported globally. During the "low phase," the warm waters from the west are transported to the eastern Pacific, and high pressure builds up over the Indonesian archipelago. A typical situation develops during which emissions from biomass burning are trapped in the lower troposphere.

The last few years, with extraordinary fires in Indonesia, have been characterized by the low phase of the Walker Circulation. (Anon 1997a, Goldammer 1998b)

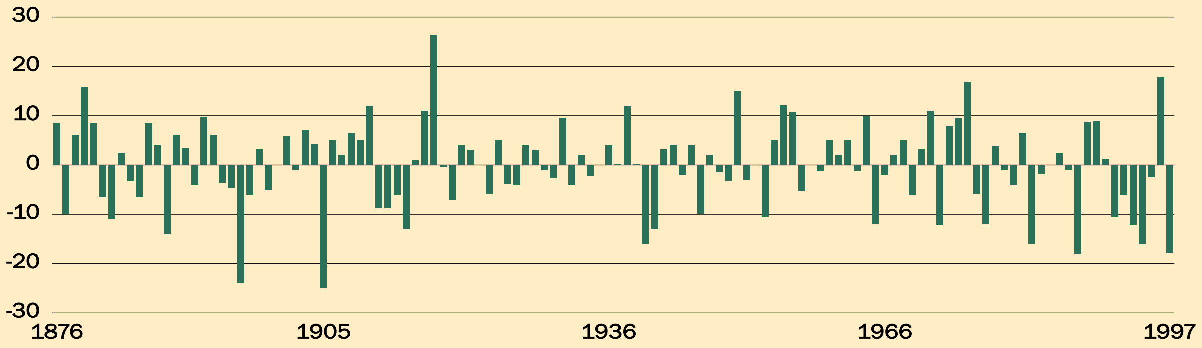
Pacific becomes drier than usual, a reverse of the *El Niño* effects. *La Niña* does not necessarily follow hard on the heels of *El Niño*. However, it has done so three times in the past 15 years. In general, slightly higher than normal rainfall has been recorded during *La Niña*; but in certain years the amount of rainfall can be much higher than in *La Niña* years (Nicholls 1993).

The last *La Niña* started to develop in mid-1998. Unusual climate conditions in 1998 that may be associated with *La Niña* included dry weather in parts of South America; wetter than normal conditions in northern Australia and the Philippines; above-normal rainfall during the southwest monsoon in India; increased hurricane activity in the Caribbean and Central America; dry spells in parts of Argentina and Chile; above-normal rainfall in southern Africa, with the exception of Zimbabwe; and possibly drier than normal conditions in the Horn of

FIGURE 1

## Visitations of *El Nińo*

**There have been 20 ENSOs in the 120 years since 1877. There is now much debate surrounding the idea that the frequency and intensity of ENSOs are increasing, and there is some evidence that this has been the trend in the past 20 years.**



The figure shows the *El Nińo* Southern Oscillation Index (ENSOI) six monthly average (April–September) for the years 1876–1997.

Source: MOE-UNDP 1998.

Africa. Several governments took steps to prepare for the 1998-1999 *La Niña*, including upgrading drainage systems, limiting development in high-risk areas, and improving flood control.

### *Impacts of* El Niño

In 1982-1983, *El Niño* caused worldwide destruction, particularly severe flooding and extensive damage in Latin America and droughts in parts of Asia. In Australia, forest fires destroyed thousands of houses and took countless lives in the *El Niño* season of 1982. The total damage wreaked by the 1982-1983 *El Niño* phenomenon globally was estimated to be between $8 billion and $13 billion, with about 2,000 lives lost. In 1991-1992, the effects of *El Niño* led to severe drought in Southern Africa, bush fires in Australia, and forest fires in Indonesia . During 1997-1998, *El Niño* spread from the Pacific to vast areas in Australia, Asia, and Africa. It caused severe droughts in Australia, Indonesia, Papua New Guinea, and Philippines; led to famine in southern Africa, and hurricanes in Mexico and the southern United States. This *El Niño* fueled forest fires in Indonesia, Malaysia, and Thailand, as well as in the Amazon.

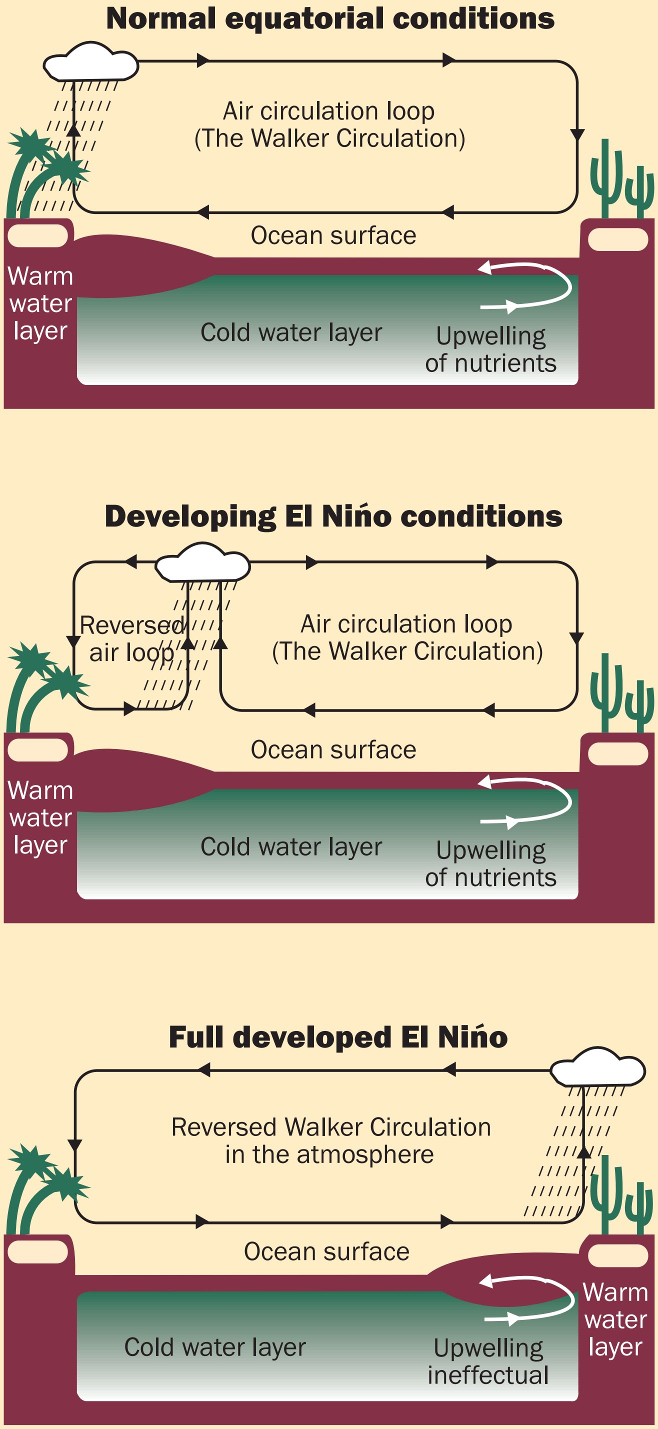
The recent devastation caused by *El Niño* has added a new urgency to a long running scientific mission: the quest to be able to forecast weather precisely, and to understand the causes and effects of unusual climate swings.

