FORUM: ISSUES, MANAGEMENT, POLICY, AND OPINIONS

MAKING A WORLD OF DIFFERENCE IN FIRE AND CLIMATE CHANGE

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ABSTRACT

Together with other stressors, interactions between fire and climate change are expressing their potential to drive ecosystem shifts and losses in biodiversity. Closely linked to human well-being in most regions of the globe, fires and their consequences should no longer be regarded as repeated surprise events. Instead, we should regard fires as common and enduring components of most terrestrial systems, including their social context. At the global scale, too much fire and the wrong kinds of fire are trumping not enough fire as the most influential fire problems we must address. Intensified fire suppression and government prohibition of burning is not a long-term solution at the global scale. Acknowledging the importance of programs to reduce emissions from deforestation and forest degradation, I propose that fire ecologists come together to elevate attention on four less-discussed priorities: ecological systems in which people depend on fire for survival and well-being; systems in which governments unwisely insist on command and control approaches to fire; places where peatlands are burning; and, places where climate-driven changes in fire will cause type conversion. Finally, I propose holding a worldwide fire summit to debate these priorities and to create

RESUMEN

Junto a otros factores, las interacciones entre los incendios y el cambio climático están produciendo cambios en los ecosistemas y pérdidas en la biodiversidad. Íntimamente ligados al bienestar humano en la mayoría de los ecosistemas del planeta, los incendios y sus consecuencias no debieran ser observados como eventos sorpresivos repetidos. En cambio, deberíamos mirar a los incendios como componentes comunes y permanentes en la mayoría de los ecosistemas terrestres, incluyendo su contexto social. A escala global, la excesiva frecuencia de algunos tipos de incendios no deseables y destructivos ha distraído la atención sobre el problema principal que es la escasez de fuegos útiles y deseables. La intensificación de las políticas de supresión de incendios y las prohibiciones gubernamentales de quemas controladas no son la solución a largo plazo al problema de los incendios a escala global. Aceptando la importancia de programas para reducir las emisiones provocadas por la deforestación y degradación de bosques, propongo que los ecólogos especializados en la ecología del fuego planteen para el debate cuatro prioridades poco discutidas para su identificación: sistemas ecológicos en los cuales las comunidades locales dependen del fuego para su subsistencia y bienestar; sistemas en los cuales los gobiernos insisten en llevar a cabo políticas de "arriba hacia abajo" de supresión de incendios; lugares en los cuales proliferan incendios de turberas; y lugares en los cuales el cambio climático produce cambios significativos en los tipos de ecosistema. Finalmente propongo una cumbre mundial sobre fuego en fire management goals at the global scale. Taken all together, these proposed steps could enable fire ecologists to mount a worldwide offensive to shape the future of fire in the era of climate change.

la que se debatan estas prioridades y se creen metas de gestión del fuego a escala global. En conjunto, estas iniciativas podrían permitir a los ecólogos del fuego montar una ofensiva global para definir la gestión del fuego en la era del cambio climático.

Keywords: climate change adaptation, fire-climate interactions, fire policy, global priorities, social-ecological systems

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INTRODUCTION

As the world burns, in one troubling fire after another, we fire ecologists sometimes feel helpless to change future outcomes at large spatial scales. In the western US, a very small percent of wildfires—those that defy human control—account for the overwhelming majority of hectares burned (Strauss *et al.* 1989). Within the global fire community, some of us live in countries that have eschewed fire for more than a hundred years, making the public very wary of fire. Others of us live in countries where fire is still used as an everyday farming and forestry practice, and is no more exciting than planting, weeding, or harvesting. As the climate changes, most of us are either observing or anticipating changes in the way fires behave and in the scope of their impacts.

Fire ecologists must emphasize three key messages in order to shift the world's focus away from the fire suppression messages of the twentieth century, and to open doors for moderating fire-climate change feedback loops during the twenty-first and twenty-second centuries. These are:

1) Fires will keep burning no matter what.
2) Millions of people around the world depend upon fire for survival.
3) Trying to control fire too tightly doesn't work.

