Convention on Biological Diversity

Secretariat

Ref: CBD/STTM/JPLD/ia

16 July 2001

NOTIFICATION

Dear Madam/Sir,

Subject: **Peer review of a document on human-induced uncontrolled forest fires and forest biological diversity**.

At its fifth meeting, held in Nairobi, Kenya, from 15 to 26 May 2000, the Conference of the Parties (COP) to the Convention on Biological Diversity adopted decision V/4 on forest biological diversity.

In paragraph 12 of the decision, the COP requested the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to consider the causes and effects of human induced uncontrolled forest fires and forest biological diversity and propose possible approaches to address negative impacts. To assist SBSTTA in its work, the Secretariat of the Convention on Biological Diversity commissioned a study to the Center for International Forestry Research (CIFOR).

I have the pleasure to invite you to take part in the peer review process of the document "Impacts of human-induced fires on biodiversity and ecosystem functioning, and their causes in tropical, temperate and boreal forest biomes". The purpose of this peer review is to get your comments on the overall balance and soundness of the scientific, technical and socio-economic aspects covered by the document.

I would be grateful if you could review the attached document and submit your comments no later than **3 August 2001.**

Yours sincerely,

Hamdallah Zedan
Executive Secretary

To: Experts concerned by Forest Biological Diversity and Forest Fires and CBD National focal points

Attachment: Impacts of human-induced fires on biodiversity and ecosystem functioning, and their causes in tropical, temperate and boreal forest biomes

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Impacts of human-induced fires on biodiversity and ecosystem functioning, and their causes in tropical, temperate and boreal forest biomes

CIFOR[1]

1. Introduction

The negative impacts associated with large-scale uncontrolled forest fires have increased worldwide over the past two decades (Goldammer et al., 1990; Goldammer, 1999; Nepstad et al., 1999; IUCN/WWF, 2000). By far the worst forest fires, in terms of burnt area, in recent times occurred in 1997-98 when as much as 20 million hectares of forest were impacted worldwide. As a comparison, this figure is much larger than the gross annual deforestation of 13.5 million ha/year (Food and Agriculture Organisation, 2001).

Despite the devastating picture evoked by media reports and the Internet in recent years, it is important to remember that fire is a vital and natural part of some forest ecosystems, and that humans have used fire for thousands of years as a land management tool. Similarly, the El Niño climate event that is often blamed for creating the drought conditions necessary for such large-scale fires is not a new phenomenon. Explorers in Southeast Asia in the 15th and 16th centuries report fires in peat swamps in southern Borneo in years known to have been El Niño years (Brookfield et al., 1995). However, in the latter part of the 20th century, changes in the man-fire dynamic and an increase in El Niño frequency (Byron et al., 1998), have lead to a situation where fires are now a major threat to many forests and their biodiversity therein. Tropical rain forests, in particular, which were once thought to be resistant to fires, are now experiencing large-scale fires due to unsustainable management practices (Kauffmann et al., 1988; Woods, 1989; Uhl et al., 1990; Holdsworth et al., 1997; Cochrane et al., 1999; Nepstad et al., 1999). Temperate forests in the United States in which fire was deliberately suppressed for management and political reasons are now experiencing devastating wildfires due to an unnatural accumulation of fuel (Agee, 1993).

As a result of the impact of large-scale forest fires in the 1980s and early 1990s, the issue has been forced onto the international agenda. In Agenda 21 at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, the fires were mentioned as one of the many threats to forests. In the same year, the Bandung Fire Conference held in Indonesia provided the impetus for three long-term fire projects in Indonesia (Dennis, 1999). As a direct result of the 1997-98 forest fires the seriousness of the issue and the problems caused ten internationally funded projects or assessments have commenced (Dennis, 1999). Furthermore, the Rome Declaration on Forestry of March 1998 made special mention of forests fires thus keeping the issue on the international agenda.

Despite the sharp media focus, the position on international agendas and the many donor funded development and research projects, forest fires continue to be a problem in many countries. It is also interesting to note the varying areas of focus of this attention. In the Indonesian research showed that many of the early fire projects focussed on doing something practical about the problem such as fire prevention, control and management without a thorough understanding of the underlying causes of the fires or the real ecological impacts (Dennis, 1999). However, since the 1997-98 fires, attention has shifted more towards understanding the underlying causes. Despite these efforts surprisingly little attention has been paid to the impact of fires on forest ecosystems and biodiversity. Out of the 36 fire projects carried out or ongoing in Indonesia, a country of great biological diversity, between 1983 and 1998, only one addressed biodiversity. However, the research community has faired better, notably the work carried out in the Amazon (Nepstad et al., 1999).

[1] Paper prepared by

This paper will bring together the results of a literature study on the main impacts of human-induced, uncontrolled fires on forest biological diversity and forest ecosystem functions in tropical, temperate and boreal forests. Based on the findings, a number of proposals to address the negative impacts of these fires are presented.

2. The major impacts of human-induced, uncontrolled forest fires on biological diversity and forest ecosystem functioning, and their underlying causes

Globally, no reliable, consistent and comprehensive statistics about the annual distribution and extent of forest fires exist. However, the FAO in its latest decadal forest resources assessment (Food and Agriculture Organisation, 2001) has included forest fire statistics for the first time but these are by no means comprehensive. There are no data for Africa, few for Asia, Oceania, and the Americas, but a complete dataset for Europe. As examples, the annual average for during the 1990s was 68,000 ha for Spain, 1.8 million ha for the Russian Federation, 500,000 ha for Canada and 67,000 ha for Mexico (Food and Agriculture Organisation, 2001). Some of the countries badly affected by fires, such as Indonesia and Brazil have no fire statistics presented in FAO Forest Resources Assessment 2000.

Clearly, obtaining global forest fire statistics is a difficult task; often governments in developing countries do not have sufficient human or technical resources to carry out the assessment. Official government forest fire estimates can vary widely from non-official sources. This is well exemplified by the burnt area estimates for the Indonesian fires of 1997-98. The Ministry of Forestry stated that 263,000 ha of forestland burned in 1997 and 550,000 ha in 1998 (State Ministry of Environment, 1998). Based on satellite image analysis, and in some cases field checks, a combined group of non-government organisations came up with different estimates; the most widely cited of which is 4.7 million hectares of forest impacted by fire (Asian Development Bank, 1999).

