

# Fire and sustainability: considerations for California's altered future climate

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**Abstract** In addition to reducing greenhouse gas emissions, actions to achieve a sustainable coexistence with wildfire need to be taken now. In this paper we suggest several important policy, planning, and management changes that should be made, regardless of the many uncertainties in predicting future fire regimes. Similar to how other natural hazards are addressed, a risk-based framework for fire-related decisions is crucial. Reintroduction of fire to fire-prone ecosystems, careful use of fire surrogates, and creation of new and flexible policies will be needed for successful ecosystem management. Growing incompatibilities between urban development and wildfire also require a serious reevaluation of urban planning and building in fire-prone locations to reach a sustainable coexistence with fire. Our future cities and communities must be less susceptible to wildfire damage, and the ecosystems upon which we depend must be made more resilient to further disruptions in fire regimes.

## 1 Introduction

Fire is an integral natural disturbance in many terrestrial ecosystems across the planet, and especially so in fire-prone portions of California (Fig. 1). There are, however, relatively few studies about interactions between wildfire and projected climate change in California (Malanson and Westman 1991; Davis and Michaelson 1995; Miller and Urban 1999; Lenihan et al. 2003; Fried et al. 2004). Little is therefore known about how future fire regimes will ultimately behave, and the timing and patterns of fires can be driven by several factors. For example, longer fire seasons, greater climatic variability, and more lightning strikes have been predicted for some parts of the world (e.g., Wotton and Flannigan 1993; Price and Rind 1994); however, these projections may only be valid at coarse spatial scales, and great local uncertainty remains for any given place. We also face large uncertainties about shifts in the frequency and intensity of extreme fire weather episodes in California,

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which could have major consequences for fire regimes under scenarios of climate change (Davis and Michaelson 1995; Field et al. 1999; Moritz et al. 2004).

Because our knowledge is limited, we focus here on policy, planning, and management recommendations that meet a variety of future needs related to wildfire in California. We consider the recommendations as “no regrets” actions that will be beneficial, regardless of what climate changes do actually occur. Given projected population growth in California and how future climates may change, action must be taken now to achieve a sustainable coexistence with wildfire. Fire is a necessary component of many North American ecosystems; we should not, and in the end cannot, keep fire out of these ecosystems. What we must do, however, is execute policies that will enable us to live with fire in our wildland ecosystems. Our future cities and communities must be less susceptible to wildfire damage, and the ecosystems upon which we depend must be made more resilient to further disruptions in fire regimes. The recommendations presented here are primarily in the context of California, but they could provide useful guidance for many fire-prone regions of the world.

## 2 Policy, planning, and management

### 2.1 A risk-based framework

We will always be faced with limitations on the level of resources available for fire-related activities, whether for hazard mitigation or for reintroducing a needed ecological disturbance. In addition, many in society simply view fire as a threat to be eliminated, instead of accepting it as a natural – even if sometimes dramatic and unpredictable – ecosystem process. Such challenges are only going to become more complex under an altered future climate. To confront such complexities, we must reach consensus on a framework for evaluating fire-related decisions and a specific level of acceptable risk we will tolerate. For example, there are policies and planning guidelines to accommodate other natural hazards that affect the landscapes we inhabit. Planning requirements may exist for areas within a 100-year floodplain, and we have engineering solutions for infra-structure to withstand earthquakes of different magnitudes. If a fire approaches a specific location, what flame lengths are acceptable and how much prior vegetation clearance is needed to achieve an acceptable level of risk? Do we want to prepare for the 90th, 95th, or 97.5th percentile worst fire weather day? How do we view events greater than that magnitude? What probability of undesirable outcomes – escaped fires, unnatural fire severities, smoke production, and losses of lives or structures – do we allow? By comparison, do we construct buildings to withstand a 9.0 earthquake? To answer these questions, we need the scientific basis for evaluating different alternatives; however, it is ultimately a social and political process to identify the level of risk and losses we can tolerate. Not surprisingly, many of the same issues surround climate change and the risk of large flood events (Olsen 2006), another risk management discipline that could provide guidance for how to accommodate large fires as natural disturbances (Moritz 2003).