## The Array of Impacts

The burning of forests and biomass has serious impacts, direct and indirect, often resulting in loss of life, livestock, and capital. The damage caused by fire is often difficult to quantify, especially when nontangible losses are involved. The impact of forest fires has several dimensions—environmental/ecological, social,

FIGURE 2 **The Walker Effect**

**Change in the temperature of the sea affects wind patterns, which affect weather globally.**



**Normal equatorial conditions**

**Developing El Nińo conditions**

**Full developed El Nińo**

Source: Institute of Ocean Sciences, Canada, *Down to Earth*, December 1997.

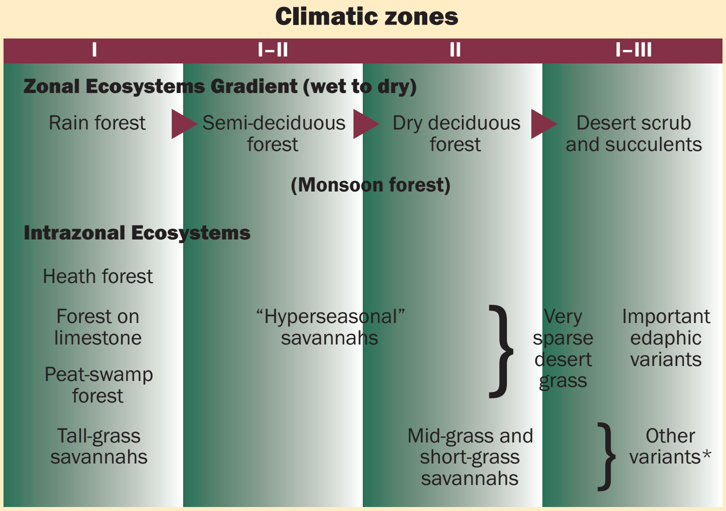
Tropical lowland rain forests are essentially nonflammable vegetations, but once invaded by grasslands they become easily degraded by frequent fires

economic, and others, which could be onsite and offsite. The extent of these impacts depends on the frequency and intensity of fires, fuel load, type of forest involved, and climatic factors.

### Ecological and Environmental Impacts

The ecological impact of forest fires is manifest in the degradation of the quality of vegetation; expansion of savannah and sterile grasslands; erosion of biodiversity; damage to the health of forest ecosystems; plant mortality; loss of wildlife habitat; air, river, and estuary pollution; and overall ecological retrogression. Some authors point out that as humans ascend the ladder of civilization, their needs grow in arithmetical progression and the corresponding pollution grows in geometrical progression (Muralikrishna 1999). Fires affect the quality and productivity of soil by destroying humus and altering its chemistry, increasing soil temperature, attacking microbial inhabitation, reducing moisture retention capacity of the soil, causing erosion of surface soil and nutrient loss, increasing runoff, lowering the subsoil water table, and causing desertification—ultimately reducing the carrying capacity of the land involved.

FIGURE 3 **Generalized Spatial Gradient of Tropical Ecosystems**



*Mostly anthropogenic.
Source: Mueller-Dombois 1978.

#### *Influence on Ecosystems*

Fire has been, and continues to be, particularly destructive in tropical Africa, while high fire frequency in tropical Australia has resulted in a generally more fire-adapted vegetation. Tropical lowland rain forests are essentially nonflammable vegetations, but once invaded by grasslands they become easily degraded by frequent fires, destroying a good portion of their floristic and ecological potential. Slash fires following logging increase the fire hazard in tropical forests because they promote the establishment of fire-prone grasses. Therefore, fire as a management tool has a different outcome in tropical as compared to temperate forests.

Within the tropics (from latitudes 23° N to 23° S), three types of tropical lowland climate are recognized:[1] the humid tropics (I), the subhumid or semidry tropics (I-II), and the dry tropics (II). The three tropical climate zones are based on mean monthly rainfall and temperature distribution. These three zones correspond roughly to the potential terrain of the three zonal forest types: tropical rain forest (zone I, extending to about 10° N and 10° S of the equator in tropical America, Africa, and Southeast Asia), semideciduous forest (zone I-II, recognized as a broad climatic transition zone in tropical America and Africa, but almost absent in Southeast Asia), and dry deciduous forest (zone II, which is the largest tropical climate type). Zone III represents edaphic (soil-influenced) and other variants.

A generalized spatial gradient of the tropical ecosystems is shown in Figure 3.

Zonal tropical rain forests occur typically on well-drained, deeply weathered lateritic[2] clay soil (oxisols and ultisols), which contain little organic matter and nutrients. These soils are highly acidic (generally pH 4.2-5.6) and contain poor oxide clays with low exchange capacities. They commonly undergo irreversible drying when exposed to strong desiccation.

Whitmore (1984) described several other tropical lowland rain forests that occur on quite different soils. These are the tropical heath (Karangas) forests on podzolized[3] sands; the rain forests on limestone, ultrabasic (serpentine) rock, calcareous sand and coral rocks along beaches; and peat-swamp forests. All are significant edaphic variants, which can be treated as intrazonal forest types in the tropical rain forest terrain.

