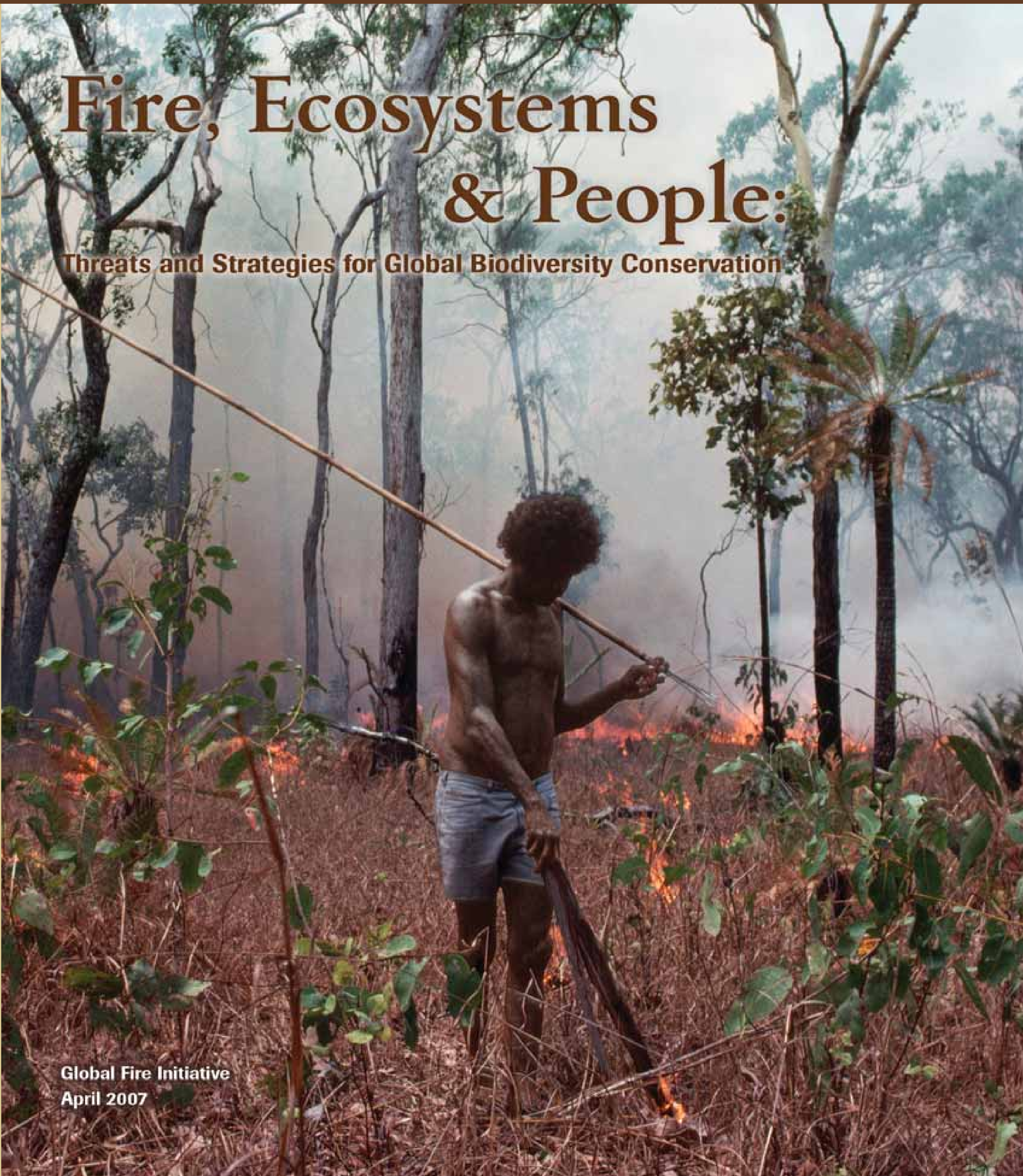
The Nature Conservancy

SAVING THE LAST GREAT PLACES ON EARTH

Fire, Ecosystems & People:

Threats and Strategies for Global Biodiversity Conservation



Global Fire Initiative

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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. While there were others on the team who had more experience in fire science and management, it was Jill's wisdom, experience, and big-picture thinking that framed all of our discussions and focused us on the linkages among fire, conservation and human welfare.

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Global Fire Partnership

The Nature Conservancy, University of California, Berkeley's Center for Fire Research and Outreach, IUCN and WWF 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.

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

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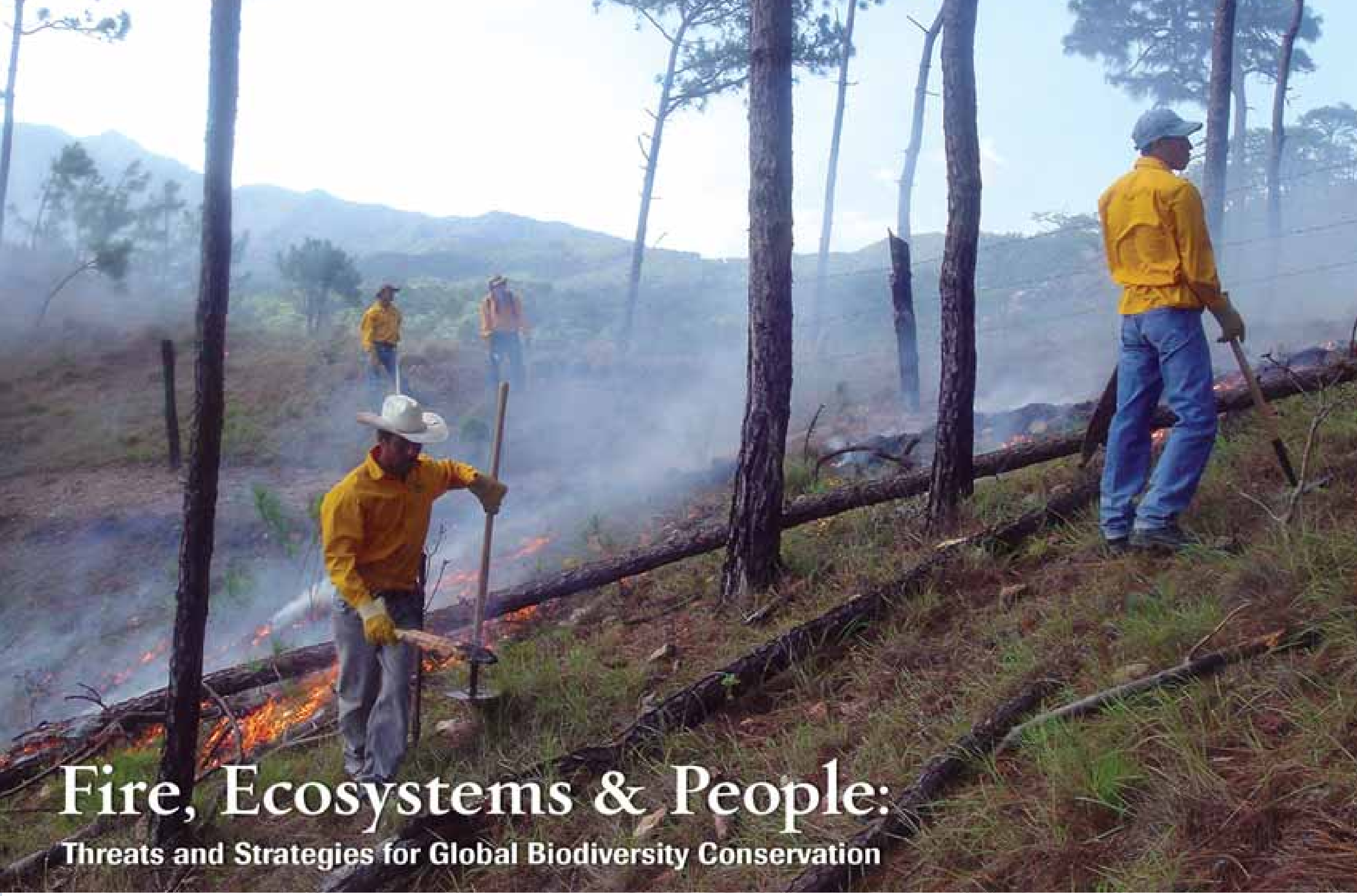
To download this document, graphics and subsequent versions, go to http://nature.org/initiatives/fire/science. The assessment is ongoing. Experts are invited to contribute to the study using an online, interactive tool. E-mail fire@tnc.org to request access.