In order to make a difference at the global scale, we fire ecologists should concentrate our research, education, and management efforts at the level of social-ecological systems in four areas:

1) Where people depend on fire for survival and well-being;
2) Where governments unwisely insist on command and control approaches to fire;
3) Where peatlands are burning; and
4) Where climate-driven changes in fire will cause type conversion.

THREE KEY MESSAGES FIRE ECOLOGISTS MUST ENGRAIN IN WORLD CONSCIOUSNESS

Fires Will Keep Burning No Matter What

Although we understand it, the fact that fires will continue to burn is a message that has been difficult for fire ecologists to embed in the world's consciousness. At small temporal and spatial scales, most of Western society views fires as repeated surprise events. However, viewing fire in geologic time coupled with modern satellite data reveals a story of ongoing occurrence. Every fire ecologist should share Adam Voiland's two-minute video, "A Global Tour of Fire," with anyone who will watch: students, neighbors, dinner guests, airplane passengers—anybody. Access it at http://www.nasa.gov/mission_pages/fires/main/modis10.html.

There really isn't a choice about having vegetation fires on earth. Photosynthesis isn't going to stop, and the resulting stored energy will eventually be released either by respiration or combustion. In geologic time, we've had wildfires since vegetation started growing on land, about 420 million years (Scott and Glasspool 2006). At large spatial scales, there is no shortage of ignition sources from people or lightning. The fire reality is that roughly 300 million ha burn each year in vegetation fires (Giglio *et al.* 2006). At the turn of the twenty-first century, biomass burning from fires accounted for a fourth to a third of greenhouse gas emissions worldwide (Levine 1996), releasing between 2.0 PgC yr^{-1} to 3.2 PgC yr^{-1} (van der Werf *et al.* 2006).

Millions of People around the World Depend upon Fire for Survival

Ninety percent of vegetation fires are started by people (Davidson-Hunt and O'Flaherty 2007), and most often by people in poorer sectors of society who rely on their skillful use of fire for getting food. Burning cropland to control disease and to convert stubble to fertilizer; burning for clearing and maintaining pastures and controlling pests; burning to aid hunting and gathering; and burning forests to maintain trees, mushrooms, and herbs are common practices repeated in many geographies. Modernizing all of agriculture by converting fire-dependent systems to industry-dependent systems is not practical or ecologically sustainable in the near term. So, to think at the global scale, fire ecologists must include fire-dependent agricultural systems into a global fire budget—the amount of fire and biomass burning that constitutes an acceptable and necessary baseline for sustainable ecosystems and cultures worldwide.

Fire ecologists must also engage in partnerships that integrate into global problem-solving the health impacts from smoke, and from fire's contribution to greenhouse gas emissions. Extended periods of haze from region-wide fire events can send millions of children, the elderly, and adults with pre-existing respiratory conditions to hospitals and emergency rooms (World Health Organization 1998). Using mortality coefficients from the World Health Organization, the American Cancer Society, and others, a first global estimate is that 300 000 people die annually from exposure to smoke particulates from landscape fires (Johnston *et al.* 2012). Certainly this estimate will be refined, but the point will remain: smoke from vegetation fires is a strain on human health, and probably to that of other animals.

As the future of greenhouse gas regulation unfolds, our efforts to burn more in fire-adapted ecosystems will be evaluated not on benefits to plants, animals, and soils, but on the amount of greenhouse gases produced. For example, the Rim Fire of 2013, known for entering Yosemite National Park that year, burned 104 000 ha (USDA Forest Service 2013). Its size was moderate among wildfires in US history. A generic calculation using the national emission factor for forest wildfires in the coterminous US suggests that the Rim Fire emitted roughly four million metric tons of carbon dioxide (CO_2) (National Wildfire Coordinating Group 2011), although unpublished estimates using local vegetation data are more than twice that amount. The generic estimate is the equivalent to the amount of CO_2 emitted by 800 000 cars for a year (US Environmental Protection Agency 2011). A wildfire of only 610 ha in US forest fuels would emit 25 000 metric tons of CO_2, the annual level above which US factories and other facilities must report their CO_2 emissions to federal authorities (US Environmental Protection Agency 2009). In the past, each fire was local, affecting primarily local ecosystems and communities. Today, every fire is also the world's fire, linked to climate change feedback loops.

