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Overview: Global fire regime conditions, threats, and opportunities for fire management in the tropics

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3.1 ABSTRACT

Fire is a natural process that has played a major role in shaping our environment and maintaining biodiversity worldwide. However, over 60% of the world's terrestrial habitats have altered fire regimes. At least 20% of global habitats are classified as fire-sensitive, including most tropical habitats; they are composed of species that did not largely evolve in the presence of fire. Over 70% of these fire-sensitive habitats have altered fire regimes. While fire has been, and still is, an important tool used by humans to cultivate agricultural landscapes, when human actions cause too much, too little, or the wrong type of fire, it can threaten our environment by releasing unacceptable levels of greenhouse gases into the atmosphere, providing pathways for harmful invasive species, altering landscape hydrology, impairing local and regional air quality, and presenting a direct and often increased risk to human habitation. Recognizing the value and need to assess the world's fire regimes, The Nature Conservancy, University of California at Berkeley, World Conservation Union (IUCN), and World Wildlife Fund (WWF) completed an expert-based analysis of the state of the world's fire regimes based on currently available data and expert opinion. The major sources of fire regime alteration worldwide include climate change, agriculture and ranching, deforestation, rural and urban development, energy production, fire exclusion and suppression, invasive species, plantations, and arson. Integrated fire management (IFM) is an approach that considers both damaging and beneficial fires within the context of the natural environments and socio-economic systems in which they occur. IFM takes into account fire ecology, socio-economic issues, and fire management technology to generate practical solutions to fire-related threats to biodiversity.

3.2 INTRODUCTION

Fire is a natural process that has played a major role in shaping our environment and maintaining biodiversity worldwide. Fire's benefits and impacts are diverse and extensive; fire often determines the distribution of habitats, carbon, and nutrient fluxes, and the water retention properties of soils. Although over 50% of the world's terrestrial habitats depend on fire for ecological sustainability, ongoing changes in fire regimes (through increasing or decreasing fire's intensity, frequency, and extent) are promoting extensive habitat degradation. Over 60% of the world's terrestrial habitats have altered fire regimes. At least 20% of global habitats are classified as fire-sensitive (Shlisky *et al.*, 2007), including most tropical habitats; they are composed of species that did not largely evolve in the presence of fire. Over 70% of these fire-sensitive habitats have altered fire regimes (Shlisky *et al.*, 2007).

Besides its importance as a natural phenomenon, fire has been, and still is, an important tool used by humans to cultivate agricultural landscapes. However, in habitats where fire is infrequent—such as in much of the moist tropical forests—human introduction and frequent use of fire can disrupt their natural process of recovery and lead to social, economic, species, and environmental losses. Conversely, many tropical ecosystems such as savannas and grasslands are accustomed to fire and dependent on it for ecological health. Fire exclusion in these systems often results in reduced biodiversity and increased vegetation density, often increasing risks of catastrophic fire over time. In sum, when human actions cause too much, too little, or the wrong type of fire, it can threaten our environment by releasing unacceptable levels of greenhouse gases into the atmosphere, providing pathways for harmful invasive species, altering landscape hydrology, impairing local and regional air quality, and presenting a direct and often increased risk to human habitation.

To decrease the impacts of human intervention on global fire processes, a series of management strategies need to be performed and disseminated. These fire management strategies must incorporate the ecological and social roles of fire, as well as the restoration and maintenance needs of habitats. A recent global assessment revealed that 8 of 14 of the world's terrestrial major habitat types[1] fall short of a 10% goal for effective conservation (NC, 2006). Three of these eight habitat types are tropical: tropical dry broadleaf forests, tropical coniferous forests, and tropical grasslands, savannas, and shrublands. These habitats not only do not have sufficient area to protect a full spectrum of the world's biodiversity, but in many cases current land uses and protection policies still allow habitat conditions to fall below ecological standards for biodiversity health. Land protection or management policies must allow for appropriate fire management—be it prescribed burning for biodiversity benefit, fire prevention to protect fire-sensitive habitats, or other fire-related management actions.

[1] Major habitat types, or biomes, are groupings of ecoregions that share similar environmental conditions, habitat structure, and patterns of biological complexity. At a global scale, these groups of ecoregions reflect the broadest ecological patterns of biological organization and diversity (Olson *et al.*, 2001).

Fire is a complicated conservation issue since it rarely stands alone. Rather, fire interacts with many other global threats to biodiversity: logging, agricultural expansion, urban and exurban development, land use change, energy development, overgrazing, fire exclusion, climate change, invasive species, hydrological developments, and transportation infrastructure. These threats universally alter the ecological role of fire by causing too much, too little, or the wrong kind of fire relative to ecological baselines. Ignoring fire as a global conservation issue—whether fire is a key ecological process or a threat to biodiversity and human livelihoods—can have unwelcome and far-reaching consequences.

An assessment to determine the role of fire across the world's terrestrial habitats, and the major ongoing changes in the natural role of fire, is fundamental to development of effective conservation policies. This chapter presents results from the most complete assessment of the world's fire regimes to date. This assessment is based largely on expert opinion, and is translated into maps that illustrate the distribution and quality of the world's fire regimes. This chapter also reviews the ecological context of tropical fire regimes, their current state, and the reasons for their maintenance or degradation. Then it offers an integrated solution for managing fire for people and nature.