Confusion over forest fire terminology is also widespread. “Forest fires” was commonly used to describe the Indonesian and Amazonian fires but a large percentage of these fires were not in forests. Media reports, in particular, did not distinguish between fires in forests and fires in non-forest. Another confusing term is “forestland” fires, in many countries the state designates land as forestland but it does not always mean that the area is forested. Such confusion makes it difficult to compare and contrast forest fire statistics. Apart from the need for increased clarity on the type of vegetation burned, there is also a need for improved information on the degree of the fire damage caused to forest. Keeping these distinctions clear makes a great difference both in assessing the damage and the prospect for recovery, the social and economic cost of the fires, and in understanding the causes.

Fire can be a natural and important part of disturbance regimes in many forests but in others can cause devastation. Some ecosystems, such as the Mediterranean shrublands and many pine forests, are fire dependent, and their continued existence depends on the periodic occurrence of fires (Chandler et al., 1983). In some forests, fire is deliberately used as a management tool (prescribed burning) to maintain ecosystems, allow regeneration and clear debris. Although some forest fires occur naturally, a combination of human activity, fuel availability, and climate accounts for the majority of fires. While the weather conditions that create drought and influence the flammability of forests are quite natural, the factors that have turned those events into a disaster are predominantly man-made. In temperate and boreal forests, lightning can be an ignition source but in the moist tropics the contribution from lightning is insignificant. In boreal and temperate forests management practices, which deliberately suppress fires, have created a situation where catastrophic fires are now a major problem. The vast majority of fires in the tropics are set intentionally for land clearing and conversion, swidden agriculture and arson. In the past two decades, extended and frequent droughts coupled with increased pressures on land and unsustainable forest use, especially in the tropics have led to an increase in catastrophic fire events.

In terms of the impact of large-scale uncontrolled fires, at a global scale, they can influence the chemical composition of the atmosphere and the reflectivity of the Earth's surface. At the regional and local scale, forest fires change biomass stocks, alter the hydrological cycle with knock-on effects to marine systems such as coral reefs, reduce visibility to near zero, impact plant and animal species functioning and detrimentally impact on the health and livelihood of the human population. Smoke from fires can significantly reduce photosynthetic activity (Davies et al., 1999).
Apart from the effect on forest vegetation, fire can have a significant impact on forest vertebrates and invertebrates. In forests where fire is a natural part of the system, species are adapted to a natural fire regime and can benefit from the aftermath of a fire. However, in forests where fire is not a natural disturbance, or where man suppresses the natural fire regime the impact on species can be negative. The direct effect of fire on forest fauna is death. Indirect effects of fires are far reaching and longer term and include loss of habitat, stress, loss of shelter, food and territories. The indirect effects include loss of habitat, stress, loss of shelter, food and territories. Fires can also cause the displacement of territorial birds and mammals, which may upset the local, balance and ultimately result in the loss of wildlife, since displaced individuals have nowhere to go. Loss of food trees reduces the carrying capacity of the forest, causing overall decline in species that rely on fruits for food, this is especially true in tropical forests. The destruction of standing cavity trees as well as dead logs on the ground affects most small mammal species and cavity nesting birds (Kinnaird et al., 1998). The loss of key organisms in forest ecosystems, such as invertebrates, pollinators and decomposers, can significantly slow the recovery rate of the forest (Boer et al., 1989).

The majority of impacts of uncontrolled, human-induced fires on forests ecosystems are generally negative. From an ecological standpoint, any positive impacts would depend entirely on location, timing, intensity, and frequency of fires. If fire was a natural part of the ecosystem and a human-induced, uncontrolled fire happened to coincide then the impact could be consistent with ecological requirements and therefore positive. From a human perspective, if people have been using fire in a landscape for many years to maintain or manipulate specific values and an uncontrolled, human-induced fire took place, it may do what people would have intended and be consistent with human intentions. There may also be opportunistic, short-term benefits people to take advantage of. In situations where fire is not a natural or not normally a human-induced part of the ecosystem the impacts would be neutral or negative. However, fire-induced change is not automatically negative to all things and all people, although the positive aspects may be specific to sub-groups of plants or animals.

3. Impacts of forest fires on tropical forests

In the tropics, fires occur every dry season in savanna woodlands, monsoon forest and tropical pine forests. The focus of this paper will be forests, not woodlands, but it is important to note that dry season fires in the understorey occur regularly and frequently in savanna woodlands such as the miombo of tropical Africa (Trapnell, 1959; Kikula, 1986; Frost, 1996). In the tropical rain forests fire is not a natural disturbance but in the past two decades it has become an increasing threat. Tropical rain forests have been particularly badly impacted by forest fires since the early 1980s. Some of the most notable examples will be described here. A more detailed description can be found in "The Global Review of Fires" (IUCN/WWF, 2000) and Dennis (Dennis, In prep). In 1982-83, fires affected up to 5 million hectares of forests in Borneo (Lennertz et al., 1983; Malingreau et al., 1985; Leighton et al., 1986; Woods, 1987; Woods, 1989) while in the same years, fire also affected vast areas of rain forest in West Africa, notably in Côte d'Ivoire, where 60,000 ha of forest were destroyed (Oura, 1999). In 1997-98, as much as 4.7 million hectares of forest burned in Indonesia, mainly in Sumatra and Borneo, and 1.5 million hectares of forest burned in northern Brazil (Nepstad et al., 1999). In 1998, forest fires also burned in Venezuela, Colombia, Surinam and Guyana. Fires returned to the region in 1999, including Peru, Bolivia and Paraguay. In the same year, Central America and Mexico were also badly affected by fires with as much as 1.5 million hectares of forest was damaged, affecting numerous protected areas. The United Nations considered the 1997-98 fires in Indonesia and Brazil so bad that they dispatched United Nations Disaster Assessment and Coordination Teams to carry out assessment missions (UNDAC, 1998; UNDAC, 1998). Forest fires hit Ethiopia in March 2000, the first big fires since 1984. The threatened, afro-montane forests and moist tropical forests were badly damaged with as much as 53,000 ha of Bale National Park destroyed (Global Fire Monitoring Centre et al., 2000).