Predictions based on climate change models make the need to engage in serious, transparent problem-solving even more compelling. Sixty-two percent of the Earth's surface is predicted to experience increases in fire activity (Moritz *et al.* 2012). For every degree Celsius rise in temperature, area burned in large portions of Colorado, New Mexico, and Arizona in the USA is projected to increase by 300% to 650% (National Research Council 2011). Across northern latitudes, boreal forest and tundra ecosystems will experience increases in fire activity (Moritz *et al.* 2012), releasing not only carbon dioxide, but substantial amounts of methane (CH_4) from smoldering organic soils.

Trying to Control Fire Too Tightly Doesn't Work

At the global scale, too much fire and the wrong kinds of fire now trump not enough fire as the most influential fire problems that ecologists must face. Fire ecologists must frame arguments for government prohibition of burning and more effective fire suppression in terms of the global reality. Excluding fire in large areas over extended time scales doesn't work and never will. We need to be courageous about sharing examples from around the world where central governments have bumped up against the limits of their influence in containing fire. In Madagascar, for example, restrictions on burning were legislated nationally to protect timber and other resources in 1907 and 1913, little more than a decade after French colonization of the country (Kull 2002). In the face of a century of heavy sanctions against using fire, local people who depend upon fire for survival have developed a complex system of social resistance in which fire management is clandestine: fires are lit at night and burn unattended. Local communities protect fire practitioners' identities, resisting government inquiry into who started a particular fire, and burning is done during periods when locals know that the government is unlikely to enforce sanctions (Kull 2002).

This pattern is repeated in many countries: when fires are troublesome, centralized governments nearly always opt for "the pathology of command and control" (Holling and Meffe 1996). It is politically difficult to resist. When fires keep escaping our grasp, we invest in more firefighters, more airplanes, stricter rules, and stronger tactics. Unfortunately, the uncertainties inherent in managing ecological systems eventually bring unintended consequences, like the tree-thickened forests in the western US that burn over larger areas with higher severity. We ecologists study the pathology as it sets in, often wondering if we can really turn things around at scales that will make a meaningful difference.

WHAT FIRE ECOLOGISTS CAN DO

The United Nations and others have adopted Reducing Emissions from Deforestation and Forest Degradation (REDD+; Morales Barquero *et al.* 2014) as a primary approach to avoiding CO_2 emissions from vegetation fires. Widely discussed in policy and carbon accounting circles, REDD+ programs use payment for carbon credits to fund programs that aim to reduce deforestation and its carbon consequences, particularly in developing countries of the tropics. Forest loss and carbon releases from related decomposition account for roughly 12% of anthropogenic CO_2 emissions worldwide (van der Werf 2009). Given the advantages of REDD+ for reducing emissions, for pushing carbon science forward, and for addressing the social and ecological consequences of deforestation, refinement of REDD+ should continue. Still, we must complement these programs with additional effort. Here are four less-discussed circumstances for ecologists to consider in order to make a difference in the world's fire challenges:

1) Where people depend on fire for survival and well-being;

2) Where governments insist on command and control approaches to fire;
3) Where peatlands are burning; and
4) Where climate-driven changes in fire will cause type conversion.

Where People Depend upon Fire for Survival and Well-Being

On every continent except Antarctica, people still use fire on the land for survival and well-being. To the extent that indigenous people have rights to continue traditional practices, they have a right to burn and fire ecologists respect that. But, tacit support is only the beginning. The West Arnhem Land Fire Abatement Project is using funding from ConocoPhillips to actively support indigenous people's traditional burning practices. This has not only helped to maintain tropical savannas, it has also reduced greenhouse gas emissions by roughly 50% of the pre-project baseline and provided a million US dollars in annual income to Aboriginal Australians (Fitzsimons *et al.* 2012).