For more information on The Nature Conservancy's Global Fire Initiative, see http://nature.org/fire.



Fire, Ecosystems & People:

Threats and Strategies for Global Biodiversity Conservation

Members of a local community conduct a prescribed burn in Chiapas, Mexico. This work is part of the community's Integrated Fire Management Plan, which spells out where and when fires will be allowed. © Víctor Negrete Paz/CONANP

Executive Summary

It is widely understood that—as a result of human actions—fire is behaving differently today than at any other time in human history. Fire plays a vital role in maintaining many ecosystems and the communities that depend on them. In order to develop effective conservation strategies, we have to understand the relationships between fire, people and the environment.

Only 25% of the terrestrial world assessed exhibits intact fire regimes. Ecoregions with degraded and very degraded fire regimes cover 53% and 8% of the globe, respectively. More than half (53%) of the earth's ecoregions are fire-dependent, while 22% are fire-sensitive and 15% fire-independent (the remaining 10% have not been assessed). There is a strong link between the degradation of fire regimes and the loss of biodiversity.

The top causes of altered fire regimes globally are urban development; livestock farming, ranching and agriculture; fire use and fire suppression; resource extraction (including energy production, mining and logging); and climate change. These threats can be addressed by adopting a framework called Integrated Fire Management. The first step of Integrated Fire Management includes identifying potential environmental, social and economic benefits and consequences of fire. This information helps communities decide how, when and where fire will occur on the land.

Specific recommendations for community-based practitioners, country governments and multi-lateral institutions include:

1. Evaluate whether the effects of fire will be detrimental, beneficial or benign;
2. Weigh the relative benefits and risks of fire and human actions; and
3. Implement appropriate policies, increase fire management capacity, educate citizens about the role of fire, and learn and adapt along the way.

Mopping-up after a prescribed burn by students in a FAO Instructors' Course on Community-based Fire Management in Mpumalanga National Park, South Africa. © Ronald Myers

This Report

The Global Fire Partnership, 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. This report summarizes new findings on the current role and status of fire around the globe, and discusses related consequences for people and ecosystems. We review the main causes of "altered fire regimes" as well as some similarities and differences among the major regions of the globe, also known as "realms."

The Global Fire Partnership released its original report on the role and status of fire, ***Fire Ecosystems and People: A Preliminary Assessment,*** at the World Conservation Congress in 2004. It made a compelling case that altered fire regimes represent a high-priority, global conservation issue. This second report is a more in-depth synthesis of more recent findings. It includes results for many areas not assessed in the original report, as well as new and expanded information on the causes of altered fire ecology, and recommendations for needed actions. This report describes some specific steps countries and organizations can take today to improve human safety and health, while allowing fire to play its natural role where appropriate. A number of callout boxes included throughout illustrate key points, such as the changing role of fire in wet tropical forests, and present more detailed information on assessment methods and specific conservation strategies.

The first section of the report discusses fire in the context of environmental sustainability and explains fire's complex relationships with other issues such as climate change, land use change and invasive species. The second section explains the various roles that fire can play in ecosystems, including how human-caused ignitions fit into the picture. After the methods chapter we present the key findings of the assessment and then discuss the top five threats to maintaining the ecological role of fire. Case studies from southern Chile and Indonesia illustrate how these threats appear to be manifesting similarly and differently in different places. The final section discusses the benefits of Integrated Fire Management and calls for a number of specific actions based on the assessment findings.

Contents

This area in Sepang, Selangor, Malaysia was once a peat swamp that was drained to plant oil palm. The combination of improved access and drier conditions is creating widespread fires in such places. © A. Ainuddin Nuruddin

Fire is a Global Conservation Issue

This section explains the role that fire plays in shaping and maintaining ecosystems and how humans, historically but also today, use fire as a tool for survival. The significance of fire's ecological role leads directly to the conclusion that global conservation efforts must take fire into account.

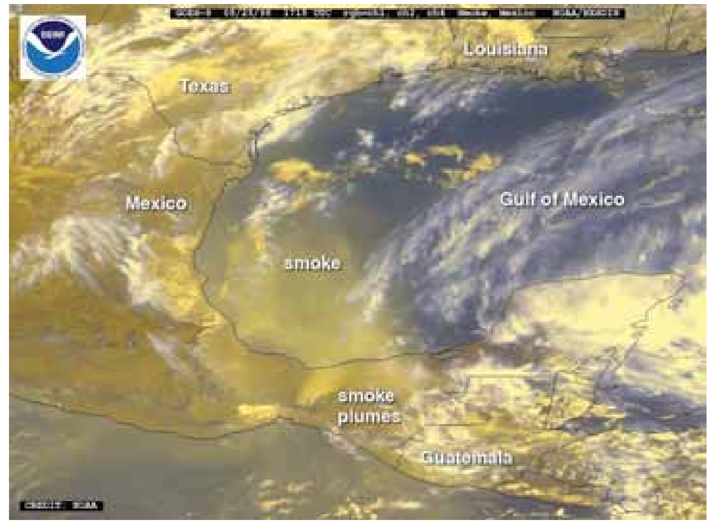
Fire is a natural process that has played a major role in shaping our environment and maintaining biodiversity world-wide. Fire's benefits and impacts are extensive; the majority of the world's terrestrial habitats depend on fire for ecological sustainability.

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 tropical broadleaved 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[1] fall short of a 10% goal for effective conservation (The Nature Conservancy 2006; see Box 1). In addition to the safeguarding of habitats in



In 1998, an El Niño year, fires burning throughout Central America and Mexico created smoke plumes that affected people as far north as Texas.

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.

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 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 (Box 2). 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.

There are a variety of ways invasive plants can change how fire behaves in ecosystems. In this case, the fern *Lygodium microphyllum* has created "ladder fuels" that will allow low-intensity surface fires to spread into the crowns of these cypress trees. © Mandy Tu

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.

Box 1. **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% 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.

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 Box 3) 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 et al 2005). Evidence suggests that human induced fires accelerate the trend of ecosystem transformations caused by climate change in the long term (Kershaw et al. 2002).

Box 2. **Agriculture and Human Land Use:** The Advancing Front of Fire in the Amazon Basin

One-third of the global area that burns annually is in the tropics (Mouillot and Field 2005). While "natural" fire is not unprecedented in tropical systems, most are sensitive to too frequent fire because it is detrimental to ecosystem health. Most often fires in tropical broadleaved forests are set by humans, either intentionally to clear forest patches and manage pasture and agricultural fields, or by accident when intentional fires escape from these fields (Nepstad et al. 1999).

Farmers and ranchers use fire as a labor-saving practice that can quickly clear a patch of forest. Initial inputs of potassium and carbon from burned material can create fertile soil in the first growing season, and sometimes longer. These changes in land use in tropical broadleaved forests tend to create drier conditions, leading to increased susceptibility of the forest to understory fires and a higher incidence of fires overall (Alencar et al. 2004). The loss of forest cover can then render the soil susceptible to erosion and eliminate the principal source of nutrients. When farmers abandon less fertile ground, land clearing is expanded to new areas.

In Amazonia, large-scale fire patterns often follow major human colonization, which causes large-scale patterns of deforestation (Skole and Tucker 1993), road construction (Laurance et al. 2001, Nepstad et al. 2001), and logging activities (Cochrane et al. 1999, Nepstad et al. 1999).

Land uses in the region are a primary source of "too much fire" in these forests, which is further exacerbated by climatic fluctuations. A study near Paragominas, a 35-year-old ranching and logging center in eastern Amazonia, found that 91% of the standing forest area that burned over the 10-year study period caught fire during El Niño Southern Oscillation (ENSO) years, when severe drought may have increased both forest flammability and the escape of agricultural fires (Alencar et al. 2004). This study also concluded that the percentage of forest that had been previously logged or burned, forest fragment size, distance to charcoal pits, distance to agricultural settlements, proximity to forest edge, and distance to roads were correlated with forest understory fire. Forest fragment degradation and distance to ignition sources accurately predicted the location of 80% of the forest fires observed during the ENSO event of 1997–1998. We can expect that increases in fire activity will continue to occur in response to future rural development programs plus the additional impact of climate change in this region. These fires are causing biodiversity loss, degrading local air quality and human health, creating regional haze, and changing water supplies, not to mention the economic losses.