Because scarce resources are typically allocated among several competing needs, our decision framework must incorporate the costs and benefits related to fire. Such an approach needs to include the ecological benefits of a naturally functioning fire regime or the possibility of fire surrogates, as well as the future economic value of spending resources on some fire-related activity. We need the ability to evaluate the costs and benefits of spending funds now on retrofitting homes in a fire-prone location (e.g., a one-time

expenditure likely to reduce home ignition by  $X\%$ ), versus fuel reduction efforts there (e.g., treatments that require ongoing maintenance, reducing flame lengths or ember production or fire spread rates by  $Y\%$ ). The adverse ecological and economic effects of vegetation treatments, such as erosion or the spread of invasive species, must also be factored in. Decision frameworks that incorporate some of the important variables mentioned here have been proposed (e.g., Miller et al. 2000; Finney, 2005), but California lacks one that is comprehensive and flexible enough for complex fire-related decisions.

## 2.2 Resilient ecosystems

We have minimal knowledge of how natural variation in fire regimes will be affected in the future, yet we need to restore the inherent resilience of fire-prone ecosystems where possible. Despite the complexity in local fire regimes, regional fire activity can oscillate in phase with year-to-year climatic variability. For example, the area burned annually across the southern USA tends to decrease in El Niño years and increase during La Niña years (Swetnam and Betancourt 1990). In some parts of California, however, the relationship between fire and climate oscillators appears to be more variable (Keeley 2005; Fry and Stephens 2006). As climate changes, it is likely that relationships between fire and climate oscillators may also change, accentuating or at least changing the timing and intensity of the physical stresses that ecosystems will already be facing. The possibility of such scenarios requires that we do what is possible to facilitate ecosystem resilience, so that natural disturbances (insects, disease, drought, fire) are accommodated without mortality outside a desired range. Natural variation, or reference conditions derived from historical ecological data, can be used to assist in the definition of desired future conditions (Swetnam et al. 1999; Stephens and Fulé 2005), but we must be clear that managing for ecosystem conditions that occurred 150–200 years ago is probably not appropriate for the next century. Instead, an emphasis on creating heterogeneous conditions, protecting biological refugia, and avoidance of ecological threshold transitions (e.g., vegetation type conversion, loss of keystone species) may be most beneficial as ecosystems respond to novel fire-related conditions and interactions.

Increased application of the existing federal Wildland Fire Use (WFU) policy in more remote areas of California would allow fire to be reintroduced into a variety of ecosystems (Stephens and Ruth 2005). Admittedly, there is the possibility of asset loss inherent in such a policy, but a well-defined and accepted level of risk would facilitate fire regime restoration. Fires ignited by lightning and allowed to burn through WFU in more remote areas can produce positive effects, provided they are carefully managed and monitored. Without extensive use of WFU, expensive fuels management techniques in many forests will be needed at appropriate spatial scales and arrangements (Finney 2001), or many of California's ecosystems will remain susceptible to uncharacteristically severe fire and future climate changes. Broader implementation of the WFU policy would offer an unprecedented opportunity to gather valuable ecological and organizational information about reintroducing fire across an array of regions and landscapes. Creation of fire-resilient landscapes is critical because we have learned that the question is not if California's diverse ecosystems will burn, but when, where, and with what intensity.

Because of scientific uncertainties and the difficulty of precisely predicting future fire regimes, adaptive management programs must be incorporated into future management decisions to allow for continued learning and evaluation (Stephens and Ruth 2005; Husari et al. 2006). This will allow managers, scientists, and the public to determine if management actions are actually producing more resilient ecosystems, and if they are