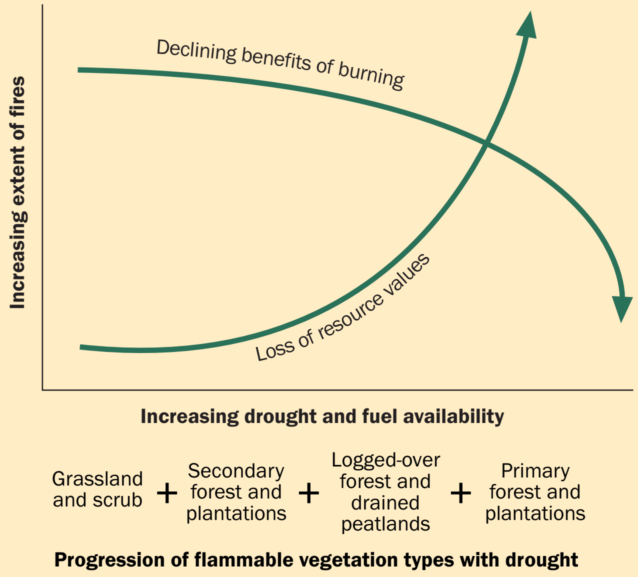
Peat-swamp forests are an important rain forest type in Southeast Asia (Whitmore 1984), as well as in tropical America and Africa (USDA-FS 1981). In spite of their often turflike accumulation of organic matter, natural fires have apparently not been observed in this edaphic variant of the tropical rain forest. Savannahs are the most widespread tropical vegetation type today, with different subtypes due to edaphic variations in the tropical seasonal environments.

It is not proposed to go into the details of various types of vegetation. In all cases, however, it is necessary to have a clear idea about the positive and negative roles of fire. Figure 4 provides an illustrative case.

## Release of Greenhouse Gases

Forest fires contribute to global climate change and warming. Burning of forests also destroys an important sink for atmospheric carbon. Biomass burning is recognized as a significant global source of emissions contributing as much as 10 percent of the gross carbon dioxide and 38 percent of tropospheric ozone (Goldammer and Seibert 1990, Landsberg 1997).

FIGURE 4 **Conceptual Diagram of Losses and Benefits of Forest Fires in Indonesia**



Source: IAP Working Group, Indonesia, 1999.

Depending upon the severity of annual burning and the weather, the emission products added to the atmosphere from biomass burning amount to 220-13,500 gigatons (Tg) of carbon dioxide, 120-680 Tg of carbon monoxide, 2-21 Tg of nitrous oxides, and 11-53 Tg of methane gas. The situation, obviously, is not very comforting. According to one estimate, in just a few months the burning that took place in 1997 in Indonesia released as much greenhouse gases as all the cars and power plants in Europe emit in an entire year (Kristof 1997). Scientists have estimated that from 1850 to 1980, between 90 billion and 120 billion metric tons (mt) of carbon dioxide were released into the atmosphere from tropical forest fires.

In comparison, during that same time period, an estimated 165 billion mt of carbon dioxide were added to the atmosphere by industrial nations through the burning of coal, oil, and gas.

In just a few months the burning that took place in 1997 in Indonesia released as much greenhouse gases as all the cars and power plants in Europe emit in an entire year

According to recent estimates, some 1.8 billion-4.7 billion mt of carbon stored in vegetation may be released annually by wildland fires and other biomass burning (Crutzen and Andreae 1990). However, not all of the biomass burned represents a net source of carbon in the atmosphere. The net flux of carbon into the atmosphere is due to deforestation (forest conversion with and without the use of fire) and has been estimated by Houghton (1991) to be in the range of 1.1 billion-3.6 billion mt per year.

Wildfires burning in radioactively contaminated vegetation lead to uncontrollable redistribution of radionuclides, e.g., the long-living radionuclides caesium ($^{137}Cs$), strontium ($^{90}Sr$), and plutonium ($^{239}Pu$). In the most contaminated regions of Belarus, Russian Federation, and Ukraine, the prevailing forests are young and middle-aged pine and pine-hardwood stands with high fire danger classes. In 1992, severe wildfires burned in the Gome region (Belarus) and spread into the zone of 30 kilometers (km) radius around the Chernobyl Power Plant. Research reveals that in 1990 most of the $^{137}Cs$ radionuclides were concentrated in the forest litter and upper mineral layer of the soil. In the fires of 1992, these radionuclides were lifted into the atmosphere. Within the 30-km zone, the level of radioactive caesium in aerosols increased 10 times (Dusha-Gudym 1996).

Smoke emissions from wildfires affect human health, particularly causing respiratory ailments, and in some cases, disease and death

### *Combustion Products*

The immediate effects of burning are the production and release of gases and particulates into the atmosphere, affecting its chemistry. The instantaneous aerial combustion products of burning vegetation include carbon dioxide, carbon monoxide, methane, nonmethane hydrocarbons, nitric oxide, sulfur oxide, methyl chloride, polycyclic aromatic hydrocarbons, and other gases that are released and returned to the atmosphere in a matter of hours. The greenhouse gases, viz. carbon dioxide and methane, influence global climate, while combustion particulates also affect global radiation. Methane, nonmethane hydrocarbons, and nitric oxide are all chemically active gases that affect the oxidizing capacity of the atmosphere and lead to the photochemical production of ozone in the troposphere. Recently, it was discovered that biomass burning is also an important global source of atmospheric bromine in the form of methyl bromine. Bromine leads to the chemical destruction of ozone in the stratosphere and is about 40 times more efficient in the process than chlorine on a molecule-to-molecule basis. Burning also enhances the biogenic emissions of nitric oxide and nitrous oxide from soil. Biomass burning affects the reflectivity and emissivity of the earth's surface as well as hydrological cycle by changing rates of land evaporation and water run off (Crutzen and Goldammer 1993; Goldammer 1993a; and Anon 1997a, 1998).

Combustion products are a significant source of transboundary atmospheric pollution. The smoke cloud due to fires in the Amazon area showed up on satellite images on 24 August 1995 spread over an area of 7 million km$^2$ covering all of Brazil's Amazon region and parts of Columbia and Paraguay. The concentration of atmospheric particle pollution in some areas in Mato Grosso, Brazil, reached 900 micrograms (µg) per m$^3$, three times higher than the safe level.

## Social Impacts

Apart from causing transboundary air pollution, smoke emissions from wildfires affect human health, particularly causing respiratory ailments, and in some cases, disease and death.

They also cause visibility problems, which may result in a breakdown of communication systems, accidents, and economic loss. Other social impacts include damage to energy and electric installations, disruption in the supply and distribution of food, displacement of people from affected areas, and temporary closure of educational establishments and production units.

