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EDITORIAL OPINION

Does It Make Sense to Restore Wildland Fire in Changing Climate?

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Abstract

Forest restoration guided by historical reference conditions of fire regime, forest structure, and composition has been increasingly and successfully applied in fire-adapted forests of western North America. But because climate change is expected to alter vegetation distributions and foster severe disturbances, does it make sense to restore the ecological role of wildland fire through management burning and related activities such as tree thinning? I suggest that some site- and date-specific historical conditions may be less relevant, but reference conditions in the broad sense are still useful. Reference conditions encompass not only the recent past but also evolutionary history, reflecting the role of fire as a selective force over millennia. Taking a long-term functional view of historical reference conditions as the result of evolutionary processes can provide insights into past forest adaptations and migrations under various climates. As future climates change, historical reference data from lower, southerly, and drier sites may be useful in places that are higher, northerly, and currently wetter. Almost all models suggest that the future will have substantial increases in wildfire occurrence, but prior to recent human-caused fire exclusion, fire-adapted pine forests of western North America were among the most frequently burned in the world. Restoration of patterns of burning and fuels/forest structure that reasonably emulate historical conditions prior to fire exclusion is consistent with reducing the susceptibility of these ecosystems to catastrophic loss. Priorities may include fire and thinning treatments of upper elevation ecotones to facilitate forest migration, whereas vulnerable low-elevation forests may merit less management investment.

Key words: climate change, Durango pine, fire, Jeffrey pine, ponderosa pine.

Introduction

North American forests adapted to disturbance regimes of frequent fires have been the focus of efforts to reinstate surface fire, alone or in combination with tree thinning, to reduce stand density and hazard of severe fire, re-create historical species composition, and restore self-regulating processes of nutrient cycling, productivity, and regeneration (Covington et al. 1997; Allen et al. 2002; Falk 2006). Research suggests that these goals are broadly feasible in many sites across the range of ponderosa pine (*Pinus ponderosa*) and related species (e.g., *Pi. jeffreyi*, *Pi. durangensis*) that dominate millions of hectares from Mexico to Canada. To illustrate briefly a range of examples, a management strategy in U.S. National Parks of allowing naturally ignited fires to burn on large landscapes has resulted in self-limiting fire patterns in California (Collins et al. in press) and tended to thin mesic species that had invaded while fire had been excluded (true firs, *Abies concolor* and *A. lasiocarpa*) while conserving surface fire–adapted species (ponderosa pine and Douglas-fir [*Pseudotsuga menziesii*]) in Arizona (Fulé & Laughlin 2007) (Fig. 1). Prescribed burning and thinning have been shown to substantially reduce the projected intensity of simulated wildfires under severe weather conditions at the scale of entire states across the Rocky Mountains (Fiedler et al. 2002, 2004); the conclusions of modeling studies have been validated with actual examples of reduced fire behavior in treated stands even under the most severe wildfires of the past decade (Pollet & Omi 2002; Finney et al. 2005). Economic analysis suggests that forest thinning and burning treatments would more than pay for themselves just by avoiding wildfire suppression costs, even without accounting for ecological and social consequences of severe fires (Snider et al. 2006). Finally, restoration treatments have been shown experimentally to restore ecosystem productivity (Kaye et al. 2005), plant community composition (Laughlin et al. 2006), and elements of wildlife habitat (Germaine & Germaine 2002; Waltz & Covington 2004). In sum, the early results of a few decades of restoration efforts suggest that it may be possible to recapture many key aspects of structure, composition, and function consistent with historical reference conditions, helping to sustain these important forests.

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Figure 1. Ponderosa pine forests across the current elevational range in which they occur at Grand Canyon, Arizona, U.S.A. (a) Low-elevation ponderosa interspersed with woodland may be most vulnerable to climate change. (b) Midrange ponderosa in a relict site exhibiting structure composition and fire regime generally consistent with historical reference conditions. (c) High-elevation ponderosa mixed with other conifers burning in a "wildland fire use" managed fire in 2003 (National Park Service photo). This use of fire reduced fuel and preferentially thinned mesic species.