The expansion of fire into tropical systems not generally accustomed to fire (and which also harbor much of the world's biodiversity and sequestered carbon), could destroy globally-unique habitats and disrupt global climate systems. The patterns we see in the Amazon are replicating themselves across similar habitat types around the world. Other geographies will have their own suite of issues, including how human land uses have *reduced* the amount of ecologically appropriate fire, with often catastrophic results for human communities and the environment.

In order to craft effective strategies, conservation organizations and partners need to understand ecosystem and human relationships to fire.

Altered fire regimes can change the species composition, structure 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.

An Australian aborigine uses fire as a land management tool in Arnhem Land, Northern Territory, Australia. People around the world have legitimate reasons for starting fires, and many cultures have gained an intimate knowledge of fire behavior, having used fire as a tool for centuries. © Penny Tweedie/CORBIS

Box 3. **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.

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 more fire than would have occurred naturally through the introduction of invasive exotic species, or excessive human-caused ignitions.

Intact fire regimes are 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.

Assessment Methods:

Scientific Collaboration Leads to Understanding Fire Ecology, Threats and Strategies

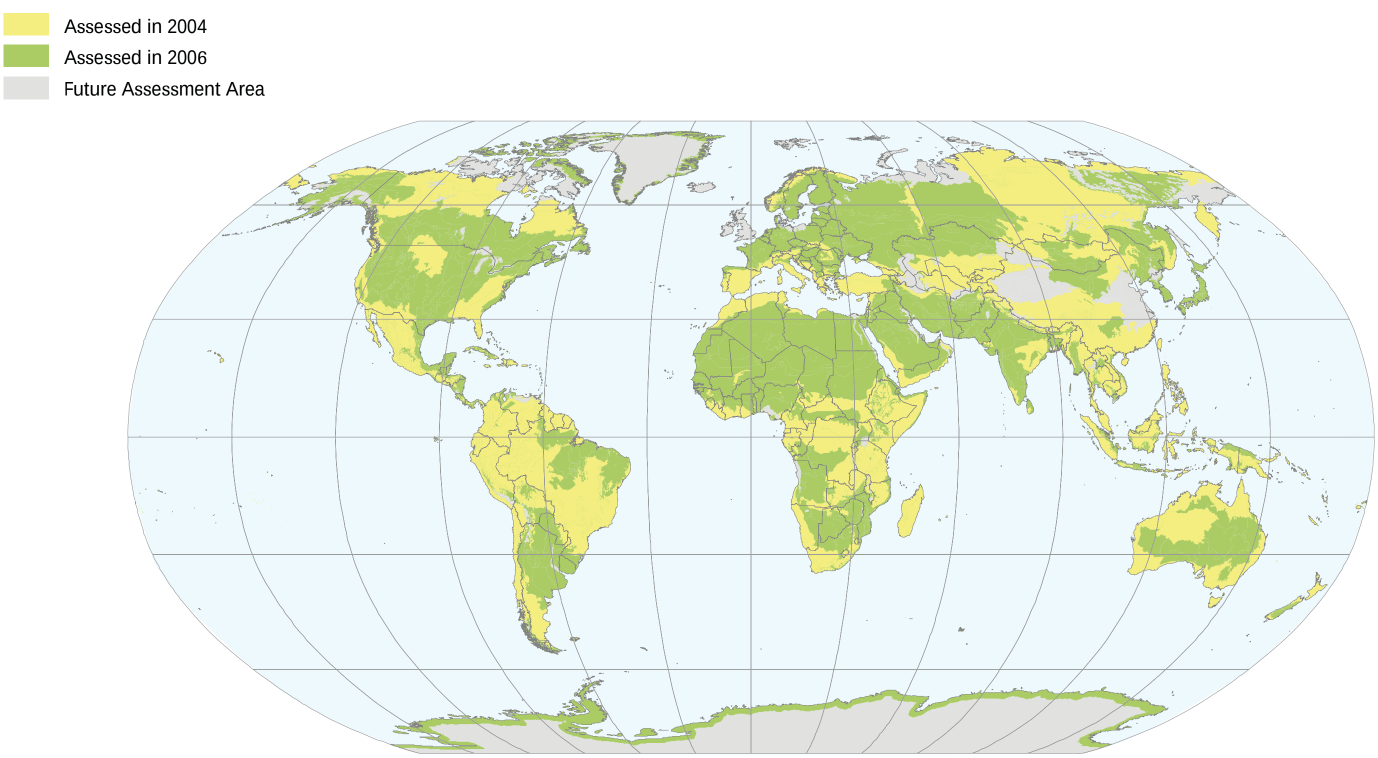
The Global Fire Partnership (GFP) recognizes the need to assess the state of the world's fire regimes, craft effective conservation strategies, and build a global constituency of partners to address fire as a conservation issue. In March 2004, the GFP gathered a group of fire experts and policy-makers 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[2]. 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.

Attendees of the Nearctic realm expert workshop review data. © Faith Kearns

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 (Figure 1). 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,

Figure 1: Map of realms/ecoregions assessed in 2004 and 2006.



Box 4. **Global Fire Assessment WebGIS: Portal to Scientific Assessment**

We developed a web-based Geographic Information System (webGIS) Global Fire Assessment tool to facilitate data collection during expert workshops for the Global Fire Assessment. This internet tool, which was designed in part based on recommendations from experts participating in the first realm-level workshop (Nearctic), was used in the Indo-Malay and Neotropic workshops. 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/. E-mail fire@tnc.org for more information.

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 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, 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) (see Box 4) 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.

