Fire, ecosystems and people: Threats and strategies for global biodiversity conservation[1]

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Abstract

Fire plays a major role in shaping our environment and maintaining biodiversity. When fire regimes are altered, they can contribute to climate-changing greenhouse gases into the environment, provide a pathway for harmful invasive species, alter the hydrology of a site, and present a direct risk to biodiversity and human habitation. Effective biodiversity conservation requires, among other things, that fire is allowed to play a natural role and at the same time that it does not pose a threat to biodiversity or human well-being. The Global Fire Partnership (GFP) includes The Nature Conservancy, World Conservation Union (IUCN), University of California at Berkeley Center for Fire Research and Outreach, and the World Wildlife Fund (WWF). The GFP implemented 3 expert workshops between January and July 2006 covering four broad biogeographic realms to establish scientifically credible data consistently at coarse ecoregional levels for global biodiversity conservation. Results revealed that 25 percent of terrestrial area is intact relative to fire regime conditions. Ecoregions with degraded fire regimes cover 53 percent of global terrestrial area while ecoregions with very degraded fire regimes cover 8 percent. Assessment continues of the remaining 13 percent. Globally, boreal forests and taiga are the most intact systems relative to fire regime conditions, and

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Mediterranean forests, woodlands and scrub are the most degraded. Based on regional expert workshops, the top threats to maintaining an ecologically-acceptable role of fire include ecosystem conversion (e.g., livestock ranching, agriculture, urban development), resource extraction (e.g., energy production, mining, logging and wood harvesting), and human-caused fires or fire suppression. Effective biodiversity conservation depends on building global to local constituencies and partnerships focused on abating the leading causes of altered fire regimes, enabling public policies and local capacities to make a difference at ecologically-relevant scales, educating practitioners and policy- and decision-makers about the ecological role of fire and the ecological and social costs of altered fire regimes, implementing Integrated Fire Management, creating economic incentives for maintaining intact fire regimes, monitoring fires and changes in land use and land cover, enforcement of laws that support ecologically-appropriate fire prevention and fire use, and being adaptive to changing knowledge, social and political contexts, and ecological conditions.

Introduction: Fire is a Global Conservation Issue

Fire is a natural process that has played a major role in shaping our environment and maintaining biodiversity world-wide. Fire's benefits and impacts are extensive; the majority of the world's terrestrial habitats depend on fire for ecological sustainability. Fire often determines the distribution of habitats, carbon and nutrient fluxes, and the water retention properties of soils. In habitats accustomed to fire and dependent on it for ecological health, fire exclusion often results in reduced biodiversity and increased vegetation density, often increasing risks of catastrophic fire over time.

In addition, fire has been, and still is an important tool used by humans to shape the land, producing cultural landscapes that can also support ecological health. However, in habitats not accustomed to fire – such as in much of the world's wet tropical forests – human introduction of fire can transform them in ways that lead to social, economic, species, and environmental losses. When human actions cause too much, too little, or the wrong kind 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.

The United Nations Millennium Development Goals – adopted by 189 out of 193 nations in 2000 – includes a goal to ensure environmental sustainability. While most countries have committed to the principles of sustainable development, tangible action has not been sufficient to reverse the loss of the world's environmental resources (UN 2005). This includes actions necessary to reverse the loss of the ecological benefits of fire from our natural environment, and to prevent fire from destroying habitats that are sensitive to it.

Given the extensive benefits and risks to environmental, social, and economic well-being from fire, biodiversity conservation must take fire into account. A recent global assessment revealed that eight of 13 of the world's terrestrial major habitat types[20] fall short of a 10 percent goal for effective conservation (The Nature Conservancy 2006). In addition to the safeguarding of habitats in protected areas such as National Parks and other natural areas, effective biodiversity conservation requires, among other things, that fire be allowed to play its ecological role, while not posing a threat to biodiversity or human well-being. This means that land protection or

[20] 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).

management policies must allow for appropriate fire management – be it prescribed burning for biodiversity benefit, or fire prevention to protect fire-sensitive habitats.

Fire is a complicated conservation issue since it rarely stands alone. It interacts with many other global threats to biodiversity: agricultural expansion, urban and exurban development, land use change, energy development, overgrazing, fire exclusion, climate change, invasive species, logging, water developments, and transportation infrastructure. These same 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 considered as a key ecological process or a threat to biodiversity and human livelihoods – can have unwelcome and far reaching consequences.