3.3 ASSESSING THE WORLD'S FIRE REGIMES

Assessing the condition of the world's fire regimes poses challenges. Comprehensive, consistent, and compatible fire-related data are generally not available worldwide. In some areas, there are rich datasets at varying resolution that include important fire-related attributes, such as fire history, ignition sources, and fire sizes, frequencies, and intensities over a number of decades (e.g.. Canada, the United States). In other areas, easily accessible and readily available data may not exist for any important fire- related attributes.

Recognizing the value and need to assess the world's fire regimes, The Nature Conservancy, University of California at Berkeley, World Conservation Union (IUCN), and World Wildlife Fund (WWF) (collectively known as the "Global Fire Partnership" or GFP) completed an expert-based analysis of the state of the world's fire regimes based on currently available data and expert opinion. In March 2004, the GFP gathered a group of fire experts and policy makers from around the world in Switzerland to discuss global fire regimes and biodiversity conservation. The results of that workshop (NC, 2004) represented the first coarse-scale assessment of where and to what extent fire is beneficial or harmful to conserving biodiversity and led to the more recent results described in this section.

The GFP implemented three expert workshops between January and July 2006, covering four broad biogeographic realms: Australasia, Indo-Malay, Nearctic and Neotropic.[2] Realm-level workshops established a consistent global dataset of the

[2] The Australasia realm includes Australia and Papua New Guinea, the Indo-Malay includes India and Southeast Asia, the Nearctic includes Canada, the U.S., and Mexico, and the Neotropic includes South and Central America (Olson *et al.*, 2001).

ecological roles of fire and threats to maintaining those roles at a coarse resolution. Workshops also illuminated linkages between fire, climate change, and other human-caused threats to biodiversity, while also strengthening collaboration and partnerships among experts, managers, and policy makers.

WWF ecoregions were used as a foundation for the assessment because they are available consistently around the world, and represent a manageable level of resolution for a rapid, expert-driven global assessment. During realm-level workshops in 2006, experts were organized into regional teams of scientists, land managers, and decision makers to review existing data, capture expert knowledge, and transfer information between scientists and decision makers. For the four biogeographic realms assessed between January and July 2006, the workshop process incorporated new or refined data from more than 68 scientists, land managers, and policy makers from 13 countries and multi-lateral governmental and non-governmental organizations. Participants interactively and collaboratively reviewed and refined spatial data on fire ecology (fire regime types), top threats to maintaining fire's ecological roles, and key strategies for abating fire-related threats. Expert input was captured through an interactive web-based geographic information system (webGIS) and submitted in real time into a master database housed at the University of California at Berkeley Center for Fire Research and Outreach. Sources of fire-related threats and key strategies for abating altered fire regimes followed the IUCN–Conservation Measures Partnership classification (IUCN–CMP, 2006). The expert global database was analyzed to summarize patterns in natural fire regime characteristics, current fire regime types and conditions, and threats to maintaining fire regimes by major habitat type and realm.

3.4 FIRE REGIME TYPES

Climate, topography, soils, and vegetation combine to create unique fire regime dynamics. Ecosystems can coarsely be classified in terms of their relationship to fire regime characteristics such as fuels, flammability, ignitions, and fire spread conditions within a given ecosystem. Experts used three categories of fire dependency to classify the fire ecology of terrestrial habitats: fire-dependent, fire-sensitive, or fire-independent:

- *Fire-dependent ecosystems* are those where most of the species have evolved in the presence of fire, and where fire is an essential process for conserving biodiversity (e.g., savannas, temperate coniferous forests). Excluding fire from these systems, or introducing ecologically inappropriate fire (i.e., at an inappropriate frequency, severity, or seasonal timing) can substantially alter these systems.
- *Fire-sensitive ecosystems* are those where most of the species have not largely evolved in the presence of fire. While fire may play a secondary role in maintaining natural ecosystem structure and function in fire-sensitive systems, the introduction of ecologically inappropriate fire can have an extensive negative impact on biodiversity (e.g., tropical moist broadleaf forests). Too much fire in