## Air Quality and Health

The main constituent of the smog that adversely affects health is particulate matter. The "WHO [World Health Organization] Health Guidelines for Episodic Vegetation Fire Events" that arose from the meeting of experts held in Lima, Peru, 6-9 October 1998, stressed the necessity of ground-based air quality monitoring of particulate matter in all countries affected by regional haze from vegetation fires. Ideally, $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 microns) should be measured since that size fraction has a significant health impact. If that is not possible, $PM_{10}$ or total suspended particulates (TSP) should be measured. The WHO draft document also recommends that additional pollutants such as ozone, nitric oxide, sulfur dioxide, carbon monoxide, aldehydes, and polyaromatic hydrocarbons be measured, if possible, to provide a comprehensive assessment of the health risks resulting from exposure to haze components. Measurement of carbon monoxide, carbon dioxide, and TSP would also allow some partitioning of smoke into flaming and smoldering sources and evaluation of the biomass particulate conversion ratio.

As the concentration of airborne particles rises, a corresponding rise in hospital admissions (and even deaths) is noted. Even though evidence is piling up increasingly on the lethal effects of particles, scientists are yet to fathom the extent of damage they can cause to public health. (See Boxes 2 and 3.)

### Economic Impacts

Fire is one of the least expensive and simplest tools for preparing land for growing agricultural crops. However, once out of control, it can lead to long-term site degradation and other detrimental impacts. Fire can thus be a source of positive and negative impacts—the reason why rural societies

Fire can be a source of positive and negative impacts—the reason why rural societies considered fire as a good servant, but a bad master

## BOX 2 The Air Quality Standards for $PM_{10}$ Set by International Agencies

| Agency | Standard | Time Period |
|---|---|---|
| ALA (proposed) | 10 μg/ $m^3$ | Annual average |
| ALA (proposed) | 18 μg/ $m^3$ | 24-hour average |
| US EPA | 50 μg/ $m^3$ | Average annual ambient standard |
| US EPA | 150 μg/ $m^3$ | 24-hour average |
| United Kingdom | 50 μg/ $m^3$ | 24-hour average |
| Indian Standard | 60 μg/ $m^3$ | Annual average |
| WHO | 70 μg/ $m^3$ | 24-hour average (European Ambient Air Quality Guideline) |

Note: All figures in micrograms per cubic meter (μg/$m^3$).
Source: Deadly Particles, *Down to Earth*, 15 December 1999.

### BOX 3 Pollution and Mortality

Possible biological mechanisms by which pollution causes death include the following:

- increased susceptibility to infection from impaired immune defenses;
- airways inflammation leading to impaired gas exchange and hypoxia (deficiency of oxygen reaching the tissues of the body);
- provocation of alveolar inflammation by ultrafine particles with the release of mediators that exacerbate underlying lung diseases and increase blood coagulation;
- increased lung permeability leading to pulmonary edema (excessive accumulation of fluid on the lung tissues); and
- precipitation of heart failure in those with chronic heart disease by acute bronchitis or pneumonia induced by pollution.

Source: *Particles in Our Air: Health Effects and Concentrations*, edited by Richard Wilson and John Spengler, Harvard University Press, US, 1996.

considered fire as a good servant, but a bad master.

Apart from loss of material goods and services, forest fires cause serious direct economic losses through damage and decline in the quality of forest growing stock, reduced landscape stability, increased proneness to pests and diseases, reduced availability of forest-based raw material supplies, and the need for new investments in forest rehabilitation and fire protection. Indirectly, they affect agricultural productivity and tourism, indigenous populations and their means of livelihood, and jeopardize the prospects and ability of the rural poor to improve their standard of living.

Forest fires can also degrade other surviving forests by exerting impact on their composition, regeneration, productivity, protection functions, soil quality, wildlife, and aesthetics.

By 1990, conversion of tropical forests—much of it accomplished by open burning—had reached an estimated rate of 1.8 percent of the earth's total forestland per year

### Fire in Land and Forest Management

Controlled use of fire has been an important aspect of land and forest management. Methods and techniques have progressively evolved to suit the types of land and the nature and scale of operations, covering all aspects of fire management—prevention/protection, mitigation, suppression, damage control, and rehabilitation. There have been considerable improvements in fire management techniques, mainly in industrialized countries, through the use of sophisticated tools and equipment.

While land clearing for agriculture and estate crops has taken place on an increasing scale, a new dimension was added to forest management around the middle of the 19th century, when tree plantations were raised under a system of clear felling the natural forests and artificially regenerating them—essentially for commercial and industrial purposes. The commercial potential of the tropical forests also promoted increased rates of extraction; and the conventional and conservative "selection systems" in many cases were deliberately set aside (or diluted).

Since the beginning of the industrial revolution, humans have transformed about 40 percent of the earth's land surface. By 1990, conversion of tropical forests—much of it accomplished by open burning—had reached an estimated rate of 1.8 percent of the earth's total forestland per year. In absolute terms, this amounts to about 14.2 million ha. The implications of open burning on this scale for the global environment are startling.

A healthy forest is one that is resilient to changes. The term ecosystem health is used to define the structural and functional stability of an ecosystem and its ability to bounce back after stress (Gupta and Yunus 1998). Forest fire management is an important aspect of sustainable forest management, ensuring the health of forest ecosystems, and that negative impacts of fire are minimized and positive impacts maximized.

## Fire Science and Technology

The years since World War II, particularly the recent past, have witnessed a series of achievements in the field of fire management science and technology. More are in different stages of development. Most remarkable progress has been made in the following fields.

## Detection and Monitoring of Fires

The amount of living vegetation, and its moisture content, has a strong effect on the propagation and severity of wildland fires. Observation and assessment of vegetation greenness is therefore essential for any system of fire danger rating. Current assessment of living vegetation moisture relies on various methods of manual sampling. While these measurements are quite accurate, they are difficult to obtain over broad areas, so they fail to portray changes in the pattern of vegetation greenness and moisture across the landscape.

Space-borne remote sensing technologies have improved the capability to identify fire activities at local, regional, and global levels by using visible and infrared sensors on existing platforms for detecting temperature anomalies, active fires, and smoke plumes.

Polar orbiting weather satellites provide the potential for delivering greenness information and other parameters needed for fire management and fire impact assessment with daily global coverage at coarse spatial resolution. This is achieved using wide-angle scanning radiometers with large instantaneous fields of view.