Conservation of Habitats Worldwide: The Nature Conservancy's Global Habitat Assessments

In 2006, The Nature Conservancy completed an interim report on the state of the world's major habitat types (TNC 2006). This Global Habitat Assessment was part of the Conservancy's process for defining long-term conservation goals and priorities. This assessment showed that less than 10 percent of the following major habitat types are currently effectively conserved:

- Tropical dry broadleaf forests
- Tropical coniferous forests
- Temperate broadleaf and mixed forests
- Boreal forests/taiga
- Tropical grasslands, savannas, and shrublands
- Temperate grasslands, savannas, and shrublands
- Mediterranean forest, woodlands, and scrub
- Deserts and xeric shrublands

These habitats not only fall short of an adequate area within protected status to safeguard the full spectrum of the world's biodiversity, but in many cases current land uses and policies cause even "protected" habitat conditions to fall below ecological standards for biodiversity health. Global conservation efforts must take an integrated approach that strives to protect biodiversity, and also enables policy and land and fire management actions that are compatible with maintaining or restoring biodiversity health.

Addressing fire as a global conservation issue has benefits for societies and economies. Sustaining ecological processes, such as fire, is a key component of conservation success. However, fire ecology and how humans relate to fire combine to create complex conservation challenges. Achievement of solutions will require global partnerships, the commitments of governments, conservation and research organizations, and private partners to balance the benefits and threats of fire, and mechanisms for resource sharing between developed and developing countries.

Fire Plays a Role in Ecosystems and Society

This section introduces the concepts of fire-dependent, fire-sensitive and fire-independent ecosystems and explains what a fire regime is and how fire regimes can be altered in each of these three different ecosystem types. The consequences of altering fire regimes, for both ecosystems and humans, need to be understood in order to effectively conserve biodiversity.

The ecological role of fire around the world ranges from a process that strongly drives ecosystem structure and function (*fire-dependent* ecosystems – see definitions below) to having no evolutionary significance (*fire-independent* ecosystems). The role of fire in human society ranges from acceptance and use as a land management practice to fear of its threat to lives, property and livelihoods. Even societies that use fire as a land management tool often greatly fear fire when it is perceived as "out of control." In some ecosystems wildfire has natural selection significance, and the human use of fire as a land management tool may have long-standing cultural significance (Myers 2006, Pyne 1982, Yibarbuk 1998, Goldammer and de Ronde 2004). In many places, periodic burning is used to maintain natural fire regimes – those that are consistent and compatible with the adaptations of species and natural processes - that help to sustain and rejuvenate ecosystems (Hassan and others 2005). Evidence suggests that human induced fires accelerate the trend of ecosystem transformations caused by climate change in the long term (Kershaw and others 2002).

Definitions: Fire's Ecological Role

Ecosystems can be classified in terms of their relationship to fire regime characteristics such as fuels, flammability, ignitions, and fire spread conditions within a given ecosystem.

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 – at 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 fire-sensitive forests can also create a negative 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).

Fire-dependent, -sensitive and -independent ecosystems can be further classified in terms of their condition. For example, through human land uses, even fire-independent systems can experience greater fire incidences than have occurred naturally through the introduction of invasive exotic species, or excessive human-caused ignitions.

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.

Altered fire regimes can change the species composition, structural characteristics, and fire characteristics in any ecosystem. To effectively conserve biodiversity, we need to understand not only how fire naturally behaves in ecosystems, but also how people use or alter native fire regimes for ecological and social benefit. Certain human land uses can alter the healthy functioning of fire in any ecosystem type – whether it be fire-dependent, fire-sensitive or fire-independent. For example, rural development in *fire-dependent* ecosystems often brings with it suppression of all fire incidents – natural and human-caused - to protect human communities. Rural development in *fire-sensitive* ecosystems may have a different impact. Housing and infrastructure development is often followed by human-caused fires that require fire prevention or suppression for the sake of biodiversity conservation. In order to craft effective strategies, conservation organizations and partners need to understand ecosystem and human relationships to fire.

Assessment Methods: Scientific Collaboration Leads to Understanding Fire Ecology, Threats and Strategies

The Global Fire Partnership (GFP), launched in 2004, includes The Nature Conservancy, World Conservation Union (IUCN), University of California, Berkeley's Center for Fire Research and Outreach, and WWF. The GFP recognizes the need to assess the state of the world's fire regimes, craft effective conservation strategies, and build a global constituency of partners to address fire as a conservation issue. 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 (TNC 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 assessment described here.