In northern California, the Karuk Tribe and the US Forest Service signed an agreement to "work together to mutually coordinate planning and implementation efforts as partners in and adjacent to the Katimiin Cultural Management Area in a manner consistent with Karuk customs, culture and the Klamath Land and Resource Management Plan" (Karuk Tribe and USDA Forest Service 2012). The area is located within Karuk ancestral territory, most of which lies within the Klamath and Six Rivers national forests. The aim is to rejuvenate and expand traditional fire practices on behalf of healthy rivers that, in turn, support salmon populations, which are central to Karuk livelihoods and culture. Project leaders have engaged the US Fire Learning Network (FLN) to facilitate a stakeholder-driven planning process designed to broaden local capacity for collaborative fire management. The FLN is a twelve year old partnership among the US Forest Service, four US Department of the Interior agencies—Bureau of Indian Affairs, Bureau of Land Management, Fish and Wildlife Service, and National Park Service—and The Nature Conservancy. Its primary goals are to restore the nation's forests and grasslands and to make human communities safer from fire.

There are many more opportunities like these in which fire ecologists could play a key role. "Even small examples are important in China," says Bob Moseley, now Director of Conservation for The Nature Conservancy in Illinois, and formerly its scientist in the Chinese province of Yunnan. On the Tibetan Plateau, yak herders have used fire to reduce brush and to keep alpine meadows open for grazing. Alpine meadows on the plateau support remarkable plant species richness and endemism (Ma *et al.* 2007), contain the greatest concentration of Tibetan medicinal plants, and produce forage for production of yak butter (R.K. Moseley, The Nature Conservancy, personal communication). In the 1980s, the Chinese government began to constrain burning. Fire exclusion together with a warming climate is allowing a demonstrable march of forests and shrubs uphill into these meadows, resulting in the loss of diversity and livelihood potential (Baker and Moseley 2007, Moseley 2011).

In other places, increasing weather extremes are making traditional burning practices more difficult to employ. For example, in southern Mexico, indigenous people of Mayan descent carry out burning practices perfected during the past 5000 years. They use fire to produce corn, beans, forage, and other products from both forests and fields. Their activities provide fuel reduction and soil amendments across the landscape, at no charge. By comparison, fuel reduction projects in comparable fuels in the US can cost \$2500 ha^{-1} (Skog *et al.* 2006). However, the strong El Niño event of 1998 brought dry conditions, making traditional fires harder to control. Farmers kept burning at the traditional time with traditional tools, intending to produce their customary harvests. That year, thousands of fires escaped, 97% from human causes (Rodríguez-Trejo and Pyne 1999). In the Mexican state of Chiapas, the number of fires increased by 2.5 times compared to the six-year average, while the area burned increased by 9.3 times (Roman-Cuesta *et al.* 2003).

For Mesoamericans, climate change presents a serious fire challenge into the future Traditional fire managers already conduct their burning under modest conditions that allow fire control with available hand tools (Huffman 2013). Fire-savvy communities maintain clean firebreaks, small burn parcels create vegetation mosaics, and fire practitioners burn at night when temperatures are cool and winds are calm. Burning as the summer rains begin ensures that moisture will help keep the flames low, and fires are conducted every few years to keep fuel loads manageable. However, climate change is predicted to bring more frequent and more severe El Niño events (Magrin *et al.* 2007). Facing more fire escapes and greater pressure on traditional fire practices, local people need information from climate scientists, fire ecologists, and others in order to conceive of adapting their own practices for future survival.