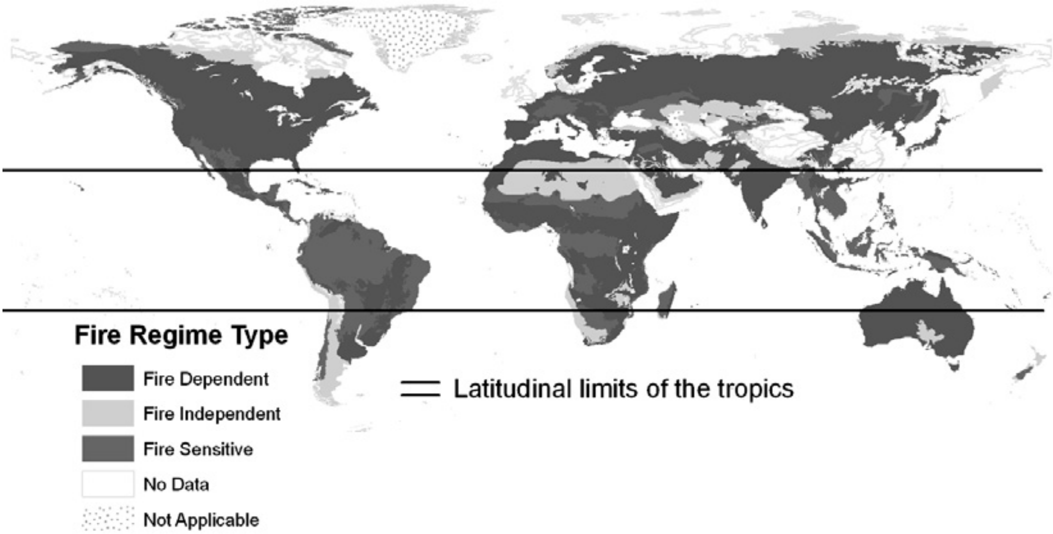

Figure 3.1. Global distribution of fire regime types (Shlisky *et al.*, 2007). *See also* Color section.

fire-sensitive forests can also create a positive feedback loop, making these forests more susceptible to fire in the future, and rapidly degrading the most intact forest ecosystems.

- *Fire-independent ecosystems* are those that naturally lack sufficient fuel or ignition sources to support fire as an evolutionary force (e.g., deserts, tundra).

The global distribution of these three fire regime types indicates that most fire-sensitive ecosystems are located in the tropics (Figure 3.1; Shlisky *et al.*, 2007). This spatial distribution can be explained by the large patches of tropical and subtropical dry and moist broadleaf forests, which due to high precipitation rarely have natural fire occurrence (Goldammer, 1990). However, the expansion of human activities such as forest conversion to agriculture or grazing fields is increasing the presence of fire and decreasing the resistance of forests to natural fire. However, it should be noted that within fire-sensitive habitats, there also exist fire-dependent ecosystems (Figure 3.2).

3.5 THE STATE OF THE WORLD'S TROPICAL FIRE REGIMES

The results from the expert assessment relative to the status of the world's fire regimes (i.e., their condition relative to being ecologically intact) show striking patterns by major habitat type and biogeographic realm.

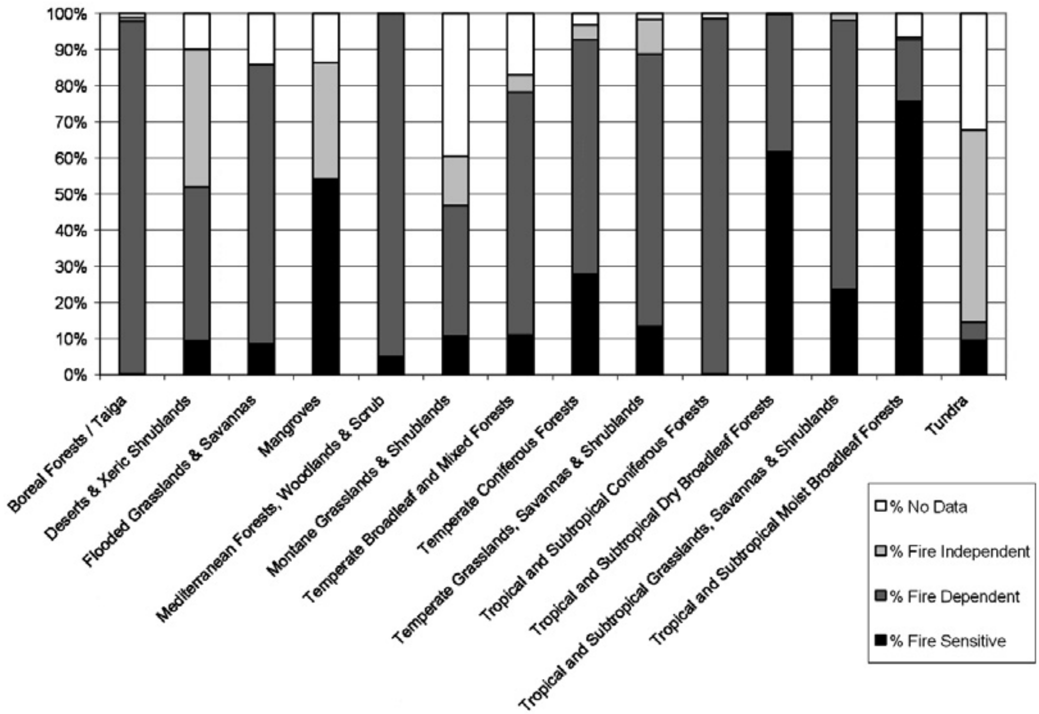

Figure 3.2. Proportion of major habitat types made up of each fire regime type (Shlisky *et al.*, 2007). *See also* Color section.