Seasonal fires occur in the monsoon and dry semi-deciduous forests of continental and South East Asia. These fires occur in the dipterocarp forests of Thailand or in the case of Myanmar and Laos, natural teak forests. Tropical pine forests (*Pinus merkusii*) and bamboo forests are also affected by fire. The combination of human activities and seasonally available flammable fuels (grass-herb layer, fallen leaves) allows the spread of surface fires. Tree species exhibit adaptive traits such as thick bark, ability to heal fire scars, re-sprouting capability, and seed characteristics. The ecological importance of these annual fires on forest formations is significant. Fire strongly promotes fire-tolerant species, which replace the species potentially growing in an undisturbed environment. For example, data collected for Thailand between 1984 and 1986 showed that about 21% of the forestland was affected by fire annually. By 1992 the burned area had dropped to 15% or ca. 1.9 million ha. In Thailand, 5% of forestland is plantations, which are twice as prone to fires as natural forests (Royal Forest Department, 1992).

3.1. Fire in tropical rain forests

Wildfires in most undisturbed, tall, closed-canopy, tropical rain forests are virtually impossible because a moist microclimate, moist fuels, low wind speeds and high rainfall create nearly non-flammable conditions (Kauffmann et al., 1988; Kauffmann et al., 1990; Holdsworth et al., 1997; Cochrane et al., 1999; Nepstad et al., 1999; Nepstad et al., 1999). However, during severe droughts, as experienced during El Niño years, rain forests may become more susceptible to fire. A shift in the general perception that fires were not a significant threat this forest type has come about since 1982-83 when an intense drought and accompanying fires destroyed large areas of the tropical forests of Borneo and in West Africa. Now it is generally thought that fire regimes in tropical rain forests, even those that are undisturbed or un-logged, have changed from one characterised by low-intensity, very infrequent surface fires to one in which fires are relatively frequent and of potentially high severity.

Fires in the tropical rain forest can be generally classified as forest surface fires and deforestation fires (Nepstad et al., 1999). In tropical peat swamp forests, a third type of fire, the ground fire can occur when peat layers ignite. The forest surface fires, which are often deceptively small and slow moving, ignite the organic debris lying on the forest floor. The principle forest damage comes not through the destruction of organic matter on the forest floor, but through the over heating of tree stems and lianas (Nepstad et al., 1999) which eventually causes the death of these plants, often months or years later. Depending on the intensity of the fire it can kill virtually all seedlings, sprouts, lianas and young trees because they are not protected by thick bark. The most important tree family in Borneo, the *Dipterocarpaceae,* is adversely affected by fire due to its thin bark, high content of flammable resin, and a lack of resprouting capability (Whitmore, 1990). However, in lightly burnt forests Dipterocarps regenerate (Leighton et al., 1986). The deforestation fire is high intensity and completely burns the forest leaving nothing alive and bare soil.

The level of pre-fire forest disturbance has a strong correlation with susceptibility to fire. In general, most investigators of the 1982-83 fires in Borneo found that fire intensity and damage sustained was significantly higher in logged-over forest with the degree of damage related to the logging intensity and residual debris on the forest floor (Lennertz et al., 1983; Leighton, 1984; Mackie, 1984; Malingreau et al., 1985; Wirawan, 1987; Woods, 1987; Woods, 1989; Wirawan, 1993). Researchers also noted that the fires in the forest had a significant negative impact on the seed-bank, seedlings and saplings, which did little to assist the recovery of the original species (Woods, 1987; Woods, 1989). Logging activities often lead to a build up of woody debris on the forests floor and an opening of the canopy. As a consequence the forest generally “dries out” and light tolerant species such as grasses and shrubs colonise the forest floor.

One of the most important ecological effects of burning is the increased probability of further burning in subsequent years, as dead trees topple to the ground, opening up the forest to drying by sunlight, and building up the fuel load with an increase in fire-prone species. The most destructive fires occur in forests that have burned previously (Cochrane et al., 1999). Many of the forests that burned in Borneo in 1982-83, or during the following El Niño droughts burned for a second time in 1997-98 (Hoffmann et al., 1999). The consequence of repeated burns is detrimental because they are a key factor in the impoverishment of biodiversity in rain forest ecosystems.

The post-fire assessment of the 1982-83 in Indonesia fires provided some qualitative assessments on regeneration potential of forests affected by fire (Schindele et al., 1989). The degree of expected recovery of the forest depended on the intensity of burning. For the undisturbed primary forest it was stated that full recovery of the forest could be expected within a few years (Schindele et al., 1989). However, in the disturbed forests, the prognosis for recovery in the presence of fire was not positive. In lightly disturbed burnt forest, the potential for recovery was good, but not without the help of rehabilitation methods. In moderately disturbed burnt forest, it was unlikely that there would be timber production for at least 70 years and in heavily disturbed forest it would take hundreds of years to return to a typical rainforest ecosystem in the absence of fire.

There has been little success with post-fire rehabilitation of tropical rainforests. Following the 1982-83 fires in Indonesia, Schindele (Schindele et al., 1989) proposed a number of rehabilitation measures such as afforestation, enrichment planting, timber stand improvement and encouragement of natural succession. However, there has been little success or commitment to rehabilitation of post-fire forests in East Kalimantan. The Sustainable Forest Management Project in East Kalimantan emphasised the importance of natural regeneration and mixed planting of native species, forest protection from further disturbance, and community participation for successful rehabilitation and management of post-fire forests (Sustainable Forest Management Project, 1999). The Indonesian Ministry of Forestry and Estate Crops introduced salvage logging as a management and financing tool in forest areas burned in 1997-98 (Sustainable Forest Management Project, 1999). Salvage logging gives companies the right to remove dead timber from severely burned logged-over forest or burned primary forest. There is some concern that salvage logging activities may adversely affect the course of vegetation succession (Nieuwstadt van et al., In prep), while there are strong indications that the practice is misused on a large scale to cut the still living trees in burnt areas.