To better understand the global role of fire in biodiversity conservation, and to identify the actions necessary to abate threats to maintaining and restoring fire's ecological role, the GFP implemented three expert workshops between January and July 2006 covering four broad biogeographic realms – Australasia, Indo-Malay, Nearctic and Neotropic[21]. Realm-level workshops were designed to establish a consistent global dataset of the ecological roles of fire and threats to maintaining those roles at a coarse resolution, which could then be applied to biodiversity conservation globally. Workshops also aimed to illuminate linkages between fire, climate change, and other human-caused threats to biodiversity, while also strengthening collaboration and partnerships among experts, managers and policy-makers.

Workshops began with preliminary global fire assessment data developed by the GFP in 2004 (TNC 2004). These data represented fire regime types, conditions, and threats across WWF Global 200 ecoregions – a subset of all terrestrial ecoregions worldwide. Between August 2005 and January 2006, literature review and expert surveys were conducted to fill the majority of gaps in the preliminary assessment. 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

[21] 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).

workshops in 2006, experts were organized into regional teams of scientists, land managers, and decision-makers to review the 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 over 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, 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, U.S.A. By providing a spatially-enabled web interface for data collection, the tool greatly facilitated the collection and storage of expert information into a master database from anywhere in the world. The tool captures contact information about experts using the tool, and then walks users through a series of questions about the role of fire, fire regime conditions, sources of fire regime alteration, and the level of scientific confidence by ecoregion. The tool is available in English and Spanish, and is publicly accessible at: http://giifweb.cnr.berkeley.edu/tnc/

Sources of fire-related threats and key strategies for abating altered fire regimes followed the IUCN-Conservation Measures Partnership classification (IUCN-CMP 2006). In some cases, regional information, such as spatial fire regime condition class data for the U.S. (e.g., U.S. Department of Agriculture Forest Service, U.S. Department of the Interior and The Nature Conservancy LANDFIRE project; www.landfire.gov), was compared to global data. Participants were also asked about the regional significance of collaborative fora, as described here, for discussing and addressing fire regime conditions and trends.

The expert global database was analyzed to summarize patterns in natural fire regime characteristics, current fire regime conditions, and threats to maintaining fire regimes by major habitat type and realm.

Assessment Results: Healthy Fire Regimes are a Component of Environmental Health

The findings of the Global Fire Assessment indicate that fire-dependent ecoregions cover 53 percent of global terrestrial area; fire-sensitive ecoregions cover 22 percent; and fire-independent ecoregions cover 15 percent. The distribution of these areas varies across biogeographic realms and major habitat types. For example, the Nearctic realm is dominated by fire-dependent ecosystems (75 percent of the realm), while the majority of the Neotropics (63 percent) are made up of fire-sensitive ecosystems. The assessment has not yet covered about 10 percent of terrestrial land area (mostly in eastern Europe and parts of Asia.

The status of fire regimes – their condition relative to ecologically intact conditions – show striking patterns by major habitat type and biogeographic realm. Globally, 25 percent of terrestrial area is intact relative to fire regime conditions. Ecoregions with degraded fire regimes cover 53 percent of global terrestrial area while ecoregions with very degraded fire regimes cover 8 percent. Assessment of the remaining 13 percent of global terrestrial area continues.

Relationships between fire and human-caused fire regime alteration – whether the fire regime is intact, degraded, or very degraded – often repeat themselves across ecoregions and time based on a handful of driving factors. Often, major habitat types experience similar threats across geographies, while the rate of change in keystone fire-related threats – urban or agricultural development, for example - may substantively differ geographically based on social contexts and the relative degree of economic development.

Globally, boreal forests and taiga are the most intact systems relative to fire regime conditions (69 percent of boreal ecoregions are considered intact), largely due to their relative geographic isolation and undeveloped nature. Mediterranean forests, woodlands and scrub are the most degraded (93 percent degraded or very degraded), largely due to their fire dependence, their attractiveness to human development, and the fire exclusion and fragmentation threats that go with this development.

Major habitat types that are considered over 30 percent intact include:

- Boreal forests / taiga (69 percent intact)
- Flooded grasslands and savannas (38 percent)
- Temperate coniferous forests (38 percent)

Major habitat types where the assessment indicates that 70 percent or more of terrestrial area is degraded or very degraded include:

- Mediterranean forests, woodlands and scrub (93 percent degraded or very degraded)
- Tropical and subtropical dry broadleaf forests (79 percent)
- Tropical and subtropical moist broadleaf forests (75 percent)
- Temperate broadleaf and mixed forests (73 percent)
- Deserts and xeric shrublands (72 percent)
- Temperate grasslands, savannas and shrublands (70 percent)
- Tropical and subtropical grasslands, savannas and shrublands (70 percent)

This assessment provides a consistent, ecologically-based snapshot of the state of the world's fire regimes, and a framework for consideration of fire ecology in land and fire management decision-making. However, it is clearly too coarse for use in development of local fire management and conservation strategies, and within-ecoregion variation in conditions and threats exist to a great extent. Regional, country, and landscape fire assessments, such as the U.S. LANDFIRE project and the Canadian BURN-P3 (Parisien and others 2005) are necessary to determine specific strategies that are relevant to local geographies and social contexts.