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

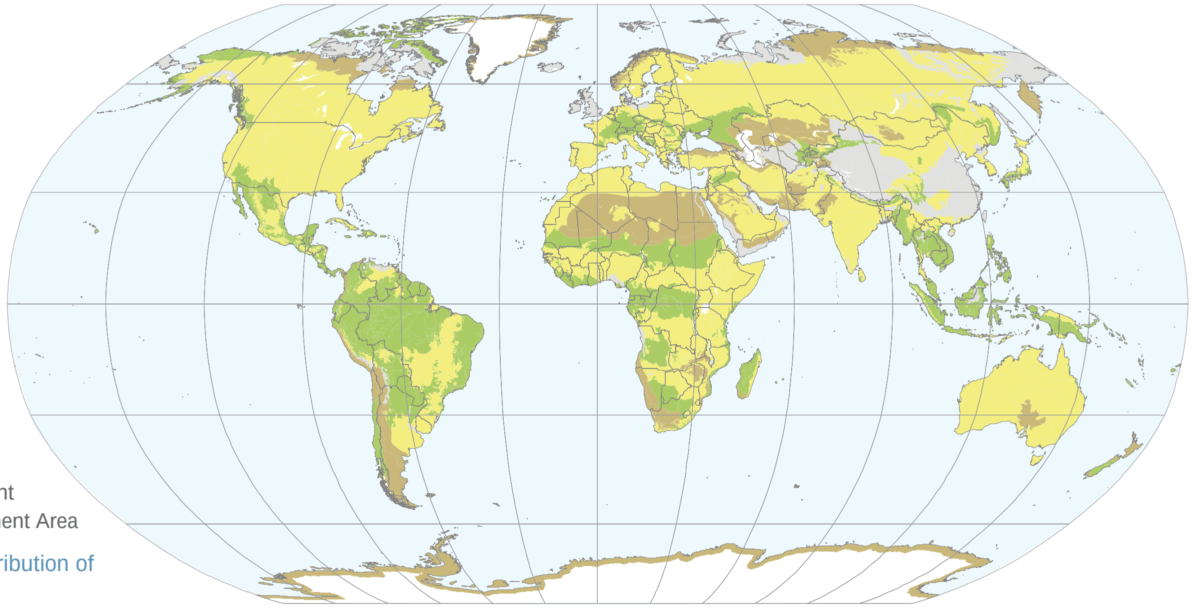


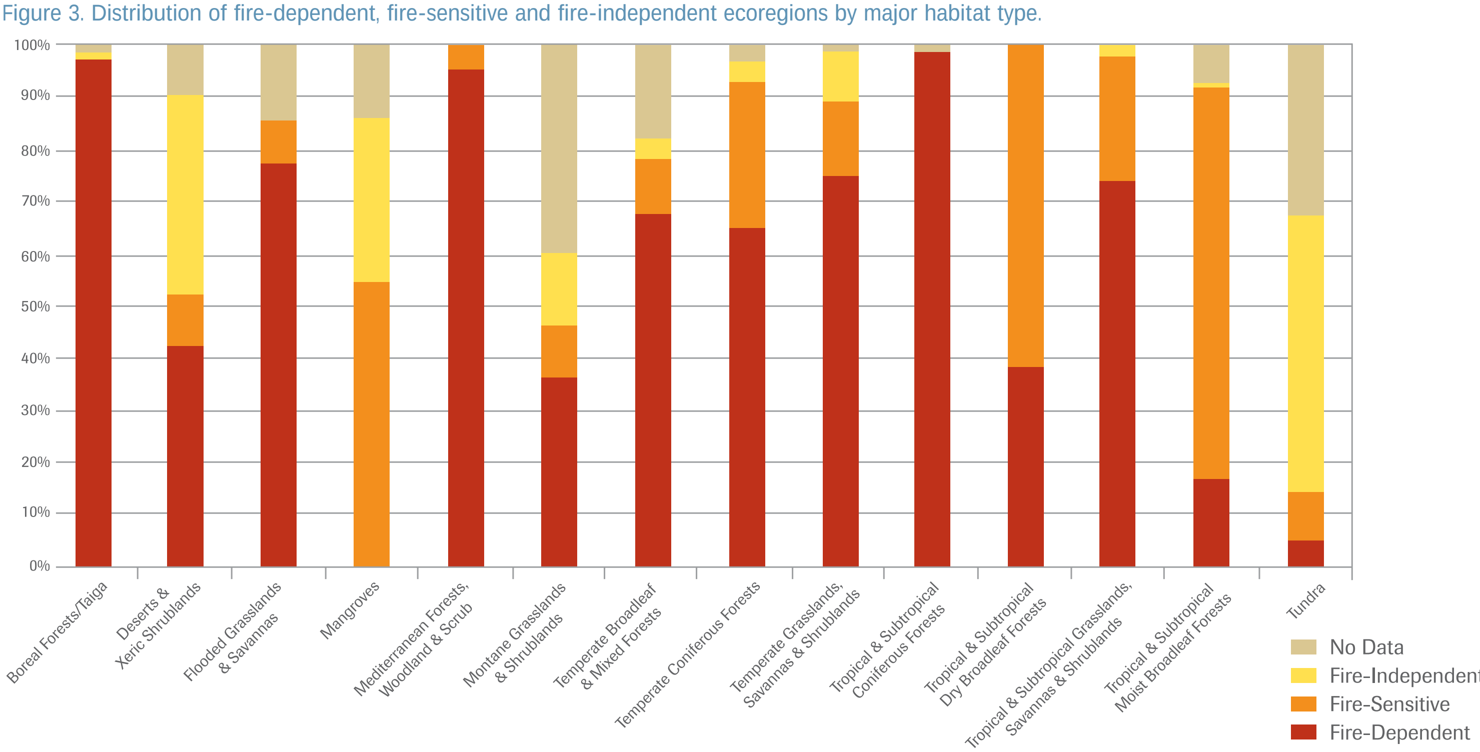
Figure 2. Global distribution of fire regime types.

The findings of the Global Fire Assessment indicate that fire-dependent ecoregions cover 53% of global terrestrial area; fire-sensitive ecoregions cover 22%; and fire-independent ecoregions cover 15% (Figure 2). The distribution of these areas varies across biogeographic realms and major habitat types (Figure 3). For example, the Nearctic realm is dominated by fire-dependent ecosystems (75% of the realm), while the majority of the Neotropics (63%) are made up of fire-sensitive ecosystems (Figure 4). The assessment has not yet covered about 10% 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% of terrestrial area is intact relative to fire regime conditions (Figure 5). Ecoregions with degraded fire regimes cover 53% of global terrestrial area while ecoregions with very degraded fire regimes cover 8%. Assessment of the remaining 13% of global terrestrial area continues.

Relationships between fire and human-caused fire regime alteration—whether the fire regime is intact, degraded, or

Figure 3. Distribution of fire-dependent, fire-sensitive and fire-independent ecoregions by major habitat type.



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% 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% 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 (Figure 6).

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

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

Major habitat types where 70% or more of the terrestrial area is degraded or very degraded include:

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

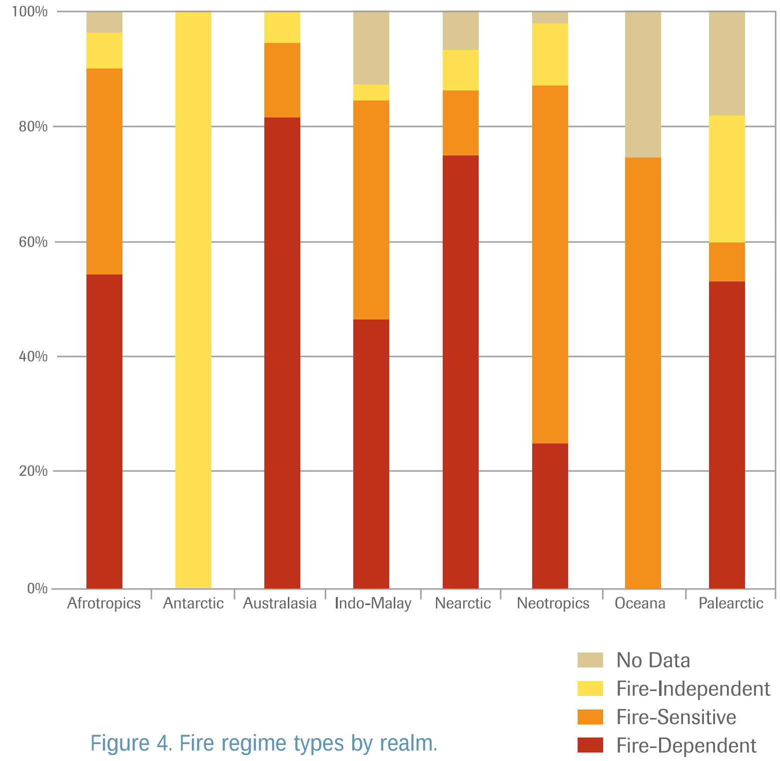


Figure 4. Fire regime types by realm.

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 developing local fire management and conservation strategies, and there is a great deal of within-ecoregion variation in conditions and threats. Regional, country and landscape fire assessments, such as the U.S. LANDFIRE project and the Canadian BURN-P3 (Parisien et al. 2005), are necessary to determine specific strategies that are relevant to local geographies and social contexts.