In terms of the ecological impact of fires in tropical rain forests, the replacement of vast areas of forest with savanna-like grasslands is probably the most negative impact. These processes have already been observed in parts of Indonesia and Amazonia (Turvey, 1994; Cochrane et al., 1999; Nepstad et al., 1999). What was once a dense evergreen forest becomes an impoverished forest populated by a few fire-resistant tree species and a ground cover of weedy grasses (Cochrane et al., 1999). In north Queensland in Australia, it has been observed that where the aboriginal fire practices and fire regimes were controlled rain forest vegetation started to replace the fire-prone tree-grass savannas (Stocker, 1981).

3.1.2. Fire in tropical peat forests

Tropical peat forests deserve special mention, as drainage of these peatlands makes them particularly vulnerable to fire, especially ground fires, which produce the noxious smoke (Asian Development Bank, 1999; Rieley, 2001). Peat land fires produced a significant proportion of the smoke generated by Indonesian fires of 1997. Within the last 10 years tropical peat forests in Southeast Asia declined by 9.5 million hectares, much of which went up in smoke (Rieley, 2001). 1997 saw some of the severest peat swamp forest fires ever known in the region. Fires penetrated into the dried-out surface peat to a depth of up to 1.5 metres, and between 750 million and one billion tonnes of carbon were released into the atmosphere from Indonesia alone (Asian Development Bank, 1999; Rieley, 2001).

3.2. Impact of forest fires on fauna in tropical forests

There are still few in-depth studies of the effect of fires on tropical rain forest biodiversity. One can draw on a number of studies that took place after the fires in 1982-83 and 1997-98 in Indonesia. The 1982-83 fires in Kutai National Park, East Kalimantan resulted in widespread mortality of reptiles and amphibians (Leighton, 1984; MacKinnon et al., 1996). Fruit-eating birds such as hornbills declined dramatically and only insectivorous birds, such as woodpeckers were common due to abundance of wood-eating insects. Rabinowitz (Rabinowitz, 1990) reports that burned dipterocarp forest in Thailand is impoverished of small mammals, birds and reptiles, and that carnivores tend to avoid burned over areas. In Borneo, the orang utan (*Pongo pygmaeus*) suffered a 33 % decline in its population decline due to the 1997-98 forest fires (Rijksen et al., 1999)). In Sumatra, Kinnaird and O'Brien (Kinnaird et al., 1998) reported fire damage in the Bukit Barisan Selatan National Park during the fires of 1997. The loss of fruit trees reduced the fruit availability to a large number of omnivorous species, such as primates and squirrels, sun bear (*Ursus malayanus*) and civets as well as ungulates such as mouse deer (*Tragulus* sp.) and muntjac (*Muntiacus* sp.). The reduction in densities of ground squirrels and tree shrews suggested that rodent densities in general declined which adversely affected the food supply for small carnivores such as the leopard cat (*Felis bengalensis*). The destruction of tree cavities effected birds and mammals such as tarsiers, bats, and lemurs. Finally, the extensive fires destroyed the leaf litter and its associated arthropod community, further reducing food availability for omnivores and carnivores (Kinnaird et al., 1998). For other tropical rain forests there is a paucity of information of the impacts on animal biodiversity. Following surface fires in the Brazilian Amazon, there was a decline in slow-moving animals, frugivores and much of the litter fauna (Nepstad et al., 1999).

3.3. Direct and underlying causes of forest fires in tropical forests

Fire is an important tool for preparing land in the tropics. For numerous reasons, man causes the vast majority of forest fires in the tropics. In terms of direct causes, there are four main anthropogenic causes of forest fires in the tropics; land clearing with fire, fire being used as weapon in land tenure or land use disputes, accidental or escaped fire, and fires connected with resource extraction (Tomich et al., 1998; Nepstad et al., 1999; Barber et al., 2000; Applegate et al., 2001). Land development strategies, such as ranching in Amazonia (Nepstad et al., 1999), or pulp or oil palm plantations in Indonesia (Barber et al., 2000; Applegate et al., 2001) use fire for land preparation and have significantly contributed to forest fires in recent years. In addition, small holder farmers use fire in the preparation of land for crops such as coffee and for swidden agriculture. These land clearing fires often escape the intended area of burn, especially during El Niño years, and burn nearby forests. Arson is a major cause of fire in many resource rich areas, where land is either scarce for agricultural production, and/or where there is resource conflict over tenure or access rights (Applegate et al., 2001). In Indonesia, it was found that arson was particularly evident in areas of natural forest on fertile soils, and areas where large landholders had obtained land for large-scale plantations, such as oil palm (Applegate et al., 2001).

A study in Indonesia identified six major underlying causes of fires, many of which are similar to findings for other tropical forests (Nepstad et al., 1999; Applegate et al., 2001). Firstly, inappropriate and uncoordinated land use allocation creates the situation where forests are converted to non-forest use such as plantations. Land tenure issues were found to be one of the most common causes of forest fires in Indonesia (Applegate et al., 2001). These problems arise in a number of situations; when informal land tenure security promotes site occupation and forest conversion, where there is no incentive for local communities to control unwanted fires for which they have no responsibility and receive no benefit, where there are overlapping land claims between local communities, migrants, large communities, large companies and forest managers, and where there is a lack of a transparent legal system to address land claims and traditional communal rights. Shifts in demographic characteristics resulting from large-scale migration also lead to forest fires due to a lack of commitment to the new location and inexperience with the use of fire in a new environment. Forest degrading practices resulting from inappropriate timber harvesting practices can be an underlying cause of forest fires, for example large-scale drainage systems in swamps that lower the water table and provide increased access (Rieley, 2001). Financial incentives/disincentives created through increased profitability of alternative land use (e.g. coffee, small holder rubber, oil palm, rubber, timber, cattle ranching) and perverse development processes and mechanisms can indirectly cause forest fires (Nepstad et al., 1999; Applegate et al., 2001). Inadequate institutional capacity resulting from lack of capability, resources and political will to monitor and deal with encroachment and other illegal activities in forest areas can lead to forest fires. Finally, inadequate forest management plans and facilities to prevent and suppress accidental or escaped fires in plantations and natural forest can lead to fires.