Short-return interval, low-resolution geosynchronous satellites such as the Geosynchronous Operational Environmental Satellite (GOES) (Prins and Menzel 1996) and polar orbiting sensors such as the NOAA AVHRR (European Commission 1996, Justice et al. 1996, Kendall et al. 1996) have been used successfully to establish calendars of vegetation state (fire hazard) and fire activities. Other satellites with longer temporal sampling intervals, but with higher resolution, such as LandSat, the French Earth Resource Satellite, SPOT, and space-borne radar sensors, deliver accurate maps of active fires, vegetation state and areas affected by fire. Because of its availability, spatial resolution, spectral characteristics, and low cost, NOAA AVHRR has become the most widely used satellite data set for regional fire detection and monitoring. Currently, AVHRR data are used for vegetation analyses and in the detection and characterization of active flaming fires, smoke plumes, and burn scars.

The middle-infrared and thermal AVHRR bands of the NOAA polar-orbiting satellites have been used for identifying fires.[4] Several techniques are used to detect active fires on regional scales using multispectral satellite data. A comprehensive validation of AVHRR active fire detection techniques through a range of atmospheric and surface conditions has not yet been performed. Several studies, however, have provided some level of validation.

### Limitations of AVHRR Fire Detection

Data are sensed by all channels simultaneously at 1.1 km spatial resolution. Data acquired by the instrument are resampled on board the satellite to 4 km spatial resolution and recorded for later transmission to one of the two NOAA Command Data Acquisition (CDA) stations, at Gilmore Creek, Alaska, and Wallops Island, Virginia. This is known as the Global Area Coverage mode of transmission. In addition, the full spatial resolution 1.1 km data can be recorded for previously scheduled areas of the world, in the Local Area Coverage mode, or can be received directly from the satellites by suitably equipped receiving stations in the High Resolution Picture Transmission mode.

Even in full configuration, with two NOAA satellites in operation, the AVHRR data provide

> Polar orbiting weather satellites provide the potential for delivering greenness information and other parameters needed for fire management and fire impact assessment with daily global coverage at coarse spatial resolution

only a limited sampling of the diurnal cycle. The orbital characteristics of the satellites result in two daytime and two nighttime orbits per location. The afternoon overpass provides the best coverage in terms of fire detection and monitoring in tropical and subtropical regions (Justice and Dowty 1994). In addition, the afternoon overpass enables detection of the full range of parameters described (i.e., vegetation state, active fires, burn scars, smoke).

Perhaps the most fundamental problem of AVHRR fire detection is that analysis is limited to relatively cloud-free areas. This can be a serious issue in tropical and subtropical regions. Cloud cover can cause an underestimation in the extent and frequency of burning, and limits the ability to track vegetation parameters. This issue is not limited to the NOAA satellite system. Dense clouds will prevent detection of the surface by all visible and infrared sensors. A satisfactory methodology for estimating the amount of burning missed through cloud obscuration has yet to be developed.

Improved fire weather forecasts are needed for forest fire management at various time and space scales

With the characteristics of the NOAA meteorological satellites, as described, it is possible to collect near real-time information to support fire management activities. (A fully automatic system has been developed to detect forest fires using data from NOAA AVHRR. The prototype system was developed in Finland and tested in four experiments in 1994 to 1997 there and in its neighboring countries).

### *Fire Weather and Seasonal Moisture Changes*

Since 1989, the use of a Normalized Difference Vegetation Index (NDVI) to monitor seasonal changes in the quantity and moisture of living vegetation has been investigated (Goward et al. 1990). Daily AVHRR data are composited into weekly images to remove most of the cloud and other deleterious effects, and an NDVI image of the continental US is computed by the US Geological Survey's Earth Resources Observation Systems (EROS) Data Center. These weekly images are obtained via the Internet and further processed into images that relate to fire potential (Burgan et al. 1996) and easily interpreted by fire managers. Four separate images are derived from the NDVI data—Visual Greenness, Relative Greenness, Departure from Average Greenness, and Live Shrub Moisture.

To improve the determination of spatial definition of fuel types requires use of a fire danger fuel model map. In the United States, the EROS Data Center has used a series of eight monthly composites of NDVI data for 1990 to produce a 159 class vegetation map of the continental United States at 1 km resolution (Loveland et al. 1991). Data from 2,560 fuel observation plots randomly scattered across the country have permitted the development of a 1 km resolution fuel model map from this. This is now being used to provide broad-scale fire danger maps.

Improved fire weather forecasts are needed for forest fire management at various time and space scales. At large time and space scales, accurate fire weather forecasts have the potential for long-range planning of allocation of scarce resources; at smaller time and space scales they have potential use in alerting, staging, and planning the deployment of fire suppression crews and equipment; at the smallest time and space scales, they can be helpful in fighting fires as well as determining optimal periods for setting prescribed silvicultural fires (Fosberg and Fujioka 1987; Roads et al. 1991, 1997).

Current US fire weather forecasts are prepared from short-range weather forecasts (one or two days) from the US National Center for Environmental Prediction (NCEP), other model output statistics, and human judgment. These fire weather forecasts include information about rainfall, wind, humidity, and temperature.

An experimental modeling system, developed at the NCEP for making short-range global to regional weather forecasts, is being developed at the Scripps Experimental Climate Prediction Center (ECPC). Although this system is focused on making and disseminating experimental global to regional fire weather forecasts for Southern California, it could easily be transported and applied anywhere else in the world.

#### *Circulation Models*

Global Circulation Models allow the integration of information crucial for assessing fire danger in a regionally or globally changed climate. This has been proven successfully for the boreal zone (Stocks and Lynham 1996, Stocks et al. 1997) and partially for tropical fire regimes (Goldammer and Price 1998).

#### *Burned Area and Emission Estimates*

The demands of forest inventory, land-use planning, and atmospheric chemistry studies require accurate knowledge of the amount of vegetation affected by fire, and the types of plants burned. High- and low-resolution sensors have proven successful in establishing reliable data sets on burned areas on a regional scale (Cahoon et al. 1994) and offer the opportunity to extend this method on a global scale.

## Technology Development

The integration of remotely sensed fire data with information obtained on the ground in geographic information systems (GIS) is increasingly being used in fire management-oriented systems (Chuvieco 1996). Remotely operated air vehicles (drones) offer reliable and safe means of information gathering for disaster-type fire situations.

A high-quality climate database is a prerequisite for modeling, including initialization, testing, and verification. Hazard ratings, haze monitoring, and prediction also require good knowledge of the state of the atmosphere, which can be provided only by meteorological observations of high quality (Tapper et al. 1998).

