PERSPECTIVE

# Adapt to more wildfire in western North American forests as climate changes

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Edited by F. Stuart Chapin III, University of Alaska, Fairbanks, AK, and approved February 24, 2017 (received for review October 25, 2016)

**Wildfires across western North America have increased in number and size over the past three decades, and this trend will continue in response to further warming. As a consequence, the wildland–urban interface is projected to experience substantially higher risk of climate-driven fires in the coming decades. Although many plants, animals, and ecosystem services benefit from fire, it is unknown how ecosystems will respond to increased burning and warming. Policy and management have focused primarily on specified resilience approaches aimed at resistance to wildfire and restoration of areas burned by wildfire through fire suppression and fuels management. These strategies are inadequate to address a new era of western wildfires. In contrast, policies that promote adaptive resilience to wildfire, by which people and ecosystems adjust and reorganize in response to changing fire regimes to reduce future vulnerability, are needed. Key aspects of an adaptive resilience approach are (*i*) recognizing that fuels reduction cannot alter regional wildfire trends; (*ii*) targeting fuels reduction to increase adaptation by some ecosystems and residential communities to more frequent fire; (*iii*) actively managing more wild and prescribed fires with a range of severities; and (*iv*) incentivizing and planning residential development to withstand inevitable wildfire. These strategies represent a shift in policy and management from restoring ecosystems based on historical baselines to adapting to changing fire regimes and from unsustainable defense of the wildland–urban interface to developing fire-adapted communities. We propose an approach that accepts wildfire as an inevitable catalyst of change and that promotes adaptive responses by ecosystems and residential communities to more warming and wildfire.**

wildfire | resilience | forests | wildland–urban interface | policy

Wildfire is a key driver of ecosystem change that increasingly poses a significant threat and cost to society. In western North America (hereafter, the West), warming, frequent droughts, and legacies of past management combined with expansion of residential development have made social–ecological systems (SESs) more vulnerable to wildfire. As the annual area burned has increased over the past three decades, we are confronting longer fire seasons (1, 2), more large fires (3, 4), a tripling of homes burned (5), and more frequent large evacuations. In 2016, the Fort McMurray Fire in Alberta, Canada and the Blue Cut Fire in southern California prompted evacuation orders for a combined total of more than 160,000 people. The costs of wildfire have also risen substantially since the 1990s. The US Congress appropriated $13 billion for fire suppression and $5 billion for fuels management in fiscal years 2006–2015 (6). Other societal costs, including real estate devaluation, emergency services, and postfire rehabilitation, total up to 30 times the direct cost of firefighting (7).

Notwithstanding these costs, many plants, animals, and ecosystem services benefit from fire, and those dependent on frequent fire have been negatively affected by the significantly reduced burning resulting from fire suppression, as compared with the period before European settlement

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Author contributions: T.S., J.K.B., P.E.D., P.M., M.G.T., and C.W. designed research; T.S., M.A.K., and N.M. performed research; T.S. analyzed data; and T.S., J.K.B., H.B.-S., P.E.D., B.J.H., M.A.K., N.M., P.M., M.A.M., R.R., M.G.T., and C.W. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1617464114/-/DCSupplemental.

(8). However the response of ecosystems to increases in wildfire activity and warming in the coming decades is not well understood. Broad heterogeneity among western forest landscapes in terms of biophysical environment, past management, human footprint, and the role of fire and future warming creates a complicated playing field. Managing ecosystems, people, and wildfire in a changing climate is a complex but critical challenge that requires effective and innovative policy strategies (9, 10).

Our key message is that wildfire policy and management require a new paradigm that hinges on the critical need to adapt to inevitably more fire in the West in the coming decades. Policy and management approaches to wildfire have focused primarily on resisting wildfire through fire suppression and on protecting forests through fuels reduction on federal lands. However, these approaches alone are inadequate to rectify past management practices or to address a new era of heightened wildfire activity in the West (11–14).

In delivering this message, we focus specifically on the distinction between specified, adaptive, and transformative resilience (15, 16). Rigorous definition and critical assessment of resilience to wildfire are needed to develop effective policy and management approaches in the context of climate change. We suggest an approach based on the concept of adaptive resilience, or adjusting to changing fire regimes (e.g., shifts in prevailing fire frequency, severity, and size) to reduce vulnerability and build resilience into SESs. Adaptive resilience to wildfire means recognizing the limited impact of past fuels management, acknowledging the important role of wildfire in maintaining many ecosystems and ecosystem services, and embracing new strategies to help human communities live with fire. Our discussion focuses on western North American forests but is relevant to fire-influenced ecosystems across the globe. We emphasize that long-term solutions must integrate relevant natural and social science into policies that successfully foster adaptation to future wildfire.