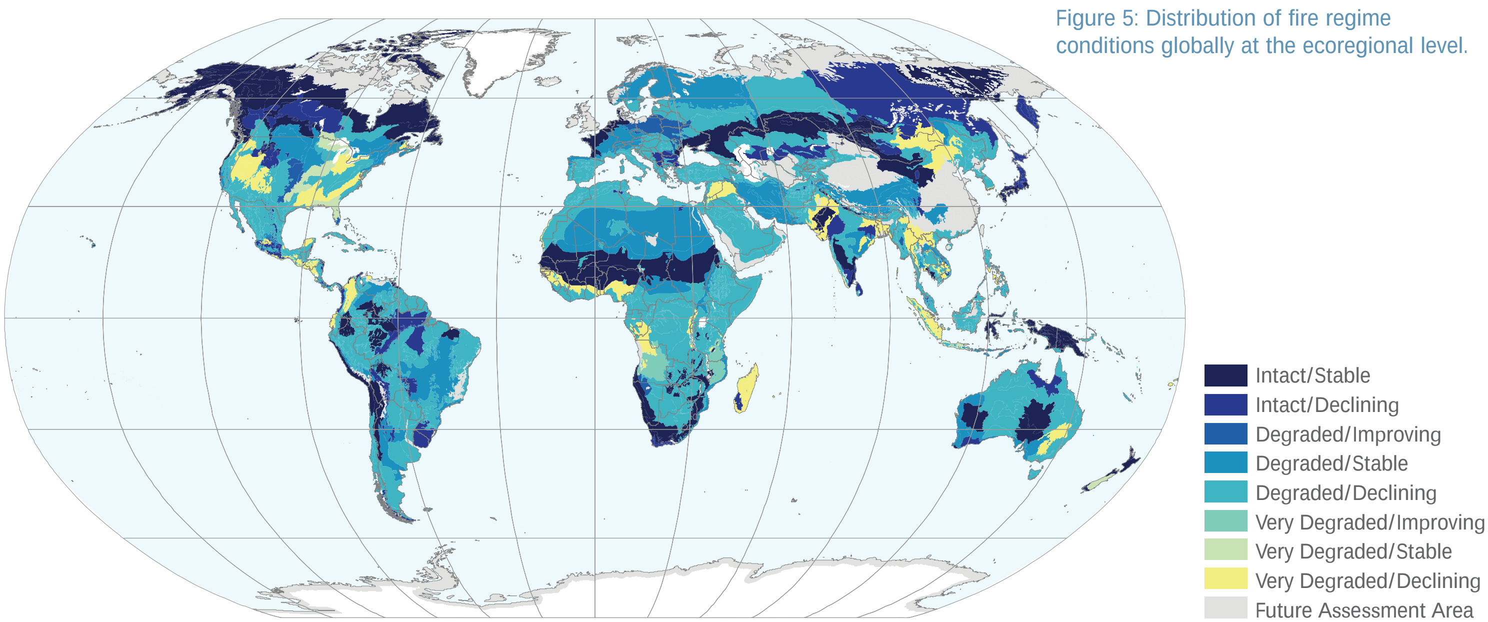


Figure 5: Distribution of fire regime conditions globally at the ecoregional level.

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 are:

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

Table 1 summarizes the top sources of threat[3] to the ecological role of fire by realm. 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.

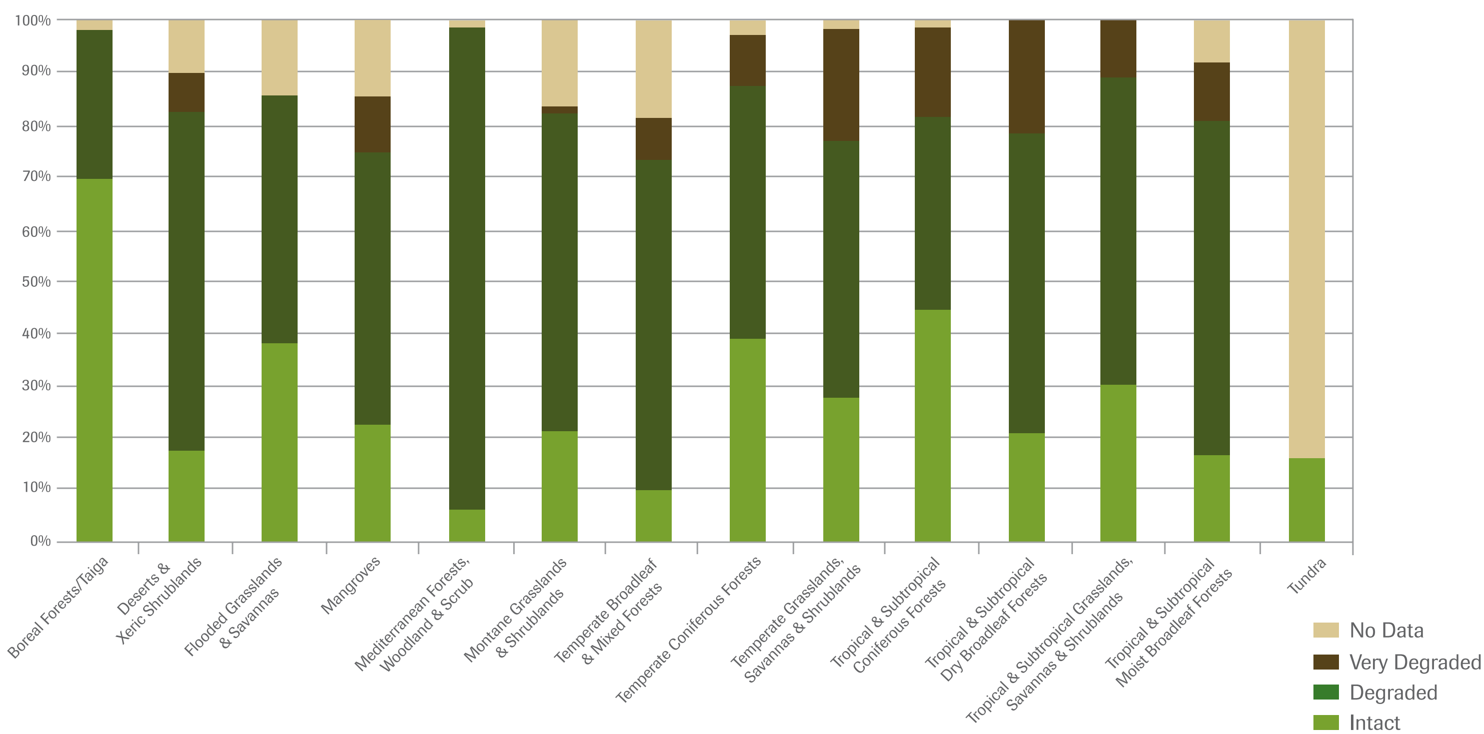
In many places, housing developments are expanding into fire-dependent ecosystems, putting human values at risk and complicating efforts to let fire play its natural role. The community of Goode Beach near Albany, Australia narrowly avoided destruction in 1997 when a wildfire burned through shrublands and woodlands in the adjacent national park. © Klaus Braun

Urban Development

Urban development is a top threat in the majority of major habitat types (13 of 14) and more than 25% 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-dependent eco-systems (Hassan et al. 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

Figure 6. Distribution of fire regime status by major habitat type.



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 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 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% of all terrestrial ecoregions assessed. In fire-dependent ecosystems, such as temperate, tropical and subtropical grasslands, savannas, and shrublands, livestock farming and ranching can reduce fuel levels, connectivity and patchiness, and thus the ability of an ecosystem to carry fire on a large scale, or can cause too much fire due to annual firing of grasses to rejuvenate them.

Agriculture is a top global source of threat to biodiversity overall, and alters fire regimes in at least 30% 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% 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.

Threat	Realm			
	Australasia	Indo-Malay	Nearctic	Neotropic
Livestock Farming and Ranching	●	●	●	●
Energy Production and Mining	●	●	●	●
Fire and Fire Suppression	●	●	●	●
Rural and Urban Development	●	●	●	●
Agriculture	●	●	●	●
Conflicts with Traditional Fire Use	●	●	●	
Climate Change	●		●	●
Logging and Wood Harvesting		●	●	●
Transportation Infrastructure	●	●		●
Invasive Species	●		●	●
Recreational Activities	●			
Gathering Terrestrial Plants		●	●	
Dams and Water Management Use		●		
Wood and Pulp Plantations				●

Table 1. Top sources of threats to restoring and maintaining the ecological role of fire by realm assessed during realm-level expert workshops January-July 2006.

A United Nations 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 et al. 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 more than 13% 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% 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 their alteration of fire regimes in the Indo-Malay, Nearctic and Neotropic realms (Table 1). 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.

Logging alters fire regimes in forests around the globe when it creates forest structures or fuel loads that are inconsistent with the natural fire regime. The Nature Conservancy and partners are working in this forest in Chiapas, Mexico to improve management practices and mitigate the effects of logging on fire regimes. © Mark Godfrey

Climate Change

Fire experts identified climate change as a potential cause of fire-related threats to biodiversity in 4% 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.

Generally, in fire-dependent systems where the ecologically-appropriate fire regime is intact, there should be no net loss of stored carbon because the biomass that burns regrows over the life of the fire cycle. However, climate change is 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 et al. 2005, IPCC 2001, Turner et al. 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 1°C since 1970, earlier snowmelt, and longer summers have increased fire frequency 400% and burned area 650% in the period 1970-2003 (Westerling et al. 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.

