LAND USE

Managing Forests and Fire in Changing Climates

Policy focused on fire suppression only delays the inevitable.

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With projected climate change, we expect to face much more forest fire in the coming decades. Policymakers are challenged not to categorize all fires as destructive to ecosystems simply because they have long flame lengths and kill most of the trees within the fire boundary. Ecological context matters: In some ecosystems, high-severity regimes are appropriate, but climate change may modify these fire regimes and ecosystems as well. Some undesirable impacts may be avoided or reduced through global strategies, as well as distinct strategies based on a forest's historical fire regime.

Fire regimes are commonly characterized by burn frequency and severity within a given area. Severity is often estimated as the proportion of overstory trees killed by fire. In general, as frequency increases, fuels have less time to accumulate, reducing intensity and subsequent tree mortality. However, a great deal of variation occurs even within fire regime types (*1*). The spatial scale and patch-size distribution of different severity classes are key in assessing whether fire regimes have changed over time and whether changes maintain or compromise forest ecosystems.

Globally, fire frequency and severity vary among forest types. Essentially all fires have high-severity effects, where most of the trees are killed, at some spatial scale and patch size. The critical issue is whether tree mortality patch sizes (and their temporal and spatial frequency) allow recovery of the same or similar vegetation types. If high-severity patch sizes are too large, microclimates and regeneration mechanisms (e.g., seed abundance and dispersal) can limit tree reestablishment (see the figure). Large high-severity patches may produce vegetation type changes, especially in forests adapted to frequent, low- to moderate-severity fire regimes or in forests that lack in situ propagule sources. Introduced species, such as nonnative grasses, also may alter forest fire regimes and lead to changes in vegetation type (*2*).

Changing fire severity is at the heart of ecological debates about historically high-frequency, low- to moderate-severity fire regimes, such as ponderosa pine (*Pinus ponderosa*) and semiarid mixed-conifer forests. A central concern is whether high-severity patches in wildfires are too large, which results in undesirable ecosystem changes (see the figure). Rising temperatures, related drought stresses, and increased fuel loads are driving high-severity patches to extraordinary sizes in some areas (*3*).

In contrast, forests adapted to low-frequency, high-severity regimes such as Rocky

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Historical forest fire regimes. (**Top**) Mixed-conifer forest in northern California with fuels accumulated from a century of fire suppression (left), mature surviving and regenerating trees in an area that had been mechanically thinned to reduce fuels and residues either removed or burned (center, 10 years after the 2002 Cone Fire), and an adjacent untreated area lacking live seed trees, now dominated by shrubs (right, 10 years after the Cone Fire). (**Bottom**) Lodgepole pine forests in Greater Yellowstone (left) regenerated abundantly from the canopy seedbank after the stand-replacing 1988 Yellowstone Fires (center, 15 years postfire), but regeneration was greatly reduced in forests of comparable age and serotiny after the 2000 Glade Fire, which was followed by summer drought 1 year after the burn (right, 10 years postfire). Forests are within 4 km of each other at each site.

CREDIT: (TOP) MALCOLM NORTH; (BOTTOM) MONICA TURNER

Mountain lodgepole pine (*Pinus contorta* var. *latifolia*) have evolved to regenerate after large, high-severity events. Seed banks stored in tree crowns survive even the highest-severity fires and are released shortly after the fire ends. If seeds germinate in open conditions conducive to relatively high growth rates, a new forest can become established in a few decades (see the figure). Other species can regenerate a new crown from one burned by fire because of dormant buds.

Future Fire Under Changing Climates

With projected climate warming (*4*), forests around the globe will likely undergo major landscape-scale vegetation changes in coming decades. In some areas, plant productivity may decline to a point where fire will become less frequent (*5*). In more productive areas, fire regimes may shift from being mostly climate-controlled (top-down) to mostly fuel-controlled (bottom-up) (*6*). In both cases, slow vegetation change may be abruptly accelerated by a change in fire regime driven by novel climatic conditions.

Increased frequency and size of large, severe forest fires are expected in Australia, the Mediterranean Basin, Canada, Russia, and the United States (*3*, *7*, *8*). In the western United States, increased frequency and size of fires is associated with increased temperatures, earlier spring snow melt, and longer fire seasons (*9*)—mechanisms that are applicable to other regions of the world.