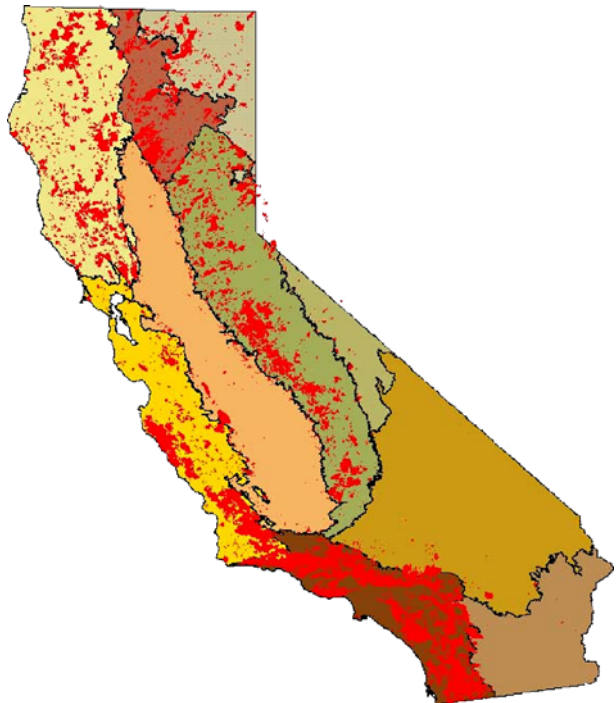
not, new approaches can be attempted to meet this objective. It is critical that information gained from adaptive management programs actually be used to refine management procedures, as opposed to being academic exercises or simply “adaptive” in name only. Despite the need for assumptions in many cases, adaptive management should not be allowed to continue based on assumptions that are shown to be faulty.

### 2.3 New fire policies

Sustainable fire policies must respond to complex social, political, and economic forces. Currently, there are diverse opinions among executive branch officials, Congress, federal agencies, state and local governments, Native American tribes, environmental groups, commodity groups, and international organizations as to what should actually be done to reduce the impacts of changing climates and to minimize the area impacted by uncharacteristically severe wildfire. Policymaking depends on technical and scientific information, but the choices made are inherently political ones (Stephens and Ruth 2005). For this reason, even if a particular issue is relatively uncomplicated and the design of a solution may be easily understood, policy formulation is often complicated. Substantive objectives, such as fuel hazard reduction, must compete for legislative and administrative attention and resources with other worthwhile objectives and programs. Budgetary concerns, for example, may override even the soundest programmatic proposals (Stephens and Ruth 2005).

When developing new fire policies it is critical to differentiate between the inherent ecological differences among the diverse ecosystems in California (Fig. 1). Indeed, one of the most common mistakes with current fire policies is their inability to distinguish between

**Fig. 1** Mapped fire history in California. Fire perimeters for the last several decades (since 1950 in some areas, but back to ~1910 in others) are shown in red, over the ecoregions of California (Hickman 1993). The spatial structure in fire patterns highlights how different natural fire regimes are across California, in addition to possible variation in the effectiveness of recent human-caused fire suppression in different areas (fire data maintained by California Department of Forestry and Fire Protection)



ecosystems that can have very different fire regimes (Gutsell et al. 2001; Agee and Skinner 2005; Stephens and Ruth 2005; Stephens and Sugihara 2006). Some ecosystems, such as chaparral shrublands, are adapted to infrequent high-intensity fire, and fire intervals that are too short can be atypical and ecologically damaging. Mixed-severity fire regimes may be more characteristic of higher elevation forests or those in moist coastal environments. Still others, such as ponderosa pine, Jeffrey pine, and mixed conifer forests, are adapted to more frequent, low-to-moderate-intensity fire regimes. Policies enacted to manage the complex interaction between fire and future climates must differentiate between ecosystems that have fundamentally different fire regimes.

#### 2.4 The WUI problem

More fire-safe planning and building in fire-prone areas would accommodate both urban and ecological processes in a more sustainable manner. Urbanization and fragmentation of natural habitats has been recognized as a major source of ecological degradation (e.g., Soulé 1991; Booth and Jackson 1997; Theobald et al. 1997). Furthermore, the primary reason we worry about wildfire is that people have developed formerly natural landscapes, building their homes and communities in fire-prone areas. To focus attention on where such development is occurring, the boundary between developed and wildland areas is sometimes referred to as the wildland–urban interface (WUI), or the wildland–urban intermix (WUI) in the case of lower-density housing. Expansion of the WUI with the development of more homes in rural and suburban areas is an important environmental issue across the United States, and there are more homes in the California WUI than in any other state (> 5 million; Radeloff et al. 2005). It is therefore imperative that we reexamine how future urban growth and fire hazard in the WUI can be mitigated to minimize expansion of the WUI (Reams et al. 2005), regardless of the climate change scenario in question. Vegetation management within and near WUI areas is certainly important, but changes specific to how we inhabit and build on landscapes are also crucial.