Cattle grazing and browsing in Malleco National Reserve, Chile (38˚ S). These *Araucria arauacanai*-*Nothofagus* forests were damaged by fires in 2002 and have subsequently been severely degraded by livestock and non-native invasive species. © M.E. González

Analyses of potential future conditions project that climate change will increase fire frequencies in all biogeographic realms (Williams et al. 2001, Mouillot et al. 2002, Hoffman et al. 2003, Nepstad et al. 2004, Flannigan et al. 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 et al. 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. We examine two regional differences in threats in the Case Studies section on the following pages.

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.

Case Studies:

Regional Differences in Fire Regimes and Threats

Regionally, some threats are more important than others. This is due to differences in vegetation types, societies, politics, economics and knowledge of local fire ecology and climate change. For example, experts revealed some similarities and differences in the top fire-related sources of threat to biodiversity. The top threats noted in the preceding section are common at least across the Australasia, Indo-Malay, Nearctic and Neotropic realms, a notably broad range of ecological conditions (Table 1).

Conservation strategies developed and implemented to address sources of altered fire regimes also vary among regions based on fire management capacity, local laws, the availability of scientific evidence of altered fire regimes and their causes, and local understanding of fire issues. The following case studies illustrate commonalities and differences in threats between two realms. The last section discusses strategies necessary to abate fire-related threats.

Neotropic Realm: The Valdivian Ecoregion

The Valdivian temperate rainforest ecoregion of southern Chile and adjacent portion of Argentina is located from 35 to 48° S latitude. This temperate forest has developed in relative isolation, resulting in high species diversity and a high degree of endemism (Armesto et al. 1998). Due to these factors, this region is considered a world conservation priority by WWF and the World Bank (Dinerstein et al. 1995). The Valdivian ecoregion includes forests dominated by different *Nothofagus* species (e.g., *N. glauca, N. obliqua, N. dombeyi, N. nervosa*) mixed with other evergreen trees, including the very long-lived species *Fitzroya cuppressoides* and *Araucaria araucana*. Although the role of fire in these forest ecosystems has not been sufficiently studied, they could be preliminarily considered fire-sensitive, and in some cases fire-dependent (e.g., *Araucaria-Nothofagus* forests; González et al. 2005).

Fire regime conditions for most of the major habitat types in the Valdivian ecoregion have been influenced by different factors during at least the last 200 years. Expansion of the agricultural frontier, livestock ranching, and large-scale logging operations between 1940 and the 1960s have had an exceptional impact on the forested landscape (Lara et al. 1996). Human land uses have changed the natural fire regime by altering the frequency, severity and source of fires. However, during the last 30 years, the most striking threat has been extensive logging of the native forests and their replacement by fast-growing and pyrophyllic *Pinus radiata* and *Eucalyptus globulus*, and other species (Echeverría et al. 2006). In many areas, isolated and fragmented native forests are surrounded by large patches of exotic-species plantations, increasing the amount of fuel and fuel connectivity, and thereby increasing the forest susceptibility to catastrophic fires. Firewood extraction also has been a significant cause of deforestation and fire occurrence. Commonly, areas that have been logged are then harvested for firewood, and subsequently burned to clear the land for livestock farming and ranching, or to be planted with exotic species.

This area in Sepang, Selangor, Malaysia was once a peat swamp that was drained to plant oil palm. The combination of improved access and drier conditions is creating widespread fires in such places. © A. Ainuddin Nuruddin

Indo-Malay: Palm Oil, Peat and Climate Change

In the Indo-Malay realm, agriculture is the greatest threat to biodiversity. Land development in Indonesia following a Ministerial Decree in 1981 led to an increased rate of deforestation from 600,000 hectares per year in the early 1980s to 1,600,000 hectares per year in less than 20 years (MoFEC 1997; World Bank 2000, cited from Murdiyarso and Adiningsih 2006). Vast tracts of forest, including peat swamp forest, have been converted to plantation crops such as rubber and oil palm. To convert the 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. As in many other parts of the world, fire is used in land preparation for plantations or agriculture. In this context, land development policies have led to extensive deforestation at the hands of ecologically-inappropriate fire use.

With the ongoing increase in palm oil prices and the production of bio-diesel, there is more pressure to open

Global and regional climate patterns influence the impact of fire on both people and ecosystems in Southeast Asia. In 1997-98, an El Niño year, many human-caused fires burned out of control, creating dangerous haze, closing airports and seriously affecting the respiratory health of more than 20 million people. © Kamarulzaman Russali/Reuters/Corbis

large areas to oil palm plantation. Further, within the context of land development, the existence of local people is unrecognized in the legal system, and they have been neglected (Murdiyarso and Adiningsih 2006). This can lead to land tenure conflicts, and often stakeholders use fires as a weapon to claim lands (Tomich et al. 1998). Therefore, social conflict has become an indirect cause of fires.

Of particular note is how the expansion of crop plantations and ecologically-inappropriate fire use has impacted peat swamps in the region. Peatlands are usually continuously wet and contain high amount of moisture even during the normal dry season. Community fires are generally small and not a problem. In non-El Niño years, access to the remote peatlands is difficult. However, when peatlands are drained for land development or agriculture, access into remote peatlands is facilitated by canals (Chokkalingam and Suyanto 2004). In this context, combinations of intensified community activities and dry conditions lead to more widespread fires. Proper management and use of water can be used to reduce the risk of the widespread fires.

Logging is also a primary cause of altered fire regimes in the Indo-Malay realm. When performed according to sustainable forest management principles, logging will result only in temporary disturbance to the forest ecosystem. However, illegal logging may cause previously closed canopy forests to be opened to direct solar radiation, drying logging debris and fueling runaway fires.

In the grasslands of the Indo-Malay realm, pastoralists practice annual burning of their grazing lands, usually prior to the beginning of the growing season, to ensure new, succulent shoots are formed that are suitable for livestock grazing. Fire is also used to facilitate hunting by burning tall grass, which acts as a camouflage for animals. Burning facilitates tracking and finding stump holes that conceal small mammals and reptiles. However, fire from these grasslands can burn out of control and spread to adjoining forests. When this occurs annually, it creates a negative feedback loop that expands the grassland area at the expense of forests.

Climate change has been shown to alter fire regimes substantially in the Indo-Malay realm. Shifts in regional climatic patterns due to climate change have caused intense El Niño events, which have resulted in severe drought. Extensive and severe fires in Indonesia have been associated with extreme dry weather during these El Niño years, which serves to accelerate fire spread (Murdiyarso and Adiningsih 2006). The Intergovernmental Panel on Climate Change (IPCC 2001) recognized that extreme events in the Asian region have increased in intensity and frequency. This is supported by Irawan (2000), who reported that, during the 1876-2000 period, the frequency of El Niño tended to increase from once in every eight years during the 1876-1976 period to once in every four years during 1977-2000. These climate-fire relationships caused the recurrence of highly damaging fires in 1982-83, 1991, 1994, 1997-98, 2002 and 2005-2006. During these events, large areas of forest in the region were burned, causing habitat loss, fragmentation and declining biodiversity.

Wildfires in tropical broadleaved forests 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 et al. 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.

Members of a local community conduct a prescribed burn in Chiapas, Mexico. This work is part of the community's Integrated Fire Management Plan, which spells out where and when fires will be allowed. © Víctor Negrete Paz/CONANP

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 (see Box 5 for an example from Mexico), 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 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 (1) payment to land owners for restoring and maintaining the ecosystem services of intact fire regimes, (2) tax or other incentives for the commercial marketing of woody biomass and other products of restoration actions, and (3) 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.

Box 5. **Needs for Integrated Fire Management in Mexico**

Evaluating whether the effects of fire will be detrimental, beneficial or benign.
In Mexico, fire-dependent ecosystems include pine forests, oak forests, grasslands, shrublands and palmetto lands, among others. Examples of fire-sensitive ecosystems include pine forests, rain forests, cloud forests, mangrove forests, fir forests and shrublands. However, as in many other parts of the world, relatively little scientific information is available to evaluate whether the effects of fire will be detrimental, beneficial or a mixture of both.