4. Impacts of forest fires on temperate forests

According to FAO, the United States had the highest annual number of reported fires in the 1990s (Food and Agriculture Organisation, 2001), although this may be more due to reporting procedures than actually having the highest number of fires. In 1998, as much as 5 million hectares of forest were affected in the United States and Canada (IUCN/WWF, 2000). The states of Idaho and Montana were particularly affected in 2000, forcing the President to declare much of Montana a disaster area. US officials said that "brush" fires raging across 11 western states were the worst in 50 years and that there were more than 60,000 fires, which burnt nearly 1.6 million hectares of land (IUCN/WWF, 2000).

In much of temperate Europe, forest fires are negligible. However, the Mediterranean Basin is an exception. Between 1989 and 1993, 2.6 million hectares of forest and woodland were destroyed by fire in the Mediterranean (Xantopoulos, 2000). Both the number of fires and burnt area are believed to have doubled since the 1970s, though some increase is thought to be due to better and more accurate forest fire monitoring (IUCN/WWF, 2000). The worst affected countries are France, Spain, Italy, Portugal and Greece. At present, the Mediterranean experiences 50,000 fires a year, which burn an estimated 600,000 hectares (IUCN/WWF, 2000). Severe fires occurred in 1998 and 2000, exacerbated by extremely hot, dry weather. Data for 1998 shows that 41,000 hectares of forest burned in Spain, and 63,000 hectares in Italy, which was worst, affected. The cumulative figure for Greece, Spain, Italy, Portugal and Spain 106,000 hectares, Italy was worst affected (IUCN/WWF, 2000).

4.1. Fire in temperate forests

Fires are a natural and important part of disturbance regimes in many temperate forests. This is seen in plant adaptations such as thick bark, which enables a species to withstand or resist recurrent low intensity fires, while less well-adapted associates perish. Some tree species, notably the Jack Pine (*Pinus banksiana)* and Lodgepole Pine (*Pinus contorta*), have serotinus (late-opening) cones. While closed, these cones hold a viable seed bank in the canopy that remains protected until fire affects the tree. After fire, the cone scales open releasing the seed into a freshly prepared ash bed. Many plant species have the ability to re-sprout after being burned, either from the rootstock or the stem (Agee, 1993). Mountain ash, a eucalypt of temperate Australia, also requires a site to completely burn and be exposed to full sun for the species to regenerate prolifically (IUCN/WWF, 2000). Forest flammability is high in the Mediterranean Basin and most plant communities are fire prone. *Quercus ilex* is resistant to mild fires and woodlands recover without any major floral or structural change (Trabaud et al., 1980). If fire is neither frequent nor intense, open cork oak (*Q. suber*) forests can be maintained without management.

4.2. Impact of forest fires on fauna in temperate forests

With regards to the effect on biodiversity, in Portugal, it was found that the current fire regime probably contributed to maintaining the bird diversity at the landscape level (Moreira et al., 2001), while in Israel, species richness in certain areas was the highest 2 - 4 years after a fire followed by a decrease over time (Kuteil, 1997). In North America, fire suppression in some areas, has contributed to the decline of grizzly bear (*Ursus arctos horribilis*) numbers (Contreras et al., 1986). Fires promote and maintain many important berry-producing shrubs and forbs, which are important food source for bears, as well as providing habitat for insects and in some cases carrion. In the 1998 Yellowstone National Park fires, Blanchard and Knight (Blanchard et al., 1990) stated: "*The most important apparent immediate effect of fires on grizzly bears was the increased availability of some food items, especially carcasses of elk*." In Australia, detrimental fire regimes contributed to the extinction of two of the three bird species and three of the four subspecies that have disappeared from Australia since European colonisation (Woinarski, 1999). Of the threatened species that have been studied in Australia, almost all show clear preference for much less frequent fire than that currently prevailing. Not all species suffer from fire, however, for instance, grass-layer beetle species in Australia's savannahs showed remarkable resilience to fire, although fires affect abundance, species and family richness. This particular research suggested that fire management should be more mindful of fire frequency rather than intensity (Orgeas et al., 2001). Similarly, in an area where frequent burning occurs on a broad scale, preserving a range of microhabitats can make a substantial contribution to conserving biodiversity (Andrew et al., 2000).

4.3. Direct and underlying causes of forest fires in temperate forests

Throughout the 20th century man has inadvertently or deliberately changed the fire regimes of temperate forests. In the United States, where prescribed burning was once popular, pressure groups organised around the U.S. Forest Service have steadily led to the suppression of fires on federal land. This has come with an increasing economic and ecological cost. Many commentators on fire in the U.S would echo the following statement by Stephen Pyne (Pyne, 1997), a renowned fire historian; "*Today there is a maldistribution of burning – too much wildfire, too little controlled fire*." The scale of the devastation caused by recent fires in the United States has added fuel to the 20-30 year old "burn, no-burn" debate. The attempted removal of fire from the environment has seriously upset many biotas as well as compromised the prospects for future fire protection. Concerning this, Pyne aptly wrote: "*Biodiversity can be lost as surely through fire exclusion as through fire excess*". After the fires of the past few years, experts agree that successes in controlling forest fires over the past 50 years have left a large amount of deadwood in the forests, providing potential fuel for large-scale wildfires. In North America, data collected by the National Interagency Fire Centre for the years 1991-97 show that lightning, debris burning and arson are consistently the three main causes of fire in the United States (IUCN/WWF, 2000). In Australia, manipulation of fire, either explicitly or by default, is the main landscape management tool in many environments and most conservation areas. Inappropriate fire regimes (too much or too little) are the main threat to many vulnerable and endangered birds (Garnett, 1992), and other biota, such as plants (Leigh et al., 1984).