The GFP global fire assessment used the following classification of fire regime conditions:

- *Intact* fire regimes include those that have fire regime characteristics (e.g., fire frequency, severity, extent, and season) within their range of natural variability.
- *Degraded* fire regime conditions are those that are considered by experts to be outside their range of natural variation, but are considered restorable.
- *Very degraded* fire regime conditions are those far outside their natural range of variability, and may not be restorable.

Globally, only about 25% of the terrestrial area is considered intact relative to fire regime conditions (Shlisky *et al.*, 2007). These areas include the northern regions of Canada, and Asia, and scattered areas in South America, Africa, and Australasia (Figure 3.3). Compared with the distribution of fire regime types, with fire-sensitive habitats mostly concentrated in the tropics, the global distribution of degraded and very degraded fire regimes is spread all over the globe (Figure 3.3). The areas of degraded or very degraded fire regimes represent 70% or more of terrestrial tropical area including tropical and subtropical dry broadleaf forests, tropical and subtropical moist broadleaf forests, tropical and subtropical grasslands, savannas, and shrub-

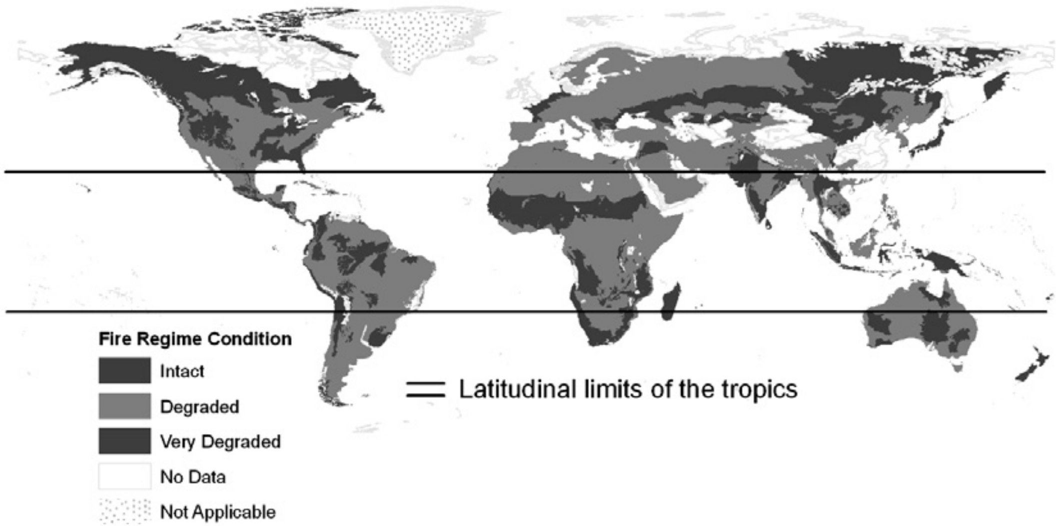

Figure 3.3. Global distribution of fire regime conditions (Shlisky *et al.*, 2007). *See also* Color section.

lands (with 79%, 75%, and 70% degraded or very degraded fire regime conditions, respectively) (Figure 3.4).

Altered fire regimes can change the species composition, structural characteristics, and fire characteristics of almost any terrestrial habitat. To effectively manage fire for people and nature, we need to understand the ecological drivers of intact fire regimes, and how people alter ecologically appropriate fire regimes for social benefit.

Relationships between fire and human land uses—the primary causes of fire regime alteration—often repeat themselves across geographic regions and time based on a handful of driving factors. Often, major habitat types experience similar fire-related threats across geographies, while the rate of change in sources of these threats—such as urban or agricultural development—may substantively differ geographically based on social contexts and the relative degree of economic development.

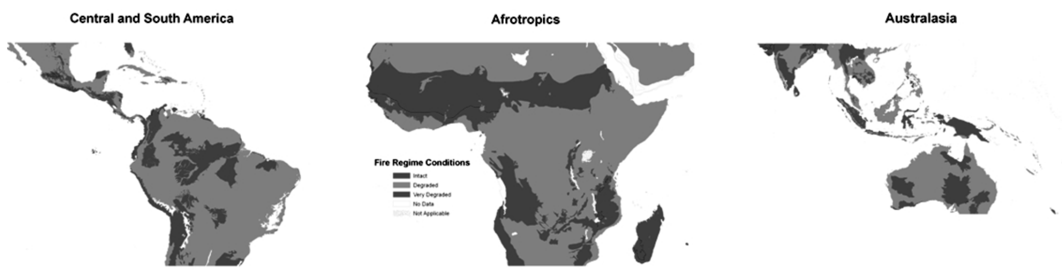

Figure 3.4. Distribution of fire regime conditions for the tropical regions of the world (Shlisky *et al.*, 2007). *See also* Color section.

3.6 CAUSES OF CHANGING FIRE REGIMES IN THE TROPICS

According to the GFP expert assessment and other analyses, the main causes of fire in the tropics originate from human sources (Goldammer, 1990). Changes in tropical fire regimes are both directly and indirectly linked with the expansion of human activities at the regional and global scale. Some of these causes include the drought promoted by climate change, logging, expansion of agriculture and livestock ranching, population growth and increased rural and urban development, energy production, fire management through exclusion or suppression, expansion of invasive species, cultivation of plantations, and arson.