Analysis: Fire's Ecological Role is Threatened by Human Land Uses, Climate Change and Public Policies

Globally, based on results of regional expert workshops for ecoregions in the Neotropic, Indo-Malay, Australasia and Nearctic realms, the top threats to maintaining the ecological role of fire in habitats include:

- Urban development;
- Livestock farming, ranching and agriculture;
- Fire and fire suppression;
- Resource extraction (i.e., energy production, mining, logging); and
- Climate change.

The remainder of this section discusses each of these threats and the extent of their influence across ecoregions, describing the various ways they can affect fire regimes and explaining why these threats are so prominent today.

Urban Development

Urban development is a top threat in the majority of major habitat types (13 of 14) and in over 25 percent of all terrestrial ecoregions assessed worldwide. Urban development directly and indirectly causes loss of biodiversity through land conversion, creates vectors for human-caused fire ignitions and invasive species, and encourages fire management policies that exclude fire from fire-dependent ecosystems. Fire management policies that accompany urban development are typically focused on fire suppression and community protection and are a direct threat to fire dependant ecosystems (Hassan and others 2005). More often than not, fire policies for community protection at the wildland-urban interface are implemented to the detriment of biodiversity conservation. Urban developments often preclude the use of ecologically-appropriate "let burn"or "wildland fire use" policies, which allow natural fires to run their course under specified environmental conditions.

Multilateral, national and local development policies generally do not adequately address the need to consider human relationships to natural fire regimes. These policies create barriers to conserving fire's role, or even create incentives to directly alter fire regimes through development. These policies often pose barriers to the use of fire in ecological restoration *or* community protection. Social transmigration schemes, whereby villages or communities are moved from one location to another for rural development purposes can also pose a threat to fire regimes. Often, transplanted communities lack familiarity with their new environment and the land and fire uses that that can be sustained there. Combined with a lack of understanding of local fire ecology, this can lead to a loss of the natural fire regime. For instance, colonization of the temperate forests of Mexico's Sierra Madre Occidental led to a drastic decrease in fire frequency in the early to mid 1900s (Heyerdahl and Alvarado 2003). More recently, extensive colonization of the Brazilian Amazon forest created a massive fire problem that it is threatening the sustainability of one of the most biodiverse biomes (Cochrane 2002).

Livestock Farming, Ranching and Agriculture

Modern and traditional grazing and ranching practices are an expanding threat to biodiversity worldwide, particularly where food security is a global priority. These practices have altered fire regimes across the vast majority of major habitat types worldwide (12 of 14), and affect almost 25 percent of all terrestrial ecoregions assessed. In fire-dependent ecosystems, such as temperate, tropical and subtropical grasslands, savannas, and shrublands, livestock farming and ranching reduces fuel levels, connectivity and patchiness, and thus the ability of an ecosystem to carry fire on a large scale.

Agriculture is a top global source of threat to biodiversity overall, and alters fire regimes in at least 30 percent of all ecoregions worldwide (and 12 of 14 major habitat types). Major habitat types particularly at risk include tropical and subtropical dry broadleaf forests, tropical and subtropical grasslands, savannas and shrublands, tropical and subtropical moist broadleaf forests, and flooded grasslands and savannas. In tropical areas, large areas of peat swamp forest have been converted to agricultural land. This results in altered drainage patterns leading to degraded peat swamp forests and high fire risk.

Slash and burn shifting agriculture and ranching are predominant practices in many parts of the developing world, and a way of life for many people. In fire-sensitive systems, such as tropical and subtropical dry and moist broadleaf forests, ecologically-inappropriate fire use for land clearing, forage management, and shifting agriculture leads to direct conversion of habitat. When fires escape, adjacent forests are also impacted. The environmental degradation that results from poor fire management practices can trap local people in a "poverty cycle", where poverty leads to environmental degradation, which then reduces the capacity of ecosystems to sustain human livelihoods.