In the Mediterranean there are few landscapes that have not been altered by the human activities of grazing, cutting, coppicing, terracing and burning. However, many of them are now abandoned or altered. One outcome of this altered pattern has been a general increase in the quantity and flammability of fuels. An additional significant factor has been the extensive establishment of pine and eucalyptus plantations for sawlog and pulpwood production. These highly flammable monocultures have sustained many of the large wildfires (Goldammer et al., 1990). An important element in the wildfire problem in the Mediterranean has been the unprecedented occurrence of arson, as many as 95% of the fires in 1989 could have been deliberately set (Goldammer et al., 1990). The specific reasons for such activities are difficult to determine but some of the reasons may be the availability of burnt lands for construction of tourist resorts, revenge or people dissatisfied by the government establishment of plantations and suppression of traditional activities (Goldammer et al., 1990). In Greece, an increase in fires since the 1980s can be attributed in a large part to the activity of people near the forest edge. New roads and an increase in car ownership offer easier access to the forest. In the hot summer months people leave the cities and seek cooler spots along the coast or in the mountains, increasing the risk of accidental fires (Xantopoulos, 2000). In Algeria, one underlying cause of fire is conflicts between local inhabitants and forest authorities. People who have been penalised for illegal wood cutting or grazing start forest fires as an act of revenge. Madoui (Madoui, 2000) suggests that this is the cause of the majority of forest fires. In the period 1907-1957, fires that occurred due to negligence (smoking, camp fires, honey collecting) accounted for as much as 52% of forest fires. In the period 1977-1991, this figure dropped to 18% with unknown causes accounting for 82% of fires.

5. Impacts of forest fires on boreal forests

Some of the largest fires in the world occur in boreal forests. In Canada in 1950, a single fire destroyed 1.4 million hectares of forest (Johnson, 1992), and in 1987 in north-eastern China 1.1 million hectares were destroyed by a single fire (Di et al., 1990). The largest area of boreal forest lies in the Russian Federation and fires are a common annual event (Shvidenko et al., 2001). In 1915, forest fires were estimated to have destroyed 14 million hectares of closed forest in Russia (Shvidenko et al., 2001). In 1998, which was an exceptionally dry year, approximately 2 million hectares of forests burned in the Eastern Russia region of Khabarovsk near the border with China and on Sakhalin Island (UNDAC, 1998). However, recent estimates from satellite imagery conclude that 7.2 million hectares of forestland (defined as State Forest Land and may include unforested areas) burned in the Asian part of Russia, of which 1 million hectares were crown fires (Shvidenko et al., 2001). Very dry conditions also prevailed in Canada where 4.5 million hectares of forest burned. Nearly ten years earlier in 1989, as much as 7.6 million burned in the Canadian boreal forests (Canadian Forest Service Website, 2001).

5.1. Fire in boreal forests

Fire, often with high intensity, is the major natural disturbance mechanism in boreal forests. Fire return times in natural forests varies greatly, from as little as 40 years in some Jack pine (*Pinus banksiana*) ecosystems in central Canada, to as long as 300 years depending on climate patterns ((van Wagner, 1978)). In NW Europe the normal fire frequency on a given site is usually 40-200 years in natural conditions. In Sweden, it has been estimated that about 1% of the forest land burned yearly before systematic suppression of fires started in the late 19th century (Zackrisson, 1977). Most boreal conifers and broad-leaved deciduous trees suffer high mortality even at low fire intensities owing to canopy architecture, low foliar moisture and thin bark (Johnson, 1992). Some pines (*Pinus banksiana, P.resinosa, P.monticola* and *P. silvestris*) have thicker bark and generally greater crown base and height, and old tall trees can often survive several fires. The disturbance regime of fire creates succession patterns responsible for the mosaic of age classes and communities. Natural wildfire pattern are dependent on a variety of variables (frequency and intensity of the fire, vegetation type, and the site factors such as slope, elevation, tree species, and age class). It is important to note that fire refuges exist in some parts of the forest on moist sites with local humidity, where fire may absent for several hundred years. Fire refuges are vital to the forest because many species may survive only in such areas, and then supply a seed source to recolonize the burned areas (Ohlson et al., 1997).

Generally, the ability of post-fire boreal forest to regenerate is high but frequent high intensity fires can offset this balance. Due to the extreme severity of the 1998 fires in the Russian Federation, more than 2 million hectares of forest have lost the majority of their major ecological functions for a period of 50-100 years (Shvidenko et al., 2001) On the contrary, in the natural forests of the northern and sparsely stocked taiga and forest tundra, particularly on permafrost sites, surface fires occurring at long-return intervals of 80 to 100 years represent a natural mechanism that prevents the transformation of forests to shrubland or grassland (Shvidenko et al., 2001). Exclusion of fire induces the build-up of organic layers that prevents melting of the upper soil and rise of the permafrost layer, resulting in impoverishment of forests, decreasing productivity, and conversion to marshes. Severe fires have had a significant negative impact on plant biodiversity. Southern species that are at the northern edge of their geographic range are particularly vulnerable. For example, in Primorsky Kray (the Russian Federation), the richness of 60 species of vascular plants, 10 fungi, 8 lichens and 6 species of mosses resulted in negative change during the previous decades, mostly due to human-induced fires and fragmentation of forests (Shvidenko et al., 2001).

5.2. Impact of forest fires on fauna

The number of the rare and critically endangered Amur (Siberian) tigers (*Panthera tigris altaica*), wild boar (*Sus scrofa*), and moose on large areas burned in 1976 in the Amur River basin Eastern Russia decreased from 1972 to 1997 by 20-50 times (Shvidenko et al., 2001). Much of the area affected by the 1998 fires is prime Amur tiger habitat, it is estimated that only 400 individuals remain in the wild. Estimates from the 1998 fires suggest that mammals and fish were badly affected; mortality of squirrels and weasels reached 70-80 %, boar 15-25%, and rodents 90% (Shvidenko et al., 2001). Increased water temperatures and high carbon dioxide levels adversely affected salmon spawning (Shvidenko et al., 2001). In North America, moose are occasionally trapped and killed by fire (Gasaway et al., 1985). However, fire generally enhances moose habitat by creating and maintaining seral communities, and is considered beneficial to moose populations (MacCracken et al., 1990). The beneficial effects of fire on its habitat is estimated to last less than 50 years, with moose density peaking 20 to 25 years following fire (LeResche et al., 1974). Extremely large, hot, and fast-moving wildfires can force moose to temporarily abandon their home ranges (LeResche et al., 1974). The effect of fire on gray wolf (*Canis lupus*) habitat is best defined by how fire affects gray wolves' prey. Beaver (*Castor canadiensis*), moose, and deer are fire-dependent species, requiring the plant communities that persist following frequent fires (Kramp et al., 1983). Similarly, now absent from the old-growth forests of Minnesota, caribou (*Rangifer tarandus*) were once an important prey for gray wolves. These forests do not provide sufficient food to sustain other ungulates for gray wolves to prey on. Due to fire exclusion, these old-growth forests have increased, checking ungulate populations and consequently limiting gray wolf populations (Heinselman, 1973). Fire was once thought to be detrimental to caribou because it destroys the slow-growing lichens formerly considered primary caribou food. Many believe that fire is beneficial to caribou in the long-term (Klein, 1982). There is no dispute that fires can kill important lichen species and that these lichens can take a minimum of 30 years to recover. However, there is dispute over what constitutes recovery, and lichen reestablishment does not always lead to caribou recovery.