To achieve a more sustainable coexistence with wildfire in future WUI areas, there are two fundamental goals to achieve. The first is to adopt urban planning guidelines that reduce the expansion and exposure of the WUI itself, producing more compact urbanized areas with less convoluted boundaries. While this shift may present a host of political challenges, it is one of the few ways to produce future communities that both minimize their ecological impact and are more easily defensible in a wildfire situation. The difficulty of evacuating people from WUI communities during wildfires is another solid justification for limiting expansion of the WUI (Cova 2005). At a minimum, new developments should strategically place large and less fire-prone landscape features, such as parks and golf courses, between neighborhoods and areas of high fire hazard where possible (Keeley et al. 2004). The second goal for future housing is to adopt much more stringent building codes in fire-prone WUI communities. Although it will take a large outreach effort to educate the public about retrofitting existing construction (e.g., high-risk wood shingle roofs), we have a chance now to ensure that much of the WUI of future decades is built in a more fire-safe manner. More effort is needed to fully address the problems living in fire-prone environments (e.g., Gill 2005), but meeting the two building and planning goals specified here should at least provide greater separation between incompatible processes on either side of the WUI. This increased separation will improve the chances for fire to burn freely in our wildlands and result in fewer losses on the urbanized side.

### 3 Conclusion

We are at a turning point, given the likely impacts of climate change on fire regimes and the anticipated population growth in California. Despite California's leadership in the U.S. in adopting carbon emissions caps and developing emissions accounting protocols, there are still important knowledge gaps in how to incorporate fire. For example, understanding the controls on fire probabilities in both space and time is central to long-term carbon sequestration efforts in forests. Baseline potential burning rates in different ecosystems are also needed, so that fire-related emissions reduction programs might be calibrated and rewarded appropriately. Although fire poses real and interesting challenges to the science behind carbon accounting efforts, we should remember that it is also a relatively predictable process that has shaped California landscapes for millenia.

In addition to drastically reducing greenhouse gas emissions, we must begin to think in terms of adaptation and resilience (e.g., Salinger et al. 2005) to eventually reach a sustainable coexistence with wildfire. Ultimately, the goal is for human communities to safely inhabit California's fire-prone landscapes, while also ensuring the long-term functioning and persistence of the ecosystems upon which we depend. Fire is an integral and needed process in many of these ecosystems, but there are major uncertainties about how an altered future climate will affect fire regimes. Adoption of a risk-based framework for fire management, reintroduction of fire to fire-prone ecosystems and careful use of fire surrogates, creation of new and flexible fire policies, and a serious reevaluation of urban planning and building in the WUI are needed to reach a sustainable coexistence with fire in the future. In addition to academic readers of this journal, we hope that these ideas resonate with human institutions such as local planning departments and commissions, fire agencies, the insurance industry, and other important groups that can drive change in policy, planning, and management. The recommendations made here are not comprehensive, but they do provide a minimal roadmap for living with fire in the future.

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### References

- Agee JK, Skinner CN (2005) Basic principles of forest fuel reduction treatments. For Ecol Manag 211:83–96
- Booth DB, Jackson R (1997) Urbanization of aquatic systems – degradation thresholds, stormwater detection, and the limits of mitigation. J Am Water Resour Assoc 22:1–20
- Cova TJ (2005) Public safety in the urban-wildland interface: should fire-prone communities have a maximum occupancy? Nat Hazards Rev 6:99–108
- Davis FW, Michaelsen J (1995) Sensitivity of fire regime in chaparral ecosystems to global climate change. In: Moreno JM, Oechel WC (eds) Global change and mediterranean-type ecosystems. Springer, New York
- Field CB, Daily GC, Davis FW, Gaines S, Matson PA, Melack J, Miller NL (1999) Confronting climate change in California: ecological impacts on the golden state. Cambridge, MA, Union of Concerned Scientists
- Finney MA (2001) Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. For Sci 47:219–228
- Finney MA (2005) The challenge of quantitative risk analysis for wildland fire. For Ecol Manag 211:97–108
- Fried JS, Torn MS, Mills E (2004) The impact of climate change on wildfire severity: a regional forecast for northern California. Clim Change 64:169–191