The broad challenge that climate change poses for ecological restoration, and for sustaining natural systems in general, is that uncharacteristically rapid alteration of environments and novel combinations of disturbances and non-native biotic factors may create conditions never before encountered in evolutionary history. The speed and severity of change may overwhelm natural processes. For example, Malcolm et al. (2002) estimated that the rates of migration required to keep pace with projected temperature increases in boreal forests would be 100–1,000 times faster than the most rapid postglacial migration of spruce (*Picea*) found in the paleoecological record. Under these circumstances, the relevance of historical conditions as a reference point and target for restoration has been challenged (Harris et al. 2006). My objectives in this article are to review the potential impacts of climate change on surface fire–adapted (hereafter, "fire-adapted") forests, ask to what extent historical reference conditions remain relevant, and suggest considerations that may be useful for evaluating the role of alternative fire management strategies.

Potential Impacts of Future Climate

Predictions of future climate characteristics are limited in precision because of the enormous complexity of Earth–atmosphere coupling, inadequate data, and insufficient understanding of the mechanisms of climate forcing. Investigations of the potential effects of climate change, therefore, have tended to apply a series of constant changes in temperature, precipitation, or other climate or environmental variables. Because no single climate model is necessarily preferred, analyses are developed under a range of climate models and social assumptions about future greenhouse gas emissions, with the argument that the evidence for particular changes is strongest when multiple models are in consensus (Seager et al. 2007).

Climate change is expected to affect forests both by movement of the suitable environmental conditions for dominant species and by altering disturbance. Geographical ranges for many dominant North American tree species are anticipated to shift northward (Shafer et al. 2001). A U.S.–wide model that incorporated climatic, edaphic, and topographic data predicted that the contemporary vegetation would not persist by 2100 AD in over half of the places where it is found at present under a high-emission scenario and would decline nearly everywhere even under a reduced-emission scenario (Saxon et al. 2005).

Disturbance regimes can be directly affected by climate change, thereby accelerating vegetation change. Seager et al. (2007) showed that the average of 19 climate models consistently predicted increasing drying for the southwestern United States/northwestern Mexico, suggesting that the level of droughts historically viewed as extreme may become the norm. In addition to mortality caused directly by drought, water-stressed forests are vulnerable to large-scale pathogen attacks (Breshears et al. 2005). Hotter, drier environments, with increasing amounts of dying vegetation, are likely to enhance the size and severity of wildfires. Area burned in Canada was projected to increase 74–118% by 2100 in a tripled CO_2 scenario (Flannigan et al. 2005). Across the western U.S. states, McKenzie et al. (2004) correlated the historical occurrence of large wildfires with warm and dry conditions. Overlaying projected future climate conditions suggested an increase from approximately 50 to 500% in area burned in 10 of the 11 states. Mechanistic links between earlier spring warming since the mid-1980s and abrupt increases in fire have already been observed (Westerling et al. 2006). Pyrogenic invasive species such as bromes (*Bromus* spp.), favored by warming, may also facilitate increased burning (Keeley & McGinnis 2007).

Despite the uncertainties of climate prediction and the complicated interacting factors, there appears to be no reason to doubt that fire will only increase as a disturbance factor that accelerates the process of forest change in coming decades. Fire-adapted forests that underwent the well-documented changes associated with extended fire exclusion, such as greater stand density, forest floor fuel accumulation, and encroachment by fire-susceptible species (Cooper 1960; Cocke et al. 2005), will be increasingly vulnerable to stand-replacing fire. And postfire vegetation will be less likely to be similar to the historical forest because severe fires often favor alternative stable states (grasslands, shrublands) rather than a return to prefire pine forest (Barton 2002; Savage & Mast 2005; Strom & Fulé 2007).

Are Reference Conditions Relevant?