Trends and projections of climate and fire responses suggest that new strategies to mitigate and adapt to increased fire are needed to sustain forest landscapes. Identifying and implementing appropriate responses will not be easy because the complexity of local-to-regional dynamics makes uniform, simple, or unchanging policy and management strategies ineffective (*10*). It is especially difficult to motivate social response to environmental transitions that unfold slowly and are thus difficult to detect before it is too late (*11*).

We suggest strategies for forests of all fire regimes: *Landowners should follow "Firewise" guidelines (*www.firewise.org/*) for houses and other infrastructure.* Increased development in fire-prone landscapes has increased suppression costs, exacerbated risk to human safety and infrastructure, and reduced management options. People living in these forests must be prepared rather than relying solely on fire departments. Some places may be so hazardous that building should be prevented, discouraged, or removed (e.g., by regulation or insurance and/or tax incentives).

Fire managers should avoid trying to uniformly blacken wildfire landscapes through burnout and mop-up operations, especially in burn interiors. As wildfire sizes have grown in recent decades, direct attack has been replaced with indirect attack, where fire lines are placed some distance from the active fire front, and then the area between is intentionally burned, often with high-severity fire, to reduce fuel and create a wider fire barrier. Unburned or partially burned patches are critical refugia that aid postfire recovery in forests of all fire regimes and should be conserved whenever possible.

Land managers could anticipate changes using models of species distribution and ecological processes and should consider using assisted migration (12). Dominant forest species may be unable to recover from fires with large high-severity patches. Replacement ecosystems of shrublands or grasslands may provide some ecological benefits, but they offer very different habitats for wildlife and have reduced carbon storage relative to native forests.

We also suggest several distinct strategies based on a forest's historical fire regime. *Mitigation in forests with historically high-frequency, low- to moderate-severity fire regimes:* (i) Restore resilient forest structure similar to historical patterns that survived during past high-fire periods (and those anticipated in the future) (see the figure). Fuel reduction and restoration treatments can increase resiliency by reducing density-dependent tree mortality (*4*) and excessive insect and/or disease problems and can increase spatial heterogeneity.

(ii) Fund forest restoration. We know how to treat forests to reduce fire hazards, with generally positive or neutral ecological effects, although impacts to wildlife with large home ranges have not been fully assessed (*13*). Public acceptance of these treatments is increasing (*14*); the barrier is cost. Treatment rates are far below what is needed for landscape resilience (*15*). Because the federal government has no jurisdiction in development policies in the privately owned urban-wildland interface, state and local jurisdictions could pay for fire suppression in the interface. This would enable a significant increase in critical forest restoration funding and would probably reduce building in the interface.

Adaptation in forests with historically low-frequency, high-severity fire regimes: (i) Expect changes in forest type and age across the landscape (see the figure). Some forest types will be relatively resilient to more frequent fires, notably resprouting or seed-banking species. However, even these forests will likely exhibit substantial changes in landscape structure, such as shifts to a preponderance of young stands (*16*).

(ii) Some forests will change to nonforest vegetation after fire. Spruce-fir (*Picea-Abies*) and interior Douglas fir (*Pseudotsuga menziesii*) forests may exhibit large changes in structure and species composition because they lack persistent seed banks or sprouting capability. Some areas may even shift to a nonforest state, especially if trees cannot reestablish in a warmer, drier climate. Such changes will not necessarily be catastrophic (e.g., a shift to nonforest could potentially increase water yield) and could be expected to reduce intensity of subsequent fires. However, shifting from forest to nonforest would affect most ecosystem services. There are no clear guidelines for increasing the resilience of these forest types—unlike for forests adapted to high-frequency, low- to moderate-severity fire regimes—other than minimizing additional stresses from excessive grazing, recreation, and salvage logging.

The annual cost of fire suppression is increasing and unsustainable; costs exceeded $2 billion in the United States in 2012. Fire policy that focuses on suppression only delays the inevitable, promising more dangerous and destructive future forest fires. In contrast, land management agencies could identify large firesheds (20,000 to 50,000 ha) where, under specified weather conditions, managed wildfire and large prescribed fire are allowed to burn, sometimes after strategic mechanical fuel treatments (*15*). Acknowledging diversity in fire ecology among forest types and preparing forests and people for larger and more frequent fires could help reduce detrimental consequences.

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