Communication systems for early warning information dissemination are generally advanced since they rely on the technology developed in the civilian telecommunication sector. Space-borne sensing and collection of real-time data for early fire warnings generally depend on systems that were not specifically designed for sensing fire precursors, active fires, and fire effects. A short overview of the most important sensors that are in use or are being built gives an indication of future possibilities.

### New Space-Borne Sensors

Remote sensing users, in addition to continuing experimentation and refinement of methods, need to provide operational monitoring data sets on regional and global scales to contribute to early warning of fire hazards, and to fire and smoke management. The development of operational automated monitoring techniques and the provision of consistent long-term data sets are challenges to be faced. Issues such as prohibitive costs of data, computing resources, data management, data archival, and distribution also need to be addressed.

Data set development is being undertaken using satellite sensing systems, which, as stated

The development of operational automated monitoring techniques and the provision of consistent long-term data sets are challenges to be faced earlier, were not designed for fire monitoring. The current suite of sensors suitable for fire monitoring have problems such as calibration, saturation, spatial resolution, orbital overpass time, and coverage, which need to be taken into account in data processing and data set compilation. It is critical that users fully understand the limitations of the data and their utility. New sensors are being designed and built that will reduce or eliminate some of these problems, but they will introduce new, and in some cases, unanticipated, ones instead. The development of new satellite data sets is an iterative process that needs to be undertaken in close collaboration with the users. The planned systems will provide a challenge in terms of presenting the amount of raw data in a suitable volume and level of information content (Goldammer 1998b, IDNDR 1997). New sensors being developed, such as the Moderate Resolution Imaging Spectroradiometer, are aimed at satisfying the demands of fire science and management.

Several international statements, commitments, and declarations on development and sustainable forest management have flagged the need to mitigate and manage forest wildfires

#### Challenges

Early warning, monitoring, and inventory of wildfires need to be accompanied by monitoring and inventory of ecological characteristics that lead to fire. Disturbances, such as insect or disease outbreaks, wind throw of trees, industrial forestry, and conversion of forests to other uses are frequently precursors to fires.

Pests and diseases stress ecosystems, resulting in production of dead matter, particularly foliage and other fine materials that are critical to fire ignition and behavior. Post-fire vegetation recovery is important to predict fire-return intervals. Advanced early warning systems will need to integrate these parameters into multilayer fire information systems. GIS technology, combined with decision support systems (expert systems), offers feasible, cost-efficient, and user-friendly solutions (Goldammer 1998b, IDNDR 1997).

#### Modern Fire Suppression Technologies

These include aircraft, communication equipment, fire-retardants, heavy field equipment, fire jumping, and water bombing. They have seen limited use in developing countries, however.

## International Actions

At the international level there is considerable interest in forest fires and haze, particularly transboundary implications, and their impact on the environment.

### Expressions of World Concern

There has been increasing global concern at the deterioration of the environment, including deforestation and resource depletion. A series of international conferences, summits, and commissions, starting with the United Nations (UN) Conference on the Human Environment held in Stockholm in 1972, have unequivocally stated that without environmental conservation, development will not be sustainable. In this connection, the crucial issue of deforestation and the need to obviate the undesirable impacts of wildfires have also been stated, implicitly or explicitly. The widespread fires seen in many countries during the 1990s—particularly those of 1997-1998—and the associated atmospheric haze pollution and negative socioeconomic impacts provided an unprecedented urgency for dealing with fires.

#### The Declarations

Several international statements, commitments, and declarations on sustainable development and forest management have flagged the need to mitigate and manage forest wildfires, in the context of controlling deforestation and forest degradation.

### *The Antalya Declaration*

The Antalya Declaration of the XIth World Forestry Congress (WFC), 13-22 October 1997, singled out forest fires for special attention. Noting with alarm the continued rate of forest loss and degradation in many regions of the world, the Congress called upon countries "to develop, implement, and review policies, plans, and management practices aimed at minimizing the destructive nature and extent of wildfires on forestlands" (WFC 1997).

### *The Rome Declaration*

The Rome Declaration on Forestry was adopted at the Second Ministerial Meeting on Forestry, in Rome, 8-9 March 1999. At that meeting, the ministers responsible for forests:

- were deeply concerned at the important challenges associated with forest loss and degradation in many regions;
- stressed the need to maintain the integrity of forests as ecosystems by promoting sustainable forest management worldwide;
- noted that the causes of forest fires are many and complex; and
- recognized the need to harness all efforts to prevent forest fires as well as to address the multiple causes and consequences of fires around the globe.

They also called upon the UN Food and Agriculture Organization (FAO) and other international organizations, donor agencies, and concerned countries to work together to address the underlying causes of forest fires; to improve the coordination of efforts to tackle, prevent, and combat forest fires; and to rehabilitate affected areas with a view to providing assistance requested by governments.

On their part, the ministers pledged:

- to work together toward a constructive and forward-looking outcome for the global forest policy dialogue at the eighth session of the United Nations Commission on Sustainable Development;
- to better coordinate and strengthen efforts to prevent, manage, monitor, and suppress forest fires, especially in anticipation of the next *El Niño* and, in the longer term, to address the underlying causes of forest fires; and
- to work closely with counterparts in other ministries in the respective countries to promote cross-sectoral policies and activities that support sustainable forest management.

Such pledges should be followed up seriously.

## **Conventions**

Conventions have had direct or indirect implications for the way the fires are managed and controlled

Although some international environmental treaties date back to the early part of the 20th century, it was not until the 1960s that concerns about environmental pollution and depletion of natural resources led to binding multilateral environmental agreements. The following conventions have had direct or indirect implications for the way the fires are managed and controlled:

*Ramsar.* Convention on Wetlands of International Importance especially as waterfowl Habitat (Ramsar Convention), Ramsar, 2 February 1971. www.ramsar.org

*World Heritage.* Convention Concerning the Protection of the World Cultural and Natural Heritage, 23 November 1972. www.unesco.org/whc

*CMS.* Convention on the Conservation of Migratory Species of Wild Animals, Bonn, 23 June 1979. www.wcmc.org.uk/cms

*Ozone.* Vienna Convention for the Protection of the Ozone Layer, Vienna, 22 March 1985, and Montreal Protocol on Substances

Nonbinding instruments are often forerunners of binding policy instruments and have at times had a more profound effect on environmental policy than binding ones

that Deplete the Ozone Layer, Montreal, 16 September 1987. www.unep.org/ozone

*UNFCCC.* United Nations Framework Convention on Climate Change, New York, 9 May 1992. www.unfccc.de

*CBD.* Convention on Biological Diversity, Nairobi, 22 May 1992. www.biodiv.org

*UNCCD.* United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Paris, 17 June 1994. www.unccd.de

Another multilateral environmental agreement that emerged after the 1972 Stockholm Conference on Environment was the 1979 Convention on Long-Range Transboundary Air Pollution, adopted by many European states, Canada, and US (UNEP 1999). Signatories have adopted a critical loads approach under the convention, which relates to the transboundary effects of haze from land and forest fires in Southeast Asia (see Box 4).