Before asking to what degree historical reference conditions are relevant in light of the extraordinary transformations that may be associated with climate change, it is helpful to consider the range of concepts represented by "reference conditions." Commonly, reference conditions are taken to mean the range of variability in ecosystem structure, composition, and function, "developed by natural processes and … self-organizing and self-maintaining" (Society for Ecological Restoration International 2002), at a particular place and time (Landres et al. 1999). Thus, the sinuosity and flow of a river before damming, or the frequency of fires and spacing of forest trees before logging and livestock grazing, could serve as evidence for the historical events and natural processes that sustained these ecosystems before recent human-caused ecological degradation. This view of reference conditions was influential in the development of restoration concepts (Aronson et al. 1993) and remains prominent in procedures advocated by the Society for Ecological Restoration International (2002). Restorationists have never suggested that reference conditions could be completely restored, given irreversible changes such as non-native invasion or extinctions of native species. For example, the invasive non-native species cheatgrass (*Bromus tectorum*) is favored by the high fire frequency characteristic of ponderosa and Jeffrey pine ecosystems, so restoration burning may need to strike a compromise—burning at longer intervals—to balance fire benefits and risks (Fulé & Laughlin 2007; Keeley & McGinnis 2007). But because climate change implies that even the fundamental biophysical environment may be altered, Millar and Brubaker (2006) questioned the value of trying to restore to "conditions that cannot be turned back." Most people would agree that it is not reasonable to seek to "restore" historical forest conditions exactly as they were in a particular place in 1750, for instance, because the climate of 2050 or 2150 is likely to be quite different at that place.

Reference conditions are not simply a historical snapshot, however; they must be viewed over much longer timescales. The fire-related adaptations of pine forests are associated with fire's role as a selective force going far back in evolutionary time (Keeley & Zedler 1998; Moore et al. 1999; Covington 2003). Our relatively detailed knowledge of fire regimes is limited to a century or so of historical records, a few centuries of tree-ring data, and up to some thousands of years of charcoal sediments (Agee 1998). But the frequent occurrence of fires among certain related pine species is consistent with adaptations that developed much longer ago when these species were found in different distributions on Earth due to ice ages or interglacial warming (Covington 2003). The fire-related traits of ponderosa and related pines, such as thick bark, protected buds, abundant seeding, and long life span (Agee 1998), had adaptive value in allowing these species to persist and dominate mountainous regions of North America over long periods characterized by droughts and ignitions.

Taking a long-term functional view of reference conditions as the result of evolutionary processes highlights three issues that are relevant to decisions about restoring the ecological role of wildland fire. First, under whatever circumstances fire-adapted pine ecosystems might persist in the future, evolutionary history suggests that fire is likely to continue to play a key role as an agent of either ecosystem maintenance (predominantly surface fire) or ecosystem change (predominantly stand-replacing fire). Second, paleoecological evidence of vegetation migration has become increasingly valuable for predicting how future distributions may track changing climate (Harris et al. 2006; Petit et al. 2008). Fire regime changes were associated with the loss and arrival of forest communities, and fires may have been the mechanism for change. For example, a shift from pulsed to sustained high charcoal inputs occurred with the transition from spruce- to pine-dominated forest in a high-elevation Arizona forest 11,000 years before the present (Weng & Jackson 1999). New research approaches are seeking to improve the temporal resolution of long-term fire records, thereby helping link migration and fire (Allen et al. 2008). Third, though climate forecasting remains imperfect, virtually every fire prediction analysis for western North America indicates that the future will be characterized by substantial increases in wildfire occurrence. Prior to recent human-caused fire exclusion and forest alteration, fire-adapted pine forests of western North America were among the most frequently burned in the world (Heyerdahl & Alvarado 2003; Swetnam & Baisan 2003; Hessl et al. 2004). Restoration of patterns of burning and fuels/forest structure that reasonably emulate historical conditions prior to fire exclusion is consistent with reducing the vulnerability of these ecosystems to catastrophic loss (Allen et al. 2002; Falk 2006).

Considerations for Fire Use in Ecological Restoration

Decisions about fire use in ecological restoration are not simple. Igniting fires, permitting natural fires to burn, and tree cutting are regulated under national and local laws and rules (Stephens & Ruth 2005). Fire use involves production of smoke, release of CO_2, costs of management, effects on wildlife, and the possibility of escaped fire. When accompanied by tree thinning or other fuel treatments, costs can rise to hundreds or thousands of dollars per hectare because the thinned trees are generally of low value. Managers and society as a whole must evaluate trade-offs among risks, costs, and benefits. In light of the changes that may be associated with climate change, I suggest the following considerations for restoration of fire.