3.6.1 Climate change

There is little information about the vulnerability of tropical ecosystems to anthropogenic changes in the climate and the atmosphere, but some preliminary studies and trends suggest possible threats. Although the future decrease in rainfall and increase in temperature caused by global warming is still a scientific debate in the tropics, temperature is expected to rise in the future in tropical regions (IPCC, 2001). Rainfall reduction is more uncertain but changes in the spatial distribution and pattern of precipitation are expected to occur in a warmer future in the tropics. In addition, our planet is expected to experience a temperature rise associated with more frequent and intense El Niño/Southern Oscillation events, which may accelerate evapotranspiration, exacerbating the effects of drought (White *et al.*, 1999; Foley *et al.*, 2003).

Andreae *et al.* (2004) found that the smoke from Amazon forest fires causes a decrease in the size of droplets in clouds which carries over to raindrops. Pollutants and water vapor retained in the atmosphere could cause a profound radiative impact on the climate system. Stronger storms release latent heat high in the atmosphere and, by doing so, affect regional and global circulation systems substantially. Thus, fires affect the hydrologic cycle, the pollutant load in the atmosphere, and the dynamics of atmospheric circulation (FAO, 2005).

Climate change influenced by anthropogenic greenhouse gas emissions has a high potential to change fire regimes in tropical regions (Goldammer and Price, 1998). One of the main influences of such phenomena is related to the increase in frequency and intensity of extreme drought events affecting the tropics (Thonicke *et al.*, 2001). These drought events are related with the occurrence of the El Niño/Southern Oscillation (ENSO; Van der Werf *et al.*, 2004). ENSO events cause regional changes in precipitation patterns and drought mostly in the north of South America, Central America, and Southeast Asia. However, it is suggested that these events are becoming more intense and frequent under an enhanced greenhouse concentration atmospheric condition (Trenberth and Hoar, 1997; Timmermann *et al.*, 1999). The last decades registered the two most intense ENSO events recorded (Timmermann *et al.*, 1999), causing severe drought and promoting large areas of understory fires in the Amazon and Indonesia regions (Tian *et al.*, 1998; Barbosa and Fearnside, 1999; Nepstad *et al.*, 1999a; Siegert *et al.*, 2001; Page *et al.*, 2002; Alencar *et al.*, 2004). The increase of fire will release more carbon to the atmosphere through both direct combustion and committed emissions from dead trees (Alencar *et al.*, 2006). The increase of CO_2 concentration in the atmosphere can directly influence the water temperature of tropical Pacific waters and generate more intense and frequent El Niño events, which will lead to more drought and fire. A future with more intensive and frequent severe droughts can create conditions for fire spread and shorten the return interval of fire in tropical forests, possibly leading to even greater land clearing.

3.6.2 Agriculture and livestock ranching

The most common type of fire in the tropics is the one used for land clearing and land use conversion (Nepstad *et al.*, 1999b; Manta and León, 2004; Dennis *et al.*, 2005). It is through the use of fire that humans have historically cleared the land, converting natural vegetation into agricultural fields and pasture (Nepstad *et al.*, 1999b; Walker *et al.*, 2000; Chazdon, 2003; Sorrensen, 2004), the most common land uses in tropical areas. In addition, fire has been widely used as an affordable management tool to convert biomass into soil nutrients, to clean pastures and avoid the spread of weeds, and to rejuvenate grazing fields (Uhl and Buschbacher, 1985; Goldammer, 1990; Manta, 2007). During the past decade, from 80,500 $km^2\,yr^{-1}$ to 92,000 $km^2\,yr^{-1}$ of forests were converted to other land uses in tropical regions through deforestation and fire (DeFries *et al.*, 2002; Achard *et al.*, 2004). The recent expansion of the agricultural frontier in tropical areas, such as soybean fields in the savanna and rainforests of Brazil or the palm oil plantations in Indonesia, has promoted large-scale deforestation and fire, fragmenting the landscape and increasing the source of ignition for forest fires (Barber and Schweithelm, 2000; Curran *et al.*, 2004; Morton *et al.*, 2006; Nepstad *et al.*, 2006; Vayda, 2006; Langner *et al.*, 2007).

The relationship between tropical agricultural production systems and land clearing has an important role in causing fire-prone conditions, and thus expanding the influence of human causes of fire in the tropics. In the Brazilian Amazon and Indonesian Borneo, fire used after deforestation or to clear pasture and crop fields is recognized to be a major source of ignition for accidental fires in agriculture lands as well as forests (Nepstad *et al.*, 1999b; Siegert *et al.*, 2001; Page *et al.*, 2002; Langner *et al.*, 2007). Therefore, deforestation promotes forest fragmentation with direct implications on large-scale edge effects, forest degradation, and regional climatic change (Cochrane and Laurance, 2002). Fragmentation increases the forest areas affected by edge effects decreasing their humidity, provoking species decay, increasing fuel material, and enhancing their susceptibility to fire (Nepstad *et al.*, 1999a; Cochrane, 2003; Alencar *et al.*, 2004; Laurance, 2004). A fragmented landscape also leads to micro-climatic and meso-climatic changes, enhancing surface warming and influencing precipitation suppression at a regional scale (Laurance, 2004; Malhi and Wright, 2004; Ometto *et al.*, 2005). Changes in the regional precipitation pattern and the availability of dry fuel material enhance forest flammability and create conditions for the spread of fires (Cochrane *et al.*, 1999; Cochrane, 2003; Nepstad *et al.*, 2004; Balch *et al.*, in press). Moreover, the increase of fires in a fragmented landscape can lead to a future change in forest composition and structure (Nepstad *et al.*, 2004).

