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Forest fire management, climate change, and the risk of catastrophic carbon losses

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Abstract
Approaches to management of fire-prone forests are undergoing rapid change, driven by recognition that technological attempts to subdue fire at large scales (fire suppression) are ecologically and economically unsustainable. However, our current framework for intervention excludes the full scope of the fire management problem within the broader context of fire–vegetation–climate interactions. Climate change may already be causing unprecedented fire activity, and even if current fires are within the historical range of variability, models predict that current fire management problems will be compounded by more frequent extreme fire-conducive weather conditions (e.g., Fried et al. 2004).

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Approaches to management of fire-prone forests are undergoing rapid change, driven by recognition that technological attempts to subdue fire at large scales (fire suppression) are ecologically and economically unsustainable. However, our current framework for intervention excludes the full scope of the fire management problem within the broader context of fire−vegetation−climate interactions. Climate change may already be causing unprecedented fire activity, and even if current fires are within the historical range of variability, models predict that current fire management problems will be compounded by more frequent extreme fire-conducive weather conditions (eg Fried et al. 2004). Concern about climate change has also made the mitigation of greenhouse-gas (GHG) emissions and increased carbon (C) storage a priority for forest managers.

A widely accepted fire management strategy is prescribed burning – purposefully setting fires under mild weather conditions to reduce fuel loads and the risk of subsequent high-severity wildfires. However, the potential for prescribed burning in some biomes to mitigate GHG emissions is contested. In northern Australia’s eucalypt savannas, non-carbon-dioxide GHG emissions (eg methane, nitrous oxides) are being reduced as part of a voluntary C offset program, by setting fires early in the dry season when mild conditions prevail, thereby reducing fuel consumption and fire severity (Russell-Smith et al. 2009). By contrast, in southern Australia’s less fire-prone eucalypt forests, this approach reportedly has little potential to reduce emissions (Bradstock et al. 2012), because the emissions from prescribed burning are likely to exceed the emissions avoided by reducing wildfire extent.
and intensity in treated landscapes. Indeed, in these systems, 3–4 areal units of prescribed fire are needed to avoid a single areal unit of wildfire (Boer et al. 2009; Price and Bradstock 2011). In the western US, prescribed burning for reducing GHG emissions from ponderosa pine forests is controversial. Fire suppression over the past century has caused a shift from surface- to crown-fire regimes, leading to an increase in tree density and fuel loads in these forests. Hurteau and Brooks (2011) posited that mechanical thinning, followed by the restoration of frequent, low-severity fires through prescribed burning, can increase the stability of live tree biomass by reducing the risk of stand-replacing wildfires. Although there is widespread acceptance that prescribed burning can reduce wildfire risk in these forests, Campbell et al. (2012) argued that the emissions from prescribed burning exceed the emissions avoided by reducing wildfire extent and intensity, thus rendering this approach ineffective in reducing GHG emissions. Clearly, a better understanding of the complex C trade-offs between prescribed fire and wildfire will be required before this important debate can be resolved.

A paradoxical feature of the debate about prescribed burning as a GHG mitigation tool is the limited consideration given to irreversible climate- and fire-driven conversion of high-biomass forests to low-biomass, non-forest states (Figure 1). Such “biome switching” is predicted by alternative stable state theory and accords with the fire ecology of some forest systems. Lindenmayer et al. (2011), for example, proposed the “landscape trap” concept, whereby strong feedbacks after logging of high-biomass eucalypt forests grossly inflate fire risk, making...
recovery to the pre-fire state unlikely. Alternative stable state theory can be similarly applied to climate-change impacts on many fire-prone forests. For instance, some fire-suppressed forests of the western US are vulnerable to conversion to non-forest states because of increasingly severe fire weather and prolonged drying. Indeed, modeling by Westerling et al. (2011) suggests that climate-driven increases in fire frequency over the next century could transform much of Wyoming’s Greater Yellowstone Ecosystem from conifer forests to more open vegetation types.

For vulnerable forests, the real value of mechanical thinning and subsequent prescribed burning, as proposed by Hurteau and Brooks (2011), may be to resist biome switching, assuming that the “expenditure” of $C$ associated with these interventions is substantially less than the avoided $C$ losses associated with a biome switch (Figure 1a). In southern Australia’s tallest eucalypt forests (Figure 1b), which are vulnerable to stand-replacing fires, broad-scale prescribed burning is impractical given the dominance of obligate seeders. In this case, extensive thinning may increase fire risk, and fire suppression may be the best management option. In contrast, in fire-resistant eucalypt forest types, dominated by resinoting tree species, there is a low likelihood that climate change could alter fire regimes sufficiently to cause biome switching (Figure 1c). At the wildland–urban interface, the most cost-effective fire management strategy for reducing the threat to human life and property may be to focus on heavy localized thinning of forests through mechanical harvesting, prescribed burning, or grazing, regardless of forest regeneration strategies (eg Figure 1; Cochrane et al. 2012; Gibbons et al. 2012).

Crucial steps in better understanding the relative risks of both orthodox and unconventional fire management interventions require predicting the vulnerability of ecosystems to state transitions due to fire–climate interactions. Where the risk is high, discriminating various alternative management approaches demands assessment of the magnitude of $C$ losses and the costs and benefits in terms of other ecosystem services, biodiversity values, and public safety. No single objective should define fire management, and an evidence-based understanding of the inherent trade-offs between different fire management regimes is imperative.

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