- Fry DL, Stephens SL (2006) Influence of humans and climate on the fire history of a Ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, California. *For Ecol Manag* 223:428–438
- Gill MA (2005) Landscape fires as social disasters: an overview of “the bushfire problem”. *Environ Hazards* 6:65–80
- Gutsell SL, Johnson EA, Miyaniishi K, Keeley JE, Diskenson M, Bridge SRJ (2001) Varied ecosystems need different fire protection. *Nature* 409:997
- Hickman JC (1993) *The Jepson manual: higher plants of California*. University of California Press, Berkeley
- Husari S, Nichols T, Sugihara NG, Stephens SL (2006) Fuel management. In: Sugihara NG, van Wagtenonk JW, Fites-Kaufman J, Shaffer KE, Thode AE (eds) *Fire in California ecosystems*. University of California Press, Berkeley CA.
- Keeley JE (2005) Impact of antecedent climate on fire regimes in coastal California. *International Journal of Wildland Fire* 13:173–182
- Keeley JE, Fotheringham CJ, Moritz MA (2004) Lessons from the October 2003 wildfires in southern California. *J For* 102:26–31
- Lenihan JM, Drapek R, Bachelet D, Neilson RP (2003) Climate change effects on vegetation distribution, carbon, and fire in California. *Ecol Appl* 13:1667–1681
- Malanson GP, Westman WE (1991) Modeling interactive effects of climate change, air pollution, and fire on a California shrubland. *Climatic Change* 18:363–376
- Miller C, Urban DL (1999) Forest pattern, fire, and climatic change in the Sierra Nevada. *Ecosystems* 2: 76–87
- Miller C, Landres PB, Alaback PB (2000) Evaluating risks and benefits of wildland fire at landscape scales. In: Neuenschwander LF, Ryan KC, Gollberg GE, Greer JD (eds.), *Proceedings of the Joint Fire Science Conference and Workshop: “Crossing the Millennium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management,”* Boise, Idaho, June 15–17, 1999, University of Idaho, pp 78–87
- Moritz MA (2003) Spatiotemporal analysis of controls on shrubland fire regimes: age dependency and fire hazard. *Ecology* 48:351–361
- Moritz MA, Keeley JE, Johnson EA, Schaffner AA (2004) Testing a basic assumption of shrubland fire management: how important is fuel age? *Frontiers in Ecology and the Environment* 2:67–72
- Olsen JR (2006) Climate change and floodplain management in the United States. *Clim Change* 76:407–426
- Price C, Rind D (1994) The impact of a 2 X CO<sub>2</sub> climate on lightning-caused fires. *J Climate* 7:1484–1494
- Radeloff VC, Hammer RB, Stewart SI, Fried JS, Holcomb SS, McKeefry JF (2005) The Wildland–urban interface in the United States. *Ecol Appl* 15:799–805
- Reams MA, Haines TK, Renner CR, Wascom MW, Kingre H (2005) Goals, obstacles, and effective strategies of wildfire mitigation programs in the wildland–urban interface. *Forest Policy and Economics* 7:818–826
- Salinger MJ, Sivakumar MVK, Motha R (2005) Reducing vulnerability of agriculture and forestry to climate variability and change: workshop summary and recommendations. *Clim Change* 70:341–362
- Soulé ME (1991) Land-use planning and wildlife maintenance: guidelines for conserving wildlife in an urban landscape. *J Am Plan Assoc* 57:313–323
- Stephens SL, Fulé PZ (2005) Western pine forests with continuing frequent fire regimes: possible reference sites for management. *J For* 103:532–542
- Stephens SL, Ruth LW (2005) Federal forest fire policy in the United States. *Ecological Applications* 15:532–542
- Stephens SL, Sugihara NG (2006) Fire management and policy since European settlement. In: Sugihara NG, van Wagtenonk JW, FitesKaufman J, Shaffer KE, Thode AE (eds) *Fire in California Ecosystems*. University of California Press, Berkeley
- Swetnam TW, Betancourt JI (1990) Fire-southern oscillation relations in the Southwestern United States. *Science* 249:1017–1020
- Swetnam TW, Allen CD, Betancourt JL (1999) Applied historical ecology: using the past to manage for the future. *Ecol Appl* 9:1189–1206
- Theobald DM, Miller JR, Hobbs NT (1997) Estimating the cumulative effects of development on wildlife habitat. *Landsc Urban Plan* 39:25–36
- Wotton BM, Flannigan MD (1993) Length of fire season in a changing climate. *For Chron* 69:187–192