Evaluating whether the effects of fire will be detrimental, beneficial or benign is of particular significance in Mexico. In 2000, the University of Chapingo—in partnership with the National Council for Science and Technology (CONACYT), the National Forest Commission (CONAFOR), the Mexico City government and the communities of San Miguel and Santo Tomás Ajusco —began the Ajusco research project to study fire ecology and Integrated Fire Management in the pinelands of Central Mexico and other ecosystems, as well as establish demonstration plots. The project sought to supplement the small amount of existing fire research in Mexico. Conservation of the forest at the Ajusco volcano (in central Mexico near Mexico City) is critical because of its fire-dependent, high altitude *Pinus hartwegii* forests (reaching 4,300 meters at the Iztaccihuatl volcano) and the potential impacts of climate change. In fact, the condition of *Pinus hartwegii* forests can be an indicator of global warming.

Weighing the relative benefits and risks of fire and human actions.
The Ajusco research project in Central Mexico is representative of fire- and society-related problems common to the whole country, as well as those common to areas influenced by urban development. This area has one of the highest numbers of fires in Mexico, most of them human-caused. The area is also representative of the environmental services that such forests provide to cities, such as clean water. This project is based on sound science generated in-situ and can be used to demonstrate biodiversity conservation within the context of common socio-economic issues.

Results from a considerable number of graduate and post-graduate research projects in the area show that low intensity prescribed burns in pine forests approximately double the number of understory species (Martínez-Hernández and Rodríguez-Trejo 2003), with these beneficial effects lasting three years following burning. Some understory species on burned sites also helped "nurse" planted trees toward successful establishment by increasing nutrient availability (phosphorous and potassium). Virtually all juvenile trees survived the low intensity prescribed burns in March, whereas hardly any survived the high intensity prescribed burns in May (Rodríguez-Trejo et al. 2007). Low crown scorch associated with low intensity prescribed burns promoted tree growth (González-Rosales and Rodríguez-Trejo 2004, Vera-Vilchis and Rodríguez-Trejo 2007) and had the additional benefit of increasing the recreational value of the landscape (Romo-Lozano et al. 2007).

Continuing fire research in Mexico will add substantially to the country's ability to understand the ecological roles of fire. However, the effective implementation of IFM also depends on the relative benefits and risks of fire, and the capacity to respond appropriately and effectively based on landscape objectives. The University of Chapingo and CONAFOR recently analyzed the Mexican federal fire program for the 2003 and 2004 fire seasons. In 2003, 8,211 forest fires covering 322,448 hectares were recorded. Half of these fires were caused by agricultural and cattle ranching activities, smokers and camp fires. The evaluation of emissions of seven pollutants from these fires reached 6.2 million Mg, a large percentage of which was released as CO_2. The losses in wood, firewood, and reforestation costs reached US$380 million, which does not account for losses in other forest resources, recreation or human health.

Box 5. (continued)

Responding appropriately and effectively.
Mexico's fire management capacity is about 10,000 people, including about 1,000 from the federal government. Mexico's federal government trains fire staff in fire-fighting, but few courses incorporate ecological considerations. However, this is beginning to change. The strengths of Mexico's fire management programs include experience, good coordination among organizations, training (e.g., fire-fighting, prescribed burning), and international cooperation (mostly with the U.S.). However, fire management resources across the country are generally inadequate to meet the need for community protection and biodiversity. Among the weaknesses are scarce human resources and equipment for attending emergencies, lack of meteorological information, and continuing poverty in forested areas. Several needs are identified in order to enhance the effectiveness of Mexico's fire management program, including more research in fire protection and prevention, fire ecology, fire effects, forest fuel models, alternative agricultural practices, prescribed burning, social issues, fire danger and Integrated Fire Management. Recommendations include increasing coordination with other organizations and peasants to conduct ecologically-appropriate agricultural burning, greater participation of states and municipal governments, increased emphasis on professional profiles over labor union decisions in hiring of firefighters, and increased material resources. The prevention, mitigation, pre-suppression and suppression capabilities of Mexico's fire management work force will benefit from a gradual change toward an Integrated Fire Management approach.

Conclusions

Our study demonstrates that only 25% 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 FireManagement—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.

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.

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 via multilateral donor organizations, ecosystem services schemes and convincing country governments to boost budgets allocated to addressing fire-related issues.

Beneficial effects of a prescribed burn at Ajusco Volcano conducted five months earlier. © Dante Arturo Rodriguez-Trejo

Notes:

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

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).

3. In this paper we use "source of threat" to mean the driving force behind a threat to biodiversity. For example, "altered fire regimes" is a threat, whereas climate change and arson are just a few of the sources behind this threat. The formal definition of "source," according to IUCN-CMP (2006), is "the proximate (human) activities or processes that have caused, are causing or may cause the destruction, degradation and/or impairment of biodiversity and natural processes."

References

Abram, N.J., M.K. Gagan, M.T. McCulloch, J. Chappell and W.S. Hantoro. 2003. Coral Reef Death During the 1997 Indian Ocean Dipole Linked to Indonesian Wildfires. *Science* 301: 952-955.

Alencar, A.A., L.A. Solorzano and D.C. Nepstad. 2004. Modeling forest understory fires in an eastern Amazonian landscape. *Ecological Applications* 14(4) Supplement: S139–S149.

Armesto, J.J., R. Rozzi, C. Smith-Ramirez and M.K. Arroyo. 1998. Conservation target in South American temperate forests. *Science* 282: 1271-1272.

Chokkalingam, U., S. Suyanto (2004) Fire, livelihoods and environmental degradation in the wetlands of Indonesia: A vicious cycle. *CIFOR Fire Brief*. October 2004, No. 3, 4pp.

Cochrane, M.A. 2002. *Spreading like Wildfire—Tropical Forest Fires in Latin America and the Caribbean: Prevention, Assessment and Early Warning.* United Nations Environment Program, Regional Office for Latin America and the Caribbean. 96pp. http://www.rolac.unep.mx/dewalac/eng/fire_ingles.pdf (also published in Spanish 109pp).

Cochrane, M.A., A. Alencar, M.D. Schulze, C.M. Souza, D.C. Nepstad, P. Lefebvre and E.A. Davidson. 1999. Positive Feedbacks in the Fire Dynamic of Closed Canopy Tropical Forests. *Science* 284: 1832–35.

Dinerstein, E., D.M. Olson, D.H. Graham, A.L. Webster, S.A. Primm, M.P. Bookbinder and G. Ledec. 1995. *A Conservation Assessment of the Terrestrial Ecoregions of Latin America and the Caribbean.* World Wildlife Fund and the World Bank, Washington D.C.

Echeverría, C., D. Coomes, J. Salas, J.M. Rey-Benayas, A. Lara and A. Newton. 2006. Rapid deforestation and fragmentation of Chilean temperate forests. *Biological Conservation* 130: 481-494.

ECE/FAO (Economic Commission for Europe/Food and Agriculture Organization of the United Nations). 1998. *Forest Fire Statistics 1994–1996*. United Nations, Geneva, 19 pp.

Flannigan, M.D., K.A. Logan, B.D. Amiro, W.R. Skinner and B.J. Stocks. 2005. Future area burned in Canada. *Climatic Change* 72: 1-16.

Goldammer, J.G. and C. de Ronde (eds.). 2004. *Wildland Fire Management Handbook for Sub-Sahara Africa.* Global Fire Monitoring Center. pp. 1-10.

González, M. E., T.T. Veblen and J. Sibold. 2005. Fire history of *Araucaria-Nothofagus* forests in Villarrica National Park, Chile. *Journal of Biogeography* 32: 1187-1202.

González-Rosales, A. and D.A. Rodríguez Trejo. 2004. Efecto del chamuscado de copa en el crecimiento en diámetro de *Pinus hartwegii. Agrociencia 38*(5): 537-544.

Hassan, R., R. Scholes and N. Ash (eds.). 2005. *Findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment.* Ecosystems and Human Well-being: Current State and Trends, Volume 1. University of Pretoria Council for Science and Industrial Research UNEP World Conservation South Africa, South Africa Monitoring Centre, United Kingdom. Island Press Washington, D.C.