5.3. Direct and underlying causes of forest fires in boreal forests

Although fire has long been used as a land-clearance tool in Russia, the political and economic crises are said to be the main underlying causes of recent large-scale fires (IUCN/WWF, 2000). Due to job scarcity and insecurity people are turning to the forests for income. Hunting, poaching (the market price for the pelt of an Amur Tiger is US$30,000), fishing, illegal logging (occurring at an unparalleled rate) and collection of forests products such as berries and mushrooms has increased significantly. These activities have led to a large increase in the number of people in the forest, which has exacerbated the risk of accidental fires. Authorities believe that 70-85% of fires are anthropogenic, and west of the Urals this figure rises to 100% (IUCN/WWF, 2000). In addition, the government does not have the human or financial resources to enforce regulations, monitor and manage forests and prevent fire. In Canada, data collected from 1981 to 1995 indicate that lightning causes some 42% of forest fires. These fires, however, burn approximately 85% of the total forest burned each year. Interestingly, it has been reported that people are responsible for starting two thirds of forest fires in Canada (Todd et al., 2000).

6. Socio-economic impact of forest fires

Many of the costs of forest fires to society are difficult to quantify in monetary terms because they involve ecological processes and services that are not traded in the marketplace but that sustain the production of food, fibre, and other commercial products. There are a number of estimates available for the economic impacts of fires and smoke from various fire events. It is not easy to compare and contrast these estimates as different methodologies are used and many include forest and non-forest fires. This is major drawback in collecting meaningful fire data for producing global evaluations.

The economic losses from the 1997-98 Indonesian fires were conservatively estimated at US$9 billion (Asian Development Bank, 1999). Breaking this figure down into its forest-related components shows that timber losses from natural forests reached US$ 2 billion, lost growth of natural forests was calculated at US$377 million, loss of non-timber forest products reached US$586 million, loss of flood protection was estimated at US$400 million, and the cost of erosion and siltation totalled US$1.5 billion. The cost of carbon emissions was estimated at 1.4 billion, based on a figure of US$10/t C. In the Amazon, total timber losses resulting from surface fires exceed several million dollars per year, and may reach tens of millions when large areas of un-logged forest catch fire because of drought induced fire susceptibility (Nepstad et al., 1999). The economic losses associated with forest fire may be much more significant for smallholders than large holders as they depend on the forest for a wide range of services and uses (Nepstad et al., 1999).

Few estimates are available for the economic impact from temperate and boreal forest fires. Timber companies owned a quarter of the land burned in 1998 in the U.S, and timber losses were estimated to exceed US$300 million (IUCN/WWF, 2000). The cost to fight the fires was US$130 million (IUCN/WWF, 2000). Preliminary estimates for the 1998 fires in the Russian Federation, suggest that timber losses might reach 400-500 million cubic metres, about 4 times the current level of harvest in Russia. Some regions have now lost their potential for industrial tree harvesting (Shvidenko et al., 2001).

Forest fires from the smoke and haze produce one of the most visible costs to society. People suffer respiratory problems, which puts pressure on meagre medical facilities in many tropical countries. According to the Brazilian Ministry of Health (Nepstad et al., 1999) twice as many patients are admitted to hospital each month due to respiratory problems during the peak of the burning season, than during other months. Estimates suggest that 20 million people were directly affected by smoke from the Indonesian fires (Barber et al., 2000). Smoke reduces visibility, provoking transportation accidents and airport shutdowns. This often leads to transboundary smoke pollution, which provokes international indignation.

7. Forest fires and climate change

Forest fires are a significant source of emitted carbon, which exacerbates global warming as well as being an irreplaceable carbon sink. Substantial amounts of carbon have been released from forest clearing at high and mid-latitudes over the past centuries and in the tropics during the latter part of the 20th century. From 1850 to 1998, approximately 270 (+/- 30) Gt C has been emitted as carbon dioxide into the atmosphere from fossil fuel burning and cement production (Intergovernmental Panel on Climate Change, 2000). About 136 (+/- 55) Gt C has been emitted as a result of land use change, predominantly from forest ecosystems (Intergovernmental Panel on Climate Change, 2000). Estimates vary but biomass burning is now recognised as a significant source of CO_2 and is generally considered to contribute between 20 and 40% of total CO_2 emission worldwide (IUCN/WWF, 2000). Carbon released into the atmosphere from biomass burning in tropical forests was estimated at 212 Gt C from vegetation and 216 Gt C from the soil (Intergovernmental Panel on Climate Change, 2000). This figure is much lower in the temperate forests, where only 59 Gt C is held in vegetation and 100 Gt C in the soil. The largest carbon stocks are in boreal forests, where 88 Gt C is in vegetation and 471 Gt C in the soil. Some estimates are available for specific fire events. Direct emissions of carbon during the 1998 fires in the Russian Far East totaled 172.8 million tons, of which forest fires emitted 133.8 million tons (Shvidenko et al., 2001). In the 1997-98 fires in Indonesia between 750 million and one billion tonnes of carbon were released into the atmosphere from peat swamp clearing and burning alone (Asian Development Bank, 1999; Rieley, 2001). One estimate calculates that fires from all the world's tropical forests in 1998 produced 1-2 billion tonnes of carbon, which is equivalent to one third of the emissions from fossil fuel burning worldwide (IUCN/WWF, 2000).