Fire and Fire Suppression

Fire regimes in almost all major habitat types (13 of 14) are threatened by ecologically-inappropriate human introduction of fire or fire suppression. Over 20 percent of all terrestrial ecoregions assessed experience altered fire regimes through direct fire suppression or human-caused ignitions outside the range of natural variation. Across fire-dependent habitats, fire suppression to protect human values not only directly alters fire regimes, but can also lead to further degradation from increased forest and shrub densities, loss of fire-adapted species, increases in fire-sensitive species, and uncharacteristic fire behavior when fires escape suppression forces.

A UN analysis of national fire policies in 1998 concluded that fire mitigation policies were generally weak, and were rarely based on reliable data of forest fire extent, causes or risks (ECE/FAO 1998). Inadequate forest management policies are often incompatible with biodiversity conservation, particularly policies aimed at total fire exclusion in fire-dependent ecosystems, which can lead to fuel accumulation and catastrophic fire outbreaks (Hassan and others 2005). Public policies that ban or severely limit burning can also put people at risk of breaking laws when their intentions are to maintain ecological processes and traditional cultures. Intentional and unintentional human-caused ignitions, where there is little fire management capacity to prevent or suppress them, degrade the ecological sustainability of fire-sensitive and fire-independent ecosystems by increasing their vulnerability to invasive species and future fires.

Resource Extraction

Fire regimes in over 13 percent of all terrestrial ecoregions assessed (and 12 of 14 major habitat types) are considered to be altered by energy production and mining. Energy production and mining is an expanding threat worldwide as development increases and global energy markets shift. Transportation infrastructures for energy and mining operations – roads, powerlines, pipelines, railroads – act as a conduit for both invasive species and increased human-caused fire ignitions in fire-dependent, fire-independent and fire-sensitive ecosystems. The alteration of fire regimes at this "development frontier" has exponentially greater consequences for biodiversity in fire-sensitive systems, where the area of fire spread and deforestation can be much greater than the area impacted by the energy and mining operations themselves.

In addition, fire regimes in over 3 percent of all terrestrial ecoregions assessed (and seven of 14 major habitat types) are considered to be altered by logging and wood harvesting. Logging and wood harvesting are of particular concern relative to its alteration of fire regimes in the Indo-Malay, Nearctic and Neotropic realms. Logging and wood harvesting can be a direct source of threat through human-caused ignitions, or through the indirect effect of altering fuels and moisture conditions that encourage "too much" fire. "Too little" fire, in terms of number and severity, may also result from fuelwood collection for domestic use by rural communities. Modification of fuelbed structure can also reduce crown fires where they are part of the natural regime. Forest certification strategies that aim to ensure ecologically sustainable logging and wood harvesting practices can be greatly improved by including the need for fire in fire-dependent ecosystems, and need for fire suppression, mitigation and prevention in fire-sensitive and fire-independent ecosystems.

Climate Change

Fire experts identified climate change as a potential cause of fire-related threats to biodiversity in 4 percent of all ecoregions worldwide and 12 of 14 major habitat types. Regional expert workshops, however, revealed a range in judgment of the relative importance of climate change compared to other sources; the actual importance of climate change in altering fire regimes may likely exceed the expert ranking.

Climate change is already increasing fire frequency and extent by altering the key factors that control fire: temperature, precipitation, humidity, wind, ignition, biomass, dead organic matter, vegetation species composition and structure, and soil moisture (IPCC 2001). These changes threaten proper ecosystem function and the provision of ecosystem services (Hassan and others 2005, IPCC 2001, Turner and others 1997). Warmer temperatures, decreased precipitation over land, increased convective activity, increases in standing biomass due to CO_2 fertilization, increased fuels from dying vegetation, and large-scale vegetation shifts comprise the most significant mechanisms through which global warming increases fire at the global scale. In the case of fires larger than 400 hectares in mid-altitude, federally-managed conifer forests of the western U.S., an increase in spring and summer temperatures of 1ºC since 1970, earlier snowmelt, and longer summers have increased fire frequency 400 percent and burned area 650 percent in the period 1970-2003 (Westerling and others 2006). The low level of human activity or fire exclusion in those forests, however, implies that climate change may cause different impacts in areas of intense human intervention.