### *Nonbinding Instruments*

Nonbinding instruments are often forerunners of binding policy instruments and have at times had a more profound effect on environmental policy than binding ones. Two nonbinding instruments adopted during the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 are the Rio Declaration and Agenda 21 (UNCED 1993). The Forest Principles[5] adopted at UNCED falls under this category.

## UN International Decade for Natural Disaster Reduction

On 11 December 1987 at its 42nd session, the General Assembly of the UN designated the 1990s as the International Decade for Natural Disaster Reduction (IDNDR). The basic idea behind this proclamation was the unacceptable and rising levels of losses that disasters continue to incur on the one hand. And on the other hand, there was the existence of a wealth of scientific and engineering know-how that could be effectively used to reduce losses resulting from disasters.

The UN World Conference on Natural Disaster Reduction, which was part of a midterm review of IDNDR activities, was held in Yokohama, Japan, on 23-27 May 1994. The UN

### BOX 4 Convention on Long-Range Transboundary Air Pollution

The Convention on Long-Range Transboundary Air Pollution (LRTAP) in Europe, which was signed in 1979 and entered into force in 1983, is a classic example of regional environmental management. The first protocols organized finance and addressed acidification and photochemical pollution. Acidification was addressed again in 1994 since it was found that the first sulfur protocol did not provide sufficient protection. Recent attention has focused on the problems caused by persistent organic pollutants and heavy metals. Future priorities include development of an innovative, multi-effect, multi-pollutant protocol aimed at nitrogen oxides and related substances, which will include protection of the environment as well as human health.

Participating countries commit themselves to periodic reporting on emissions, national strategies, and programs. Many participating countries have developed action plans or long-term strategies based on a system of cost-effective, differentiated obligations.

Clear financing, the involvement of national scientific bodies, and joint implementation have contributed to LRTAP's status as one of the most successful regional multilateral environmental agreements. Emissions of acidifying substances have decreased in all areas since the first protocols came into force. The decrease is greatest for sulfur dioxide, the pollutant causing the major problem, with expected national reductions in 2000 relative to 1980 of about one third in Central and Eastern Europe, and two thirds to three quarters in Western Europe. However, reductions of the emissions of nitrogen oxides, ammonia, and hydrocarbons are more difficult to achieve. This will be the subject of a new protocol. To exploit the advantages of the multi-effect, multi-pollutants approach, sulfur emissions will also need to be further reduced. This should increase the cost-effectiveness of controlling air pollution for all participating countries.

Source: UNEP 1999.

BOX 5

## Wildfire ’97—Principles and Needs

**Principles**

- Fire is a key element of sustainable development.
- Fire is a component of ecological processes.
- Fire is both a threat and a tool.
- Fire and its effects are not constrained by geographic or political boundaries.
- Fire is one of the few natural disturbances that can be forecasted and mitigated.
- Fire may endanger people and communities.
- Fire can disrupt local economies.
- Fire can cause irreversible impacts.
- Fire is an important element of most global ecosystems and atmospheric processes.
- Fire’s role in the global environment is not fully understood or appreciated.

**Needs**

- Increase awareness of the impact of fire on sustainable development.
- Incorporate wildland fire into land management policies.
- Compile international data on wildland fire.
- Expand our understanding of fire’s role in global processes.
- Establish international partnerships and agreements.
- Coordinate international research.
- Continue international dialogue.
- Implement appropriate technology.
- Share information, knowledge, and experience.
- Evaluate international progress in wildland fire management.

(Based on the report of the International Conference on Wildfire ’97, Vancouver, Canada, May 1997).
Source: Goldammer 1997b.

team of specialists used the opportunity to express their views on global fires. In 1997, close links were established between the IDNDR Secretariat in Geneva and the Global Fire Monitoring Center (GFMC).

In July 1997, GFMC was entrusted with the formation of a Working Group on Fire and Related Environmental Hazards of the IDNDR Early Warning Programme. The recommendations of the group, which were submitted to IDNDR in 1997, were incorporated into the Report of the UN Secretary General: “Improved Effectiveness of Early-Warning Systems with Regard to Natural and Similar Disasters” (Goldammer 1998b).

The proposed priority activities of the Working Group on Fire and Related Environmental Hazards include Global Fire Inventory, Information Exchange and Technology Transfer, Fire Research and Policies, and Agreements on Environmental Protection.

### Scientific Programs

Fire research and technology development has received considerable stimulation from scientific projects conducted under the umbrella of the International Geosphere-Biosphere Program (IGBP) and other programs devoted to global change research (Andreae et al. 1993, FIRESCAN Science Team 1996, Malingreau and Justice 1997, Van Wilgen et al. 1997). While the scope of global change research is not necessarily directed toward operational management systems, e.g., early warning of natural hazards, the spinoffs of science nevertheless have considerable potential for contributing to management solutions.

However, the application of technologies and methods of information gathering, processing, and distribution has revealed that many existing systems must be further developed to meet the requirements of precise and real-time application for early warning and management of fire and other environmental hazards.

IGBP at the Max Planck Institute for Chemistry, Freisburg, Germany, provides the basis for interdisciplinary fire research programs. One of the operational IGBP core projects is the International Global Atmospheric Chemistry (IGAC) Project, which is investigating the impact of biomass burning on the atmosphere and biosphere (BIBEX). Since 1990, interdisciplinary international research campaigns have been conducted or are

The application of technologies and methods of information gathering, processing, and distribution has revealed that many existing systems must be further developed to meet the requirements of precise and real-time application for early warning and management of fire and other environmental hazards in the planning and implementation stage, the most important of which in the tropics are the Southern Tropical Atlantic Regional Experiment (STARE) and the Southeast Asian Fire Experiment (SEAFIRE) (see Chapter 3).