Fires caused during deforestation activities also represent the greatest source of CO_2 released to the atmosphere through biomass burning and further soil decomposition in tropical regions. Achard *et al.* (2004) suggested that 71% of land use change in carbon dioxide emissions came from burning after deforestation. This amount represented about one-fourth of the anthropogenic carbon dioxide emissions to the atmosphere during the 1980s and 1990s (IPCC, 2001; Ometto *et al.*, 2005). Amazon land use change alone is responsible for approximately 5% to 20% of global emissions (Houghton, 2003). However, deforestation-related CO_2 emissions are also of considerable concern in the Indo-Malay realm. In Indonesia, vast tracts of forest, including peat swamp forest, have been converted to plantation crops such as rubber and oil palm. To convert peat swamp forest to oil palm plantation, the water in the forest is drained, leading to peat oxidation, subsidence, and drying, which make these areas susceptible to widespread fire. Page *et al.* (2002) estimated that between 0.81 Gt and 2.57 Gt of carbon were released to the atmosphere in 1997 as a result of burning peat and vegetation in Indonesia. This is equivalent to 13% to 40% of the mean !nnual global carbon emissions from fossil fuels, and contributed greatly to the largest annual increase in atmospheric CO_2 concentration detected since records began in 1957. With the ongoing increase in palm oil prices and the production of bio-diesel, there is more pressure to open large areas to oil palm plantation. Together, deforestation, ecologically inappropriate agricultural practices, and market forces can increase the susceptibility of anthropogenic landscapes and natural vegetation to fire and lead to a major shift from an infrequent to a more frequent fire return interval in the tropics.

Another important issue related to fire occurrence and human activities surrounds the extent or period in which an area is continuously used for livestock grazing. During the last 60 to 100 years, tropical forests have been used intensively as grazing lands, in particular in the driest and most easily accessed habitats. In several places, this activity has prevented recovery after fire because, even though the main tree species are relatively resistant to grazing once they become a young tree, high pressure during the early post-fire regeneration stages may prevent the regeneration of wood species locally. This may allow development of degraded steppe formations with abundant exotic species, or shrubland of thorny bushes and low trees, contributing to the extent of degraded forests and savannas in the intertropical zone.

In sum, land use change for timber production, agriculture, and livestock ranching are important causes of change in fire regimes. The expansion of agriculture and cattle ranching has promoted large-scale fragmentation, increasing the number of sources of ignition and enhancing the susceptibility of forest fragments to fire. At the beginning of this century, the Brazilian Amazon forest has faced the second worst rates of deforestation (Ometto *et al.*, 2005; Nepstad *et al.*, 2006), contributing to the country's CO_2 emissions through biomass burning and the subsequent decomposition of soil organic matter. Transportation infrastructure investments, the expansion of cattle ranching and soybean plantations, and logging were the underlying causes behind this increase in the region (Nepstad *et al.*, 2001). The deforestation dynamic and its interaction with local and global climate is changing the fire regime in tropical regions and creating mechanisms of positive feedbacks that may lead to enhanced drought and fire spread risk, fragmentation, and degradation, as well as negative economic and human health consequences (Nepstad *et al.*, 2001; Cochrane, 2003).

3.6.3 Rural and urban development

The expansion of rural and urban development has played an important role in changing the fire regime in the tropics. Rural and urban development has been heavily influenced by road infrastructure in tropical regions of South America (Laurance *et al.*, 2001). Transportation investments have promoted intensive migration and rapid population growth to rural and urban areas located in previously remote areas. This process creates incentives for large-scale land clearing and consequently fire use. An increase in deforestation and fire in the agricultural frontier promotes landscape fragmentation and increases the number of sources of ignition. These two elements together with drier climatic conditions are determinant to fire occurrence in tropical moist forest areas, increasing the chance of more frequent fires.

3.6.4 Energy production

There are several scales in which energy production can contribute to changes in tropical fire regimes. At the global scale, fossil fuel combustion for energy production represents the major source of CO_2 emissions, an important greenhouse gas influencing global warming (IPCC, 2001). The production of charcoal for thermoelectric plants is one of the main sources of energy that have a major local impact on fire frequency and intensity. Charcoal production in eastern Amazonia, for instance, is associated with logging and the spread of forest fires (Alencar *et al.*, 2004). The expansion of soybean, sugar cane, palm oil, and other crops that can be used to produce both edible oils and biofuel also represent a threat to fire regimes since they involve land clearing, directly or indirectly taking the place of cattle pasture or logging concessions (oil palm), further advancing the agriculture frontier and converting new areas of forest and savanna.