Analyses of potential future conditions project that climate change will increase fire frequencies in all biogeographic realms (Williams and others 2001, Mouillot and others 2002, Hoffman and others 2003, Nepstad and others 2004, Flannigan and others 2005), although in some places, fire may decrease in frequency. Wildfires may create a positive feedback for global warming through significant emissions of greenhouse gases (Kasischke and Stocks 2000, Randerson and others 2006, Murdiyarso and Adiningsih 2006). Because of the difficulty in distinguishing climate change from other factors that alter fire regimes, local impacts of climate change on fire regimes remain difficult to project with precision.

Other Threats

In addition to those described above, various other sources of altered fire regimes exist around the world, including:

- Transportation infrastructures that create entry points for human-caused ignitions or alter natural fire behavior;
- Invasive species that are more or less prone to burning relative to native species;
- Lack of sufficient knowledge and fire management capacity to address too much or too little fire;
- Traditional uses of fire that fall outside natural ranges of variability;
- Gathering of terrestrial plants that alter fuels relative to their natural conditions;
- Recreational activities that encourage altered fire incidence; and
- Poverty, which puts people at greater risk from degraded ecosystems and is also a driver of degradation.

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.

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 to escaped fire. Similarly, logging and commercial plantations can make forests more vulnerable to fire's effects, causing slash and burn practices to be more problematic when carried out adjacent to these degraded forests.

Tropical wildfires are also a threat to coastal marine ecosystems in the region. Research has shown that iron fertilization by the 1997 Indonesian wildfires was sufficient to produce an extraordinary red tide, which led to reef death by asphyxiation (Abram and others 2003). The vast amounts of smoke produced by these fires also reduced visibility, and regional haze substantially impacted economic activity in the region. In conclusion, agricultural burning, peat fires and altered fire regimes as a result of unsustainable logging are the major causes of recurrent haze engulfing the region seasonally, whereas prolonged droughts intensify widespread of fires.

Recommendations: Strategies for Global Biodiversity Conservation

Integrated Fire Management (IFM) is an approach for addressing the problems and issues posed by 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 conservation area, landscape or region.

IFM facilitates implementing 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 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.

More information on the components and applications of IFM can be found in Myers (2006). Within the framework of IFM, which can be applied at any spatial scale from landscapes to nations to regions, 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:

Evaluate whether the effects of fire will be detrimental, beneficial or benign.

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

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 the local social, economic and political systems, the natural character of the habitat and fire regime, and current ecological conditions.

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 role of fire in ecosystems, or preventing fire where it is destructive.
- Promote and enable climate change, emissions, fire suppression, and air quality policies such that they protect biodiversity and human health and safety, but do not constrain the needs for restoring and maintaining fire-dependent habitats.
- Create economic incentives to manage landscapes for fire, ecosystems 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 marketing of woody biomass and other products of restoration actions, and implementation of development loan criteria that integrate fire's ecological role, and the needs to prevent harmful human-caused fires, into housing and infrastructure development, as well as other land use activities.
- Recognize gaps in capacity to address fire's ecological needs, or its threats to ecosystems and people, and build adequate capacity for Integrated Fire Management, including training, mentoring and human and material resources.

- Educate practitioners and 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 be adaptive to changing knowledge, social and political contexts, and ecological conditions.

The global needs for restoration and maintenance of fire's ecological role 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, ecosystems and people.

Conclusions

Our study demonstrates that only 25 percent of the terrestrial world assessed exhibit intact fire regimes, yet the role of fire can be vital in maintaining essential biodiversity. Urban development, resource extraction (including energy production, mining and logging), fire and fire suppression, agriculture and climate change are all contributing to the alteration of fire regimes. Integrated Fire Management -- a proven framework 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.

But what can we do to help bring about this shift toward Integrated Fire Management? How do we compel 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 will require broader and more effective communication and outreach on the part of groups such as the Global Fire Partnership. Effective collaborations that are able to tease apart ecosystem and human relationships to fire in a given place are also needed. We must also keep in mind that the causes and solutions of fire-related problems are almost always inextricably linked to other critical concerns of our day, 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.

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Global Fire Partnership: The Nature Conservancy, University of California, Berkeley's Center for Fire Research and Outreach, IUCN and World Wide Fund for Nature have pledged to work together and with partners to address the causes and ecological and social consequences of altered fire regimes around the world. The partners collected much of the data used in this assessment at a preliminary experts workshop in May 2004 and three subsequent workshops in 2006.

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Dedication: This publication is dedicated to our colleague Jill Bowling, who, along with six other WWF staff and 17 others, perished in a helicopter accident in Nepal in September 2006. Jill was one of the founders of the Global Fire Partnership. Her wisdom, experience and big-picture thinking framed all of our discussions and focused us on the linkages among fire, conservation and human welfare.