Where Governments Unwisely Insist on Command and Control

Holistic fire expertise combined with land-based demonstration projects can bring real change in places where governments are either just now tipping toward command and control of fire, or where governments recognize its limits and are ready to try more open approaches. Fire management in Spain is a good example, wherein traditional burning practices that kept fire and vegetation in balance for centuries survives only in pockets, primarily in the form of pastoralist resistance to government policies (Seijo 2005). As agricultural lands are abandoned and brush takes over, people inhabiting homes in the untended countryside are dying in wildfires. Top-down fire control is expensive, and despite the ongoing investment, researchers and local observers in some areas report that wildfire risk is increasing due to fuel accumulation and weather changes (Fernandez-Gimenez and Fillat 2012, Pausas and Fernandez-Munoz 2012). Today, the very same agencies that instituted fire prevention and suppression in Spain are now considering more collaborative approaches in which fire control organizations and local communities work together to get proactive burning done (Food and Agriculture Organization of the United Nations 2005; J. Duce Aragües, Ministerio Medio Ambiente de España, personal communication).

Where Peatlands Are Burning

Covering only three percent of the earth's land area, peatlands store 30 percent of global soil carbon, twice as much carbon as the world's forests, and about the same amount as the atmosphere (Parish *et al.* 2008). In their natural condition, peatlands are typically saturated with water or ice. When warm, dry periods interface with exposed soils, fires emit voluminous quantities of CO_2 and CH_4. The 2007 Anaktuvuk River Fire, which burned 104 000 ha along Alaska's Arctic slope, released roughly as much carbon as the entire arctic biome sequesters in an average year (Mack *et al.* 2011).

In 1997 and 1998, a strong El Niño event collided with widespread agricultural burning practices in Indonesia, igniting extensive peatlands. The fires emitted between 0.81 Gt to 2.57 Gt of carbon into the atmosphere, the equivalent of 13% to 40% of the mean annual global carbon emissions from fossil fuels (Page *et al.* 2002). An estimated 20 million people experienced respiratory illnesses (World Health Organization 1998). Because CH_4 is released from burning peat, and because the Global Warming Potential of CH_4 is

79 to 105 times that of CO_2 over a 20 year time span (Shindell *et al.* 2009, Myhre *et al.* 2013), it is essential that we address fire where peat soils dominate.

Fires in peat soils are difficult to extinguish, so avoiding ignition is important. Project FireFight Southeast Asia, a program started in 2000 by the International Union for the Conservation of Nature and the World Wildlife Fund, taught us that engaging with rural communities to meet their fire needs is a critical complement to larger-scale legislative and economic solutions. In this case, community-based fire brigades and resolving land tenure issues both play a role in preventing unwanted ignitions and fire spread.

As intractable as working with thousands of rural communities may seem, what looms larger is the potential for fires in northern latitudes to burn deeper into organic soils. A toehold for conservation practitioners, however, presents itself in the form of water management.

During the summer of 2010, more than 30 000 fires, including a thousand peat fires, burned in Russia (MunichRe 2011). Moscow was blanketed in smoke for most of the summer. Firefighting costs and agricultural losses exceeded \$2 billion. Moscow's death rate doubled to 700 lives per day. In July and August, 56 000 more people died that year than in the same months of 2009, ostensibly due to the combined effects of the heat wave and forest fires (MunichRe 2011). Factors that sustained the event included the worst heat wave since recordkeeping began in the late 1800s, and fires burning in areas that had been drained to mine peat for electricity plants (Chubarova *et al.* 2012). While we may not be able to control a heat wave in the short term, we can support land conservation and management strategies that retain water in peatlands and avoid artificial drainage.

The Canadian Boreal Forest Agreement is a multi-stakeholder example in which 19 timber companies and seven non-profit environmental organizations agreed to work together to conserve a landscape of 73 million ha (Canadian Boreal Forest Agreement 2010). Although the agreement focuses primarily on forest sustainability, boreal caribou conservation, and the prosperity of the forest sector and local communities, minimizing artificial drainage will be a coincident outcome. Member organizations have committed to suspending timber harvesting and road building (disturbances that often affect water relations) from 29 million ha in boreal caribou habitat. While avoiding development on large areas of land may not make sense everywhere, preventing peatlands from burning does, especially during the next several decades when key decisions will emerge for achieving a livable carbon balance.