(1) Forests in places most vulnerable to the effects of climate change, such as low-elevation pine forests or ecotones with woodlands or other low-elevation vegetation, may be a relatively low priority for ecological restoration. Given the high likelihood of loss, management resources might be better applied elsewhere. Instead of seeking to perpetuate low-elevation forests in their current form, managers could follow a course of facilitating their replacement with native vegetation that is presently found at lower, drier sites.

(2) Forests that currently occupy the middle range of elevation may be expected to face severe stress from climate change in the coming decades. In these places, restoration of surface fire in most sites and thinning in strategic sites will increase resistance to severe wildfire at the stand and landscape scales, insect pathogens, and invasive non-native species. The projections for climate change effects on vegetation distributions suggest that even midrange forests may not be capable of survival (e.g., Saxon et al. 2005). However, site-specific climate forecasting is uncertain, and the climate-related mechanisms of vegetation change—principally fire, bark beetles, and die-back—have stochastic elements (e.g., chance of an ignition), meaning that we cannot be sure now which places will experience the most severe changes. It is possible that even open, burned forests may be unsustainable in the heart of their present ranges, but until and unless that point is reached, forests more similar to reference conditions are the most likely to persist.

(3) Forests at the upper, wetter end of the elevational range are best positioned to survive climate change and to serve as the leading edge of upward migration. Restoration treatments based on historical reference conditions characteristic of lower elevation sites could help facilitate the transition. In the southern range of fire-adapted pines, the upper ecotone is usually a mixed-conifer forest that historically burned with surface to mixed-severity or severe fire. Application of surface fire, perhaps coupled with thinning of mesic taxa (*Abies*, *Picea*), will favor pine dominance with enhanced resistance to severe fire, shifting the surface/lethal fire boundary uphill. In the northern range, where fire-adapted pines are seral to other conifers, future climate may be more consistent with the historical situation in the Southwest where pines remained dominant. In sum, it may be logical to apply historical reference data from lower, southerly, and drier sites to places that are higher, northerly, and currently wetter sites. This may enhance vegetation transition and reduce the probability of severe disturbance with invasion by native and non-native ruderal species. The same logic would apply to ecosystem *creation*: if climate change effects outstripped migration to the point where it was considered advisable to establish pine forests in entirely new locations, a suggestion offered by Millar and Brubaker (2006), surface fire would still play an important role in the formation and maintenance of these ecosystems.

Attempting to deal with the challenges posed by climate change is humbling and difficult. Restoration of fire-adapted pine forests does not present an either/or situation; it is unlikely that a comprehensive blanket approach to management can or should be devised. However, as we move into a *more* fire-prone environment, it makes sense to use fire and fire-related characteristics of structure and composition to enhance resistance to loss and facilitate migration. Many restorationists have had a naive reliance on ecosystem stability that is appropriately being challenged by paleoecological and field ecology evidence (Cortina et al. 2006; Harris et al. 2006; Millar & Brubaker 2006). Yet even as we recognize that a broader, longer, more variable, and more functional perspective on reference conditions reduces the perception of stability, it is important to bear in mind that native ecosystems are not necessarily fragile. Since the last glacial period, fire-adapted pines of North America have occupied a vast range encompassing monsoonal, Mediterranean, and continental climates with an extraordinary diversity of soils, geomorphological types, and associated plant and animal species. These forests have already exhibited great flexibility and adaptation. Thoughtful restoration of the ecological role of fire and fire-related structure and composition should enhance the chances of persistence of some of these native forests under future climate conditions.

Implications for Practice

- Climate change will affect both vegetation distributions and disturbance, placing fire-adapted pine ecosystems under unprecedented stress. However, moving into a more fire-prone environment, it makes sense to use fire and fire-related characteristics of structure and composition to enhance resistance to catastrophic loss and facilitate migration.
- Historical reference conditions remain useful to guide management because forests were historically resilient to drought, insect pathogens, and severe wildfire. Adaptation of reference information to future climates is logical: historical characteristics from lower, southerly, and drier sites may be increasingly relevant to higher, northerly, and currently wetter sites.
- The perspective presented here focuses on western North American forests, but similar considerations may be relevant for other fire-adapted pine ecosystems in the Mediterranean, Central America, and Asia.

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