Climate change predictions by Working Group II of the Intergovernmental Panel on Climate Change report, published in February 2001, concludes that forest fires will become an increasing problem in many forest biomes. The globally averaged surface temperature has increased by 0.6 +/- 0.2°C over the 20th century and average air temperature is projected to rise to 1.4 to 5.8°C by 2100 relative to 1990 (Intergovernmental Panel on Climate Change, 2000). In Latin America, it is expected that large forest areas will be affected as a result of projected changes in climate. Climate change could add an additional stress to the adverse effects of continued deforestation of the Amazon rainforest. This impact could lead to biodiversity losses, reduce rainfall and runoff within and beyond the Amazon basin and affect the global carbon cycle. Forest fires are predicted to increase in North American forests. In boreal regions, an increase in temperature, accompanied by decreases in soil moisture, will lead to a substantial reduction in peat formation in Fennoscandian and northern Russian peatlands. Reduced soil moisture during the summer will increase drought stress and the incidence of wildfires. Tropical forests are expected to warm by 2°C above 1970s levels by the mid-21st century, with larger effects in continental interiors (UNEP-WCMC, 2000). Inter-annual variability in large-scale climate events such as El Niño may act to exacerbate rainfall extremes. The impact of human activities, such as deforestation or fire will be more important than climate change in determining forest cover in many tropical regions.

8. Proposals to address the negative impact of forest fires

8.1. To achieve a reliable and operational system for national, regional and global forest fire monitoring and reporting to facilitate amelioration strategies (CBD Articles 5, 17 and 18) through:

- Collation and storage of comparable datasets on the extent, impacts on ecosystems, biodiversity, and socio-economy, costs, and direct and underlying causes of forest fires worldwide;
- Identification of a suitable institution and an operational strategy for a clearinghouse on worldwide forest fires data; and
- Promotion and encouragement of participation of all stakeholders in providing data to the clearinghouse.

8.2. To protect ecosystems that are vulnerable to forest fires and are critically important for conservation of national and global biodiversity, such as biodiversity hot spots, and protected areas (CBD Article 8) through:

- Identification and development of appropriate fire management regimes for protected areas and biodiversity hot spots under most threat from fire in tropical, temperate and boreal forest biomes;
- Recognising local communities and multi-stakeholder interests in the use of forests, develop appropriate fire management plans in and around locations of high biodiversity value; and

- Recognising that important forest biodiversity also exists in timber production forests or outside the protected area system, develop sets of standards for the preparation of environmentally sound and sustainable management plans (including fire management) that take account of biodiversity conservation and local community needs.

8.3. To encourage community participation and involvement in fire management, prevention and suppression plans (CBD Articles 8 and 10) through:

- Promotion of community involvement and education about forest and land fires;
- Promotion and encouragement of policies that create and support community managed forests;
- Management and development of fire use to improve outcomes and reduce the incidence of agricultural fires burning beyond the area of intention;
- Mandating and equipping natural resources managers, in partnership with communities and relevant stakeholders to prepare and implement integrated fire management plans that promote a balance between fire prevention, response and restoration, and discourage strategies that rely too heavily on fire-fighting as the primary means to deal with forest fire;

8.4. To promote ecologically sustainable forest management, including environmentally sound based expansion of plantations, elimination of illegal logging, and improvement of timber harvesting practices to reduce organic debris to minimise unwanted fires (CBD Articles 11 and 12) through:

- Development of appropriate sets of standards for the development of tropical plantations (timber, oil palm, rubber) taking full account of biodiversity conservation and local community needs;
- Development of a strategy to facilitate the adoption of improved timber harvesting practices by timber companies, local communities, and local government in the tropical and boreal forest biomes;
- Identification of the economic instruments and incentives that encourage improved fire management by land users.
- Identification of why policies and regulations have not been effective in reducing the large-scale catastrophic in places such as Indonesia, Russian Far East, USA, Amazonia and the Mediterranean.

8.5. To rehabilitate degraded or burned forest lands (CBD Articles 8 and 10) through:

- Identification of methods and mechanisms to support local communities to develop remedial and income generating activities in degraded areas;
- The identification of impediments to adoption of rehabilitation processes and activities in degraded and burnt forestland in the tropics and boreal biomes.
- Identification of the economic instruments and incentives that will lead to the adoption of rehabilitation processes and activities in burnt forestland.

8.6. To identify the processes and impacts of fires in vulnerable and globally significant ecosystems including tropical and boreal peat land systems, and tropical woodlands (CBD Article 7) through:

- Identification of peatlands in the tropical and boreal biomes which are under threat from forest conversion and fire, their extent and characteristics;

- Estimation of the contribution of the respective peatland forest and tropical woodland fires to global carbon emissions; and

- Identification of the underlying causes of fires in peatland forests.

8.7. Training, education and public awareness in communities where fire is a major problem. (CBD Articles 12 and 13).

- In many areas where local communities live in and around forests, fire is a major threat to health, livelihood and forest ecosystems. There is therefore a need to develop an awareness of both the negative and positive impacts of the use of fire in these areas. This will require the use of a range of scientific and technical inputs presented in an easily accessible format, e.g. mass media and village forums;
- Build awareness among policy makers, the public and the media as to the underlying causes of forest fires, their associated societal and economic costs and the importance of addressing these in a systematic fashion.

8.8 To assess more fully the impact of forest fires on aquatic and marine systems of tropical and boreal biomes (CBD Articles 7 and 12) through:

- Assessment of the impact of smoke and increased run-off and sedimentation on tropical coral reef ecosystems;
- Assessment of the impact of smoke and increased run-off and sedimentation on boreal aquatic ecosystems.

8.9. To improve and facilitate the exchange of information on the impact and contribution of forest fires to global climate change (CBD Article 5). This could include participation in international climate change fora such as the UNFCC and IPCC. Using improved information developed under 8.1. and 8.6. above.

Appendix 1 - Bibliography

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