## Why Has Coping with Wildfire Become Such a Challenge?

Three primary factors have produced gradual but significant change across western North American landscapes in recent decades: the warming and drying climate, the build-up of fuels, and the expansion of the wildland–urban interface (WUI; the zone where houses meet or intermingle with undeveloped wildland vegetation).

In terms of climate, wildfire activity is closely tied to temperature and drought over time scales of years to millennia (2, 17–19). Globally, the length of the fire season increased by 19% from 1979 to 2013, with significantly longer seasons in the western United States (1). Since 1985, more than 50% of the increase in the area burned by wildfire in the forests of the western United States has been attributed to anthropogenic climate change (20). Increases in the number of wildfires and area burned in most forested ecoregions of the West are a result of rising temperatures, increased drought, longer fire seasons, and earlier snowmelt (1–4, 21). Specifically, since the 1970s the frequency of large fires has increased most dramatically in the forests of the Northwest (1,000%) and Northern Rocky Mountains (889%), followed by forests in the Southwest (462%), Southern Rockies (274%), and Sierra Nevada (256%), in response to earlier snowmelt and a longer fire season (21). Based on spatial overlays in western United States forests of large wildfires since 1984 (Monitoring Trends in Burn Severity, available at www.mtbs.gov/dataaccess.html and Existing Vegetation Types, available at https://www.landfire.gov/vegetation.php), we found that in northern regions with dramatic increases in fire activity (the Canadian Rockies, Middle Rockies, and Idaho Batholith ecoregions) cold/wet subalpine forests predominantly burned. These forests characteristically burn at high severity and have not experienced a significant build-up of fuels. Overall, cold/wet forests account for about a quarter of total forest burning in the US West since 1984.

Fire suppression, in addition to past logging and grazing and invasive species, has led to a build-up of fuels in some ecosystems, increasing their vulnerability to wildfire. For example, drier, historically open coniferous forests in the West ("dry forests") have experienced gradual fuels build-up in response to decades of fire suppression and other land-use practices (8, 22, 23). Historically, predominantly frequent, low-severity fires killed smaller, less fire-resistant trees and maintained low-density dry forests of larger, fire-resistant trees. Large, high-severity fires now threaten to convert denser, more structurally homogeneous dry forests to nonforest ecosystems, with attendant loss of ecosystem services (24). However, only forests in the Southwest show a clear trend of increasing fire severity over the last three decades, and only a quarter to a third of the area burned in the western United States experienced high severity during that time (25, 26). Although fuels build-up in dry forests can increase the area burned because of higher contagion, the 462% increase in the frequency of large fires in southwestern forests since the 1970s is also a result of an extension of the fire season by 3.6 mo [the average for the western United States is 2.8 mo (21)]. Overall, dry forests account for about half of the total forest burning in the western United States since 1984.

Alongside these increases in warming and fuels, the WUI has expanded tremendously in the past few decades, augmenting wildfire threats to people, homes, and infrastructure. Between 1990 and 2010, almost 2 million homes were added in the 11 states of the western United States, increasing the WUI area by 24% (27). Currently, most homes in the WUI are in California (4.5 million), Arizona (1.4 million), and Washington (1 million) (27). Since 1990, the average annual number of structures lost to wildfire has increased by 300%, with a significant step-up since 2000 (28). About 15% of the area burned in the western United States since 2000 was within the WUI, including a 2.4-km community protection zone, with the largest proportion of wildfires burning in the WUI zone in California (35%), Colorado (30%), and Washington (24%) (Fig. 1) (27). Additionally, almost 900,000 residential properties in the western United States, representing a total property value more than $237 billion, are currently at high risk of wildfire damage (29). Because of the people and property values at risk, WUI fires fundamentally change the tactics and cost of fire suppression as compared with fighting remote fires and account for as much as 95% of suppression costs (28). Together, these gradually changing variables—climate change, fuels build-up, and residential development—interact with rapid combustion to increase wildfire risks and costs to society and some ecosystems substantially.

## Potential Consequences of Future Wildfire

Wildfire activity is predicted to increase in the West over the next century (20, 30, 31). This anticipated ramp-up in burning and possible directional changes in fire regimes (e.g., increases in fire frequency, severity, and/or size) could transform the composition, structure, and function of many forest (8, 32, 33), shrubland, and grassland ecosystems (34). Changes in temperature and precipitation in semiarid shrublands and grasslands may reduce fuel availability subsequently, to the extent that fire occurrence, size, and severity in such areas will eventually decline (35). Thus, although fire activity is projected to increase in the West in the near term (i.e., in the next few decades), longer regional trends will depend on feedbacks between vegetation and fire as well as on anthropogenic alterations in vegetation and land use (36, 37).