3.6.5 Fire exclusion and suppression

Fire exclusion and suppression represent causes of fire regime alteration that have the most directed and localized effect. The suppression of fire in fire-dependent ecosystems allows fuels to build up and changes forest composition. Fuel build-up has a major influence on the intensity of wildfire events, favoring the development of species more sensitive to fire, and thus promoting changes in forest composition. In the tropics, the exclusion of fire in savanna regions that are located close to forest areas can lead to expansion of forest species into savanna areas (Hoffmann *et al.*, 2003).

3.6.6 Invasive species

The rapid spread of invasive species and the fact that they are often favored by previous disturbances contribute to their establishment and resistance to fire events. In the tropics, the influence of invasive species is more conspicuous in island environments; with time and the continuance of human-caused disturbance, this threat may increase in importance elsewhere. Depending on the characteristics of the invasive species they can become constant fuel for fire, or they can reduce the necessity of fire. In sum, fire frequency, season, and intensity can either increase or decrease due to the presence of such species.

3.6.7 Plantations

Plantations of pyrophytic species of pine and eucalyptus are another mechanism that changes the loads and continuity of fuel in tropical landscapes. Afforestation with eucalyptus and conifers in ecotone steppes and shrubland has been practiced for about 50 years as a sustainable alternative to cattle farming. There are also some systems that produce significant regional changes in fuel quality and availability, such as forests where bamboo reproduces synchronously every 50 to 70 years (e.g., *Chusquea* spp.), dies massively, and produces extremely high loads of very flammable dry matter (Keeley and Bond, 1999). Although this constitutes a natural cycle of the fuel levels in the forest, combined with a larger presence of human-caused ignitions, it could induce fire events on a large scale.

3.6.8 Arson

Arson represents one important cause of uncontrolled forest fires in the tropics. This type of premeditated fire is known to be common in areas where conflicts over natural resources are present (Vayda, 2006). Arson represents the most difficult type of human-caused fire to be accurately identified and classified due to its criminal origin. Even if frequent all over the tropics, the criminal status of arson imposes a barrier for its classification, since no one wants to assume the act of setting a fire on purpose. For that reason areas affected by arson are usually assumed and classified as accidental or escaped fires. The reasoning behind arson is usually imbedded on the expansion of land clearing, warranty of property, and pressure to assure the right to explore forest resources and land. Vayda (2006) suggests a strong linkage between arson with conflicts over land use or resource access. Occurrences of arson in the tropical forests of Brazil are usually related to the fact that land owners, wanting to convert their already logged forest into cattle ranching, set subsequent fires into the forest to impoverish it and thus provide a reasoning for its conversion to a more productive land use (Nepstad *et al.*, 1999b).

3.7 INTERACTIONS

In addition to the direct threats to maintaining and restoring fire's ecological role, threats often interact to increase the ecological, social, and economic impacts of altered fire regimes. For example, livestock farming and ranching often contributes to the introduction and spread of invasive species, which in turn alters fire regimes by changing fuel types and continuity. In addition, climate change can exacerbate the spread of ecologically damaging agriculture and ranching fires by increasing the flammability and vulnerability of adjacent habitats. Similarly, logging and commercial plantations can make forests more vulnerable to fire spread, causing adjacent slash-and-burn practices to threaten commercial forest investments.

In any particular geographic area, the sources of fire regime alteration may differ substantially due to local ecological and social conditions. In some places, while we may observe that fire regimes are altered, we may not know with certainty the ultimate cause without further investigation.

3.8 PRESCRIBED BURNING FOR ECOLOGICAL BENEFIT

Besides land clearing, humans have also used fire to manage natural vegetation through prescribed burns. This practice started to be used for fuel reduction to prevent and control wildfire occurrences mostly in fire-dependent ecosystems in temperate areas. These ecosystems have been suffering from decades of fire suppression allowing the build-up of fuel and increasing the severity and intensity of wildfires. Besides fuel control, fire management has been also prescribed to maintain and restore fire-dependent habitats (Goldammer, 1990). Humans use fire to manage natural vegetation to favor specific species succession, to conserve ecosystems, and to decrease the risk of wildfire occurrence (Bond and van Wilgen 1996).

Although prescribed burns are important for the ecological benefit of natural systems, it is not a very common practice to manage, restore, and conserve fire-dependent tropical ecosystems. Experiences of consecutive prescribed burns have been used to evaluate the mortality of fire-tolerant species in the savannas of Brazil (Miranda *et al.*, 1996). Other experiences of prescribed burns in the tropics include the control of bush encroachment in Etosha National Park in the savanna of southwest Africa (Van Wilgen *et al.*, 1990), and the replication of aborigines' fires in the savannas of Australia (Gill *et al.*, 1990; Bradstock *et al.*, 2002).