STARE was designed to investigate the atmospheric chemical consequences of fires in tropical and subtropical forests and savannahs of South America (Brazil) and Southern Africa. This first intercontinental fire experiment was conducted in the field during 1992 and involved more than 150 fire researchers from 14 nations. It demonstrated that fires on both sides of the tropical Atlantic cause elevated ozone concentrations in the troposphere during the dry season (August-November). The Southern African Fire-Atmosphere Research Initiative (SAFARI) was the African part of STARE and included fire ecology research components at a subcontinental level. In 1996-1997, additional international fire research programs were conducted in near-equator Africa.

SEAFIRE will investigate the characteristics and regional and global transport of emissions from various types of fire in tropical Southeast Asia

SEAFIRE will investigate the characteristics and regional and global transport of emissions from various types of fire in tropical Southeast Asia, such as fires used in forest conversion and shifting cultivation, and in grassland and seasonally dry monsoon forests (Goldammer 1996).

Previous and current international fire experiments under the IGBP are regularly announced in the UN-ECE/FAO *International Forest Fire News* (*IFFN*) and also published in scientific media (e.g., *Journal of Geophysical Research*).

### International Exchanges

The international community of fire specialists started to organize itself in the late 1980s. With the first issue of *IFFN*, published by the Economic Commission for Europe (ECE)/FAO Agriculture and Timber Division (now Timber Section, UN-ECE Trade Division) in 1988, a steadily increasing communication process in international fire matters was initiated. It was followed by the publication of the first scientific periodical, *Journal of Wildland Fire*, and the foundation of the International Association of Wildland Fire (IAWF) in 1992. This association provides the latest information on wildland fire issues through the journal as well as through *Wildfire* (a quarterly magazine), *Current Titles in Wildland Fire* (a monthly bulletin available on disk or printed that lists new articles, videos, and books on wildland fires), a continuously updated *International Directory of Wildland Fire* (a digital master list of 30,000 people working in the field), and an *International Bibliography of Wildland Fire* (a digital product with more than 45,000 citations on wildland fire). IAWF cosponsors fire conferences, sells and distributes publications, and provides free access to databases by telephone, fax, or E-mail (http://www.neotecinc.com/wildfire). Quick information through the Internet is provided by FireNet (http://life.anu.edu.au/landscape-ecology/firenet/firenet.html).

A series of international fire conferences has provided regular platforms for presenting and exchanging scientific results; for example:

- the biannual Conference on Fire and Forest Meteorology (formerly held in Canada and the United States, and beginning with the Australian conference in 1996 also internationally);
- the International Conference on Forest Fire Research at Coimbra University (Portugal), in 1998 for the first time in conjunction with the 14th Conference on Fire and Forest Meteorology; and
- the ECE/FAO seminars on forest fires (held at five-year intervals since 1981).

Fire management science and technology have reached a level of advancement and sophistication in industrialized countries. But in developing countries, they are still in their nascent stage, as most do not have adequate infrastructure, experience, and hardware to manage wildfire disasters.

Although bilateral assistance agreements exist and several field projects in fire management are carried out through national and international organizations, there are no facilities and/or mechanisms available to provide the necessary disaster management assistance internationally on a permanent and quick-response basis.

Besides the ECE/FAO Team of Specialists on Forest Fire, which has a restricted mandate and a regionally restricted area of influence, and some ongoing and planned regional fire research campaigns under the IGBP scheme, neither the UN system nor any other organization is providing adequate structures and mechanisms with global responsibilities in fire management.

Consequently, an information and monitoring system was needed that national and international agencies involved in land use planning, disaster management, or other fire-related tasks could utilize for planning and decision making. To fill the need, the Global Fire Monitoring Center (GFMC) was established in June 1998 in accordance with the objectives of the UN/IDNDR, recommendations of the International Tropical Timber Organization (ITTO) Guidelines on Fire Management in Tropical Forests, and recommendations of various scientific and policy conferences in the field of fire.

GFMC is located at the Fire Ecology and Biomass Burning Research Group of the Max Planck Institute of Chemistry, Germany. GFMC has established regional activities linked to Monitoring Tropical Vegetation.

For its first phase, GFMC is sponsored by the German Government's Ministry of Finance Affairs, as the country's contribution to the IDNDR. GFMC is also cosponsored by several international and national organizations; UN-ECE Trade Division; IDNDR; International Union of Forestry Research Organizations (IUFRO); International Bureau of Forest Research Association; IGBP; and US Bureau of Land Management. The fire documentation, information, and monitoring system is accessible through the Internet: http:/www.uni-freiburg.de/fireglobe.

## International Guidelines

### *Fire Management Guidelines*

ITTO has established a set of international guidelines for the protection of tropical forests against fires. This resulted in a publication, *ITTO Guidelines on Fire Management in Tropical Forests*, in 1996. The *Guidelines* contains 29 principles and recommendations covering: policy and laws, strategies (fire management planning, fire management options, fire suppression, role of communities in fire protection), monitoring and research, institutional framework and capacity development, socioeconomic considerations, land resources management, and training and public education. The *Guidelines* offers a framework for countries in the tropics, to be fine-tuned in accordance with socioeconomic, cultural, and vegetation conditions.

The International Tropical Timber Council has established a set of international guidelines for the protection of tropical forests against fires

### *Health Guidelines*

As a consequence of the 1997-1998 fires and haze, several international agencies have undertaken important initiatives. One issue that attracted attention was the health affects of smoke from vegetation fires. To address this, WHO has prepared *Health Guidelines for Episodic Vegetation Fire Events*.

## Notes

[1] Montane climate/vegetation influenced by altitudinal zonation is not included here.

[2] The residual product of rock decay.

[3] Zonal soils that develop in a moist climate.

[4] The satellite can detect fire points, normally called hot spots. It, however, was developed for weather and oceanic monitoring, both of which have temperatures below 40°C. The sensor measures the average temperature of 1 $km^2$. This does not mean that a fire has to be of this size, since a small hot fire can influence the average temperature of the 1 $km^2$ pixel considerably. Unfortunately, detecting hot spots is not flawless. Bare soil, corrugated iron, and low vegetation (grass) can also have a high temperature in the sun and are often wrongly assigned as a fire hot spot. This misclassification can account for more than half of results. Further, hot spots cannot be detected in areas with thick haze or smoke cover, as the sensor cannot penetrate haze, smoke, or cloud. Area calculation is difficult or impossible with only hot spot information.

[5] Full title: A nonlegally binding statement of principles for a global consensus on the management and conservation and sustainable development of all types of forests.