Where Climate-Driven Changes in Fire Will Cause Type Conversion

Scientists now predict that shifts in fire regimes driven by climate change will cause some ecosystems to change altogether. Isolated jungles and cloud forests are examples. Creeping into fire-sensitive systems with ankle high flames, surface fires in the humid tropics cause substantial changes in jungle life. For example, the Arapiuns wildfires that burned in the eastern central Amazon in 1997 resulted in 36 % mortality of mid-story and canopy trees >10 cm in diameter at breast height (Peres *et al.* 2003). Animals with poor climbing ability or low mobility were especially vulnerable, along with those that depend on tree cavity nests (Peres *et al.* 2003).

Along ecotones between flammable vegetation types and jungles, high humidity and moist leaf litter have traditionally provided barriers to fire spread. Combined with higher temperatures and drought, however, fires ignited along forest edges will be more likely to spread. Once burned, these fire-sensitive ecosystems become more exposed to sun and wind, spooling them into positive feedback loops of drying and burning again (Cochrane *et al.* 1999).

In places like these, research in fire ecology informed by community dialogue can go a long way. In a simple example, fire ecologists and local farmers can work together to identify burning conditions under which fires will maintain cropland and pastures at the jungle's edge, but not spread into the jungle interior.

In other places, fire-adapted temperate forests adapted to frequent, low intensity fire are increasingly vulnerable. The ponderosa pine forests of the western US are burning in large patches of high severity fire, killing all of the trees on entire mountainsides, burning homes, and taking people's lives. On the Santa Fe National Forest in New Mexico, the 2011 Las Conchas Fire burned 17 800 ha in its first six hours and generated 180 m flames (B. King, District Fire Manager, Santa Fe National Forest, USDA Forest Service, personal communication). Local residents, many of whom were familiar with fire, narrowly escaped as their homes caught fire. Citizens in Colorado died in ponderosa pine forest fires during the summers of 2012 and 2013. Because ponderosa pine trees don't reproduce across broad swaths very readily, researchers now predict that drought stress and fire will convert broad zones of ponderosa pine forests to shrublands or novel vegetation assemblages (van Mantgem *et al.* 2013, Williams *et al.* 2013).

Our best bet to save this ecosystem has three strategies, all of which are transferable to similar ecosystems around the world. First, we must move swiftly with partners to expand models of fire-adapted communities where people can live safely with fire. Second, we must purposely and repeatedly put fire into these woods when burning conditions are moderate. Finally, to be realistic, we must also develop science-based programs to address the needs of severely burned landscapes. This is especially important in socially significant watersheds, like the Rio Grande, where water supplies become compromised, and where recent evidence suggests that restoration of natural ponderosa pine communities may not be successful in the long run (Williams *et al.* 2013; A. Bradley, The Nature Conservancy, personal communication).

CONCLUSION

The potential of fire-climate interactions to overwhelm ecologists' everyday efforts is clear. Conflicts between fire management practitioners from many backgrounds and greenhouse gas managers are sure to increase over time. If conservation of fire-affected ecosystems is to be successful in the era of climate change, we fire ecologists must bring additional energy and focus to helping societies focus on solving fire problems in four kinds of places. Repeated in many geographies around the world, these are where people depend on fire for survival and well-being; where governments unwisely insist on command and control approaches to fire; where peatlands are burning; and, where climate-driven changes in fire will cause type conversion.

Finally, these themes could provide the foundation for a global fire summit. A gathering of fire ecologists and colleagues focused on conceptualizing a global fire plan could start with debating the relative merits of pursuing these and other priorities. The result could be a worldwide vision for steering fire on Earth, and an energized collective effort. If we challenge ourselves to think and act at this scale, the result could be a positive global impact, something for which future generations will thank us.

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