Increased exposure of communities to wildfire is also expected with additional warming. More than 3.6 million ha, or almost 40% of the current WUI in the western United States, is predicted to experience moderate to large increases in the probability of wildfire in the next 20 y (Fig. 2). This increase is in addition to the growing wildfire risk to developed nonurban areas (e.g., energy production) and infrastructure (e.g., power lines, pipelines) that define a broader wildland–development

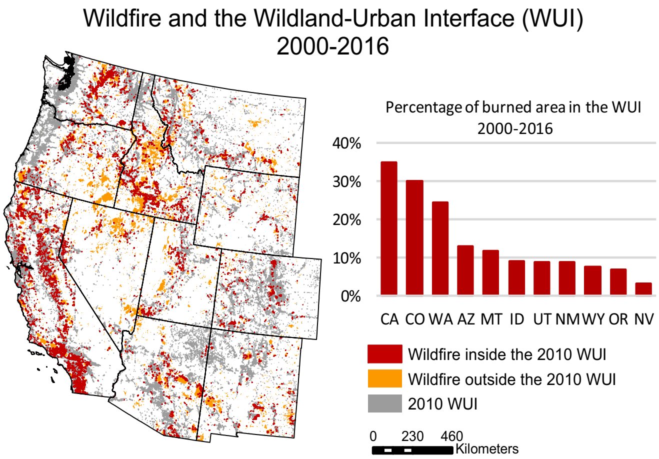


**Fig. 1.** (*Left*) Area burned by wildfires between 2000 and 2016 across the western United States inside and outside the 2010 WUI including a 2.5-km community protection zone (27). (*Right*) About 15% of the WUI burned during this period, with largest proportions of the WUI burning in California, Colorado, and Washington.

interface. Continued WUI growth will further increase human exposure to wildfires (38) and anthropogenic ignitions (37, 39). By midcentury, 82 million people in the western United States are likely to experience more and longer "smoke waves," defined as consecutive days of high, unhealthy particulate levels from wildfires (40). Climate change and increasing exposure of existing and future development to wildfire and smoke present a dangerous and vexing problem for residents, local officials, fire fighters, and managers.

Gradual but significant changes in climate, fuels, and the WUI affect wildfire impacts on ecosystems and society but are difficult to recognize and are challenging to alter meaningfully. There often is a lack of political will to implement policies that incur short-term costs despite their long-term value or to change long-standing policies that are ineffective. For example, few jurisdictions have the will or means to restrict further residential development in the WUI, although modifying and curtailing residential growth in fire-prone lands now would reduce the costs and risks from wildfire in the long term. Furthermore, although the impacts of fire suppression on fuels build-up are now well understood, fire-suppression policies still dominate current fire management (13). Projected global warming of at least 1.1–3.1 °C in the coming century offers a unique opportunity to change policy and the course of our response to wildfires (41). A paradigm shift now in approaches to WUI development and management of fire and fuels can yield tremendous benefits to society later.

## Specified, Adaptive, and Transformative Resilience to Wildfire

Resilience is increasingly invoked as a guiding principle in strategies that address the social and ecological dimensions of wildfire. The US Forest Service's National Cohesive Wildland Fire Management Strategy (42) specifically addresses the need to bolster social and ecological resilience to increasing wildfires. Although often invoked in wildfire management and policy, resilience is defined inconsistently or neglects social or ecological contexts, despite the need for uniformity and specification in setting goals and evaluating progress (43, 44).

Defining resilience to wildfire in an SES is especially challenging in the WUI, where people, ecosystems, and wildfire interact over multiple spatial and temporal scales (12). An SES is the intersection and interdependence of biophysical units and associated people and institutions. Resilience in an SES generally has been defined as the capacity to absorb disturbance so as to retain essential structures, processes, and feedbacks and to adapt to and reorganize following disturbance (45).

These perspectives of resilience, absorbing versus adapting to disturbance, offer different guiding principles for policy and management in responding to wildfire and measuring success over different planning timelines (44). Here we outline a consistent framework that defines resilience to wildfire in coupled SESs based on the concepts of specified resilience and general resilience, the latter of which includes adaptive and transformative approaches (Table S1) (15, 16, 44).