3.9 INTEGRATED FIRE MANAGEMENT

Integrated fire management (IFM) is increasingly being applied around the world to address both ecological and socio-economic problems and issues. IFM is an approach that considers both damaging and beneficial fires within the context of the natural environments and socio-economic systems in which they occur (Myers, 2006). IFM is a framework for evaluating and balancing the relative risks posed by fire with the beneficial or necessary ecological and economic roles that it may play in a given area.

In most places—from landscapes to regions—there is a need to implement cost-effective approaches to both preventing damaging fires and maintaining desirable fire regimes. When fires do occur, IFM provides a framework for (1) evaluating whether the effects will be detrimental, beneficial, or benign; (2) weighing relative benefits and risks; and (3) responding appropriately and effectively based on the stated objectives for the area in question. IFM takes into account fire ecology, socio-economic issues, and fire management technology to generate practical solutions to fire-related threats to biodiversity. Within the framework of IFM, a number of strategies are necessary to restore and maintain fire regimes in the face of increasing land use, climate change, and uninformed public policies, including

(1) ***Evaluate whether the effects of fire will be detrimental, beneficial, or benign***

- Geographic patterns in fire's ecological role, the human land uses that maintain or alter this role, and needs for community health and safety should be used to inform conservation and land management goals, priorities, and actions.

(2) ***Weigh the relative benefits and risks of fire and human actions***

- Habitats that currently have intact fire regimes are relatively rare and should be monitored for trends that may degrade the ecological role of fire, such as climate change, urban development, energy production, and agriculture.
- Fire is an integral part of many habitats, and the value of the environmental services that intact fire regimes provide must be weighed against the social and economic values of these habitats for human development and resource use.
- The benefits and risks of maintaining fire's ecological role, or preventing its detrimental environmental and social impacts, should be considered within the context of local social and ecological systems and conditions.

(3) ***Respond appropriately and effectively***

- Protect, restore, and maintain habitats that can be used to demonstrate the ecological role of fire and compatible social and economic uses.
- Promote and enable laws and policies for land uses such as agriculture, ranching, logging, energy production, housing, transportation infrastructure, and natural resources management such that they are compatible with maintaining the ecological role of fire, or preventing fire where it is destructive.
- Promote and enable public policies relating to climate change, emissions, fire suppression, and air quality such that they protect human health and safety and biodiversity, but do not constrain the needs for restoring and maintaining fire-dependent habitats.
- Create economic incentives to manage landscapes for fire, nature, and people, including payment to land owners for restoring and maintaining the ecosystem services of intact fire regimes, tax or other incentives for the commercial market-

ing of woody biomass and other products of restoration, and implementation of development loan criteria that integrate fire's ecological role.

- Recognize gaps in fire capacity, and build adequate capacity for integrated fire management, including training, mentoring, and human and material resources.
- Educate practitioners, policy makers, and decision makers about the ecological role of fire and the ecological and social risks and costs of altered fire regimes.
- Monitor fires and changes in land use and land cover for ecological forecasting, threat analysis, emergency response, and assessing the effectiveness of conservation, land management, and human development actions.
- Commit to learning and being adaptive to changing knowledge, social and political contexts, and ecological conditions.

3.10 CONCLUSIONS

Given the current lack of comprehensive and globally consistent data, expert-based, collaborative analysis of the world's fire regime conditions has proven to be a valuable tool to improve our knowledge and understanding of the state of the world's terrestrial habitats. Over 70% of tropical and subtropical dry broadleaf forests, tropical and subtropical moist broadleaf forests, and tropical and subtropical grasslands, savannas, and shrublands are ecologically degraded or very degraded in their fire regimes. Urban development, resource extraction (including energy production, mining, and logging), fire and fire suppression, agriculture, climate change, and arson are all contributing to the alteration of fire regimes, sometimes with far-reaching social and economic consequences. Integrated fire management—a proven framework, at least at the landscape level, for assessing and balancing issues posed by both damaging and beneficial fires within the ecological, social, and economic contexts in which fires occur—can help prevent further degradation of fire regimes and restore areas where fire's natural role has been altered. With time, we may see increases in regional applications of these methods.

What can we do to help bring about a shift toward integrated fire management? How do we influence people, governments, and organizations to recognize and take action to address the myriad ecological, social, and economic issues that have significantly altered fire regimes across most of the globe? Clearly this requires broad and effective communication and outreach from governmental and non-governmental partners in fire management. Moreover, quantifying the socio-economic costs of fire to various agents can stimulate changes in practices and enforcement. Effective collaborations that aim to understand ecosystem and human relationships to fire in a given locale can support consensus on possible solutions. Yet, we must also appreciate that both the causes and the solutions of fire-related problems are inextricably linked to other critical concerns, including climate change, invasive species, and forest and rangeland management practices. Ultimately, these efforts will require sustained funding, perhaps via multilateral donor organizations, ecosystems services schemes and convincing country governments to boost budgets allocated to addressing fire-related issues.

The global needs for ecologically appropriate and socially responsible fire management are enormous, and fire's relationship to human health and safety are complex. Only through collaboration and cooperation, within and across borders, can we achieve our collective goals for fire, people, and nature.

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