References

Heyerdahl, E. and E. Alvarado. 2003. The influence of climate and land use on historical surface fires in pine-oak forests, Sierra Madre Occidental, Mexico. In: Veblen, T.T., G/ Montenegro and T.W. Swetnam (eds.). *Fire and Climatic Change in Temperate Ecosystems of the Western Americas.* Series: Ecological Studies. Volume. 160. Springer.

Hoffmann, W. A., W. Schroeder and R. B. Jackson. 2003. Regional feedbacks among fire, climate, and tropical deforestation. *Journal of Geophysical Research* 108: 4721. doi:10.1029/2003JD003494.

Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, Cambridge, UK.

Irawan, B. 2000. *Stabilization of Upland Agriculture under El Nino Induced Climate Risk: Impact Assessment and Mitigation Measures in Indonesia.* CGPRT Centre Working Paper No. 62, 78pp.

IUCN-CMP. 2006. Unified Classification of Direct Threats, Version 1.0. http://www.iucn.org/themes/ssc/sis/classification.htm.

Kasischke, E.S. and B.J. Stocks (eds.). 2000. F*ire, Climate Change, and Carbon Cycling in the Boreal Forest.* Springer.

Kershaw, P., J.S. Clark, A.M. Gill and D.M. D'Costa. 2002. A history of fire in Australia. In: R. Bradstock, J. Williams and M. Gill (eds.). *Flammable Australia: the Fire Regimes and Biodiversity of a Continent.* Cambridge University Press. pp 3-25.

Lara, A., C. Donoso and J.C. Aravena.1996. La conser vación del bosque nativo de Chile: problemas y desafíos. En: Armesto, J.J., C. Villagrán, M.K. Arroyo (Eds). *Ecología de los Bosques Nativos de Chile.* Editorial Universitaria, Santiago, Chile, 335-362.

Laurance, W.F., Cochrane, M.A., Bergen, S., Fearnside, P.M., Delamônica, P., Barber, C., d'Angelo, S. y Fernandes and T. 2001. The future of the Brazilian Amazon: Development trends and deforestation. *Science* 291: 438-439.

Martínez Hernández, M.C. and D.A. Rodríguez-Trejo. 2003. Sinecología del sotobosque de *Pinus hartwegii* Lindl. en áreas quemadas. In: Corlay C., L., F. Zavala C., J. Pineda P., E. Robledo S., R. Maldonado T. (eds.). *Suelo y bosque: Conservación y aprovechamiento.* UACH. Chapingo, México. pp. 175-177.

MoFEC. 1997. *Forest Inventory and Mapping Programme.* Jakarta, Indonesia, Ministry of Forestry and Estate Crops.

Mouillot, F., S. Rambal and R. Joffre. 2002. Simulating climate change impacts on fire frequency and vegetation dynamics in a Mediterranean-type ecosystem. *Global Change Biology* 8: 423-437.

Mouillot, F. and C.B. Field. 2005. Fire history and the global carbon budget: a 1° x 1° fire history reconstruction for the 20th century. *Global Change Biology* 11: 398-420.

Murdiyarso, D. and E.S. Adiningsih. 2006. Climate anomalies, Indonesian vegetation fires and terrestrial carbon emissions. *Mitigation and Adaptation Strategies for Global Change* 12: 101-112.

Myers, R. 2006. *Living with Fire—Sustaining Ecosystems and Livelihoods Through Integrated Fire Management.* The Nature Conservancy Global Fire Initiative, Tallahassee, FL. 32 pp. http://tncfire.org/documents/Integrated_Fire_Management_Myers_2006.pdf

Nepstad, D., P. Lefebvre, U. Lopes da Silva, J. Tomasella, P. Schlesinger, L. Solórzano, P. Moutinho, D. Ray and J. Guerreira Benito. 2004. Amazon drought and its implications for forest flammability and tree growth: A basin-wide analysis. *Global Change Biology* 10: 704-717.

Nepstad, D, G. Carvalho, A.C. Barros, A. Alencar, J.P. Capobianco, J. Bishop, P. Moutinho, P. Lefebvre, U.L Silva Jr. and E. Prins. 2001. Road paving, fire regime feedbacks, and the future of Amazon forests. *Forest Ecology and Management.* 154: 395-407.

Nepstad, D.C., A. Verssimo, A. Alencar, C. Nobre, E. Lima, P. Lefebvre, P. Schlesinger, C. Potter, P. Moutinho, E. Mendoza, M. Cochrane and V. Brooks. 1999. Large-scale impoverishment of Amazonian forests by logging and fire. *Nature* 398: 505-508.

References

Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D´Amico, I. Itoua, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, T.H. Ricketts, Y. Kura, J.F. Lamoreux, W.W. Wettengel, P. Hedao and K.R. Kassem. 2001. Terrestrial ecoregions of the world: A new map of life on Earth. *Bioscience* 51: 933-938.

Parisien, M.A., V.G. Kafka, K.G. Hirsch, J.B. Todd, S.G. Lavoie and P.D. Maczek. 2005. Mapping wildfire susceptibility with the BURN-P3 simulation model. *Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre* Edmonton, Alberta. Inf. Rep. NOR-X-405.

Pyne, S.J. 1982. *Fire in America: A Cultural History of Wildland and Rural Fire.* Princeton, NJ: Princeton University Press.

Randerson, J. T., H. Liu, M. G. Flanner, S. D. Chambers, Y. Jin, P. G. Hess, G. Pfister, M. C. Mack, K. K Treseder, L. R. Welp, F. S. Chapin, J. W. Harden, M. L. Goulden, E. Lyons, J. C. Neff, E. A. G. Schuur and C. S. Zender. 2006. The impact of boreal forest fire on climate warming. *Science* 314:1130-1132.

Rodríguez-Trejo, D.A., U.B. Castro-Solís, M. Zepeda-Bautista and R.J. Carr. In press (2007). First year survival of *Pinus hartwegii* following prescribed burns at different intensities and different seasons in central Mexico. *International Journal of Wildland Fire* 16.

Romo-Lozano, J.L., N. Coss-Mendoza, D.A. Rodríguez-Trejo and F. Zamudio-Sánchez. 2007. Public preferences and the economic value of forests affected by fires in Mexico city. *Forest Ecology and Management* 234S.

Skole, D. and C. Tucker. 1993. Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. *Science* 206: 1905–1909.

The Nature Conservancy. 2004. *Fire, Ecosystems and People: A Preliminary Assessment of Fire as Global Conservation Issue.* Tallahassee, FL. October 2004. Available online in English and Spanish at: http://nature.org/initiatives/fire/science/.

The Nature Conservancy. 2006. *Interim Report on the Global Habitat Assessments.* Arlington, VA. U.S.A.

Tomich T.P., A.M. Fagi, H. de Foresta, G. Michon, D. Murdiyarso, F. Stolle and M. van Noordwijk. 1998. Indonesia's fires: smoke as a problem, smoke as a symptom. *Agroforestry Today* (January-March), 4-7.

Turner, M.G., V.H. Dale and E.H. Everham III. 1997: Fires, hurricanes, and volcanoes: Comparing large disturbances. *Bioscience* 47(11): 758–68.

UN (United Nations). 2005. *Millennium Development Goals Report 2005.* United Nations Department of Public Information. United Nations, New York. ISBN 92–1–100972–3.

Vera-Vilchis, V. and D.A. Rodríguez-Trejo. In press (2007). Supervivencia y crecimiento en altura de *Pinus hartwegii* a dos años de quemas prescritas e incendios. *Agrociencia* 41.

Westerling, A., H.G. Hidalgo, D.R. Cayan and T.W. Swetnam. 2006. Warming and earlier Spring increase western U.S. forest wildfire activity. *Science* 313: 940-943.

Williams, A.A.J., D.J. Karoly and N. Tapper. 2001. The sensitivity of Australian fire danger to climate change. *Climatic Change* 49: 171-191.

World Bank. 2000. *Indonesia, Environmental and Natural Resources Management in a Time of Transition.* Washington, DC.

Yibarbuk, D. 1998. Notes on traditional use of fire on the upper Cadell River. In: M. Langton. *Burning Questions: Emerging Environmental Issues for Indigenous Peoples in Northern Australia.* Centre for Indigenous Natural and Cultural Resource Management, Northern Territory University, Darwin. pp. 1-16.

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