When climate trends or disturbance regimes are relatively stable and well-characterized and planning horizons are short (years), specified resilience or restoration is an appropriate guiding principle. "Specified resilience" refers to the buffer capacity of a system to retain its identity after a well-specified disturbance (16). Specified resilience reflects the concept of ecological resilience, which refers to the capacity of a system to absorb or tolerate disturbance without shifting to a qualitatively different state controlled by a different set of processes (46). In terms of wildfire, specified resilience applies when fire characteristics are within the bounds of historical range of variability (HRV) of disturbance regimes and a burned forest recovers without converting to another state, e.g., to a nonforest state such as a persistent grassland. In a social context, specified resilience is evident when a community recovers economically and rebuilds similar structures in similar locations following a wildfire (44, 47). Management guided by specified resilience often values recent ecological and social dynamics, particularly when the goal is the conservation of particular species or landscapes. Such management is often informed by short temporal windows of HRV, or "recent HRV" (rHRV) (Fig. 3). This approach can be useful for responding to fires in the short term. However, when social and environmental conditions change rapidly, this approach may foster management goals that are unrealistic or unsustainable in the long run (48, 49).

When climate and wildfire trends are changing and planning horizons are intermediate (decades), general resilience is a more appropriate and desirable guiding principle. "General resilience" refers to the capacity of an SES to adapt or transform in response to unknown shocks or disturbances outside the rHRV (16). Adaptive resilience incorporates aspects of change, reorganization, learning, and adaptability in response to changing climate and disturbance regimes and is an on-going process achieved by harnessing adaptive capacity. In an ecological context, adaptive resilience refers to actively or passively supporting species compositions and fuel structures that are better adapted to a warming, drying climate with more wildfire. Management of specified resilience maintains ecosystems within the rHRV,

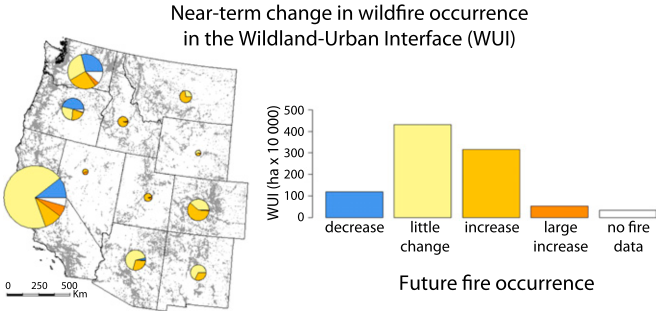


**Fig. 2.** (*Left*) Area of the WUI in the conterminous western United States, classified according to projected near-term changes in fire occurrence. The size of each pie is scaled relative to the area of the WUI (both intermix and interface) in each state, based on data from Martinuzzi, et al. (27). Within each pie, slices represent the proportion of WUI area overlapping the five categories of projected fire occurrence for the period 2010–2039, based on data from Moritz, et al. (30). (*Right*) The bar chart summarizes the area of the WUI projected to experience each level of change in fire occurrence in the western United States.

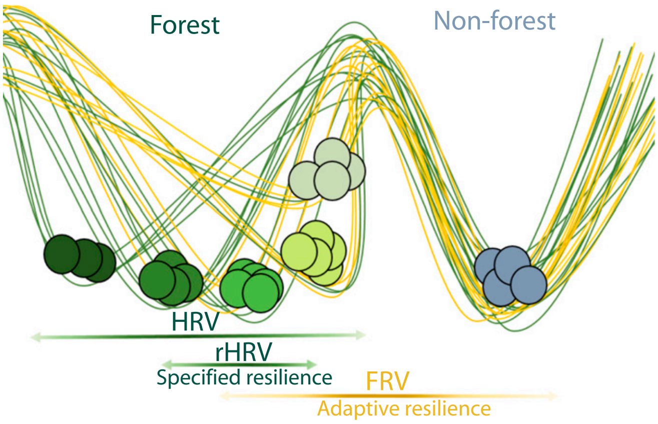


**Fig. 3. Conceptual ball-and-basin representation of specified and adaptive resilience across a forested landscape. Lines defining basins depict the ranges of variation in fire regimes across forest types. Sets of green balls reflect the variation in abundance and composition within different forest types, and the set of blue balls represents nonforest ecosystems. Specified resilience of forests to wildfire is maintained within basins that fall within an rHRV of fire regimes over recent decades to centuries, typically derived from historical documents, remotely sensed data, and tree-ring data. Longer definitions of HRV reflect variation in fire regimes over the last 4,000–5,000 y, when present-day forest types were established in most regions; these data are derived from paleoecological reconstructions. Adaptive resilience to changing fire regimes is reflected within basins that fall within the FRV (yellow). Under the FRV, shifts to nonforest ecosystems remain unlikely in some cases (lower green balls) and more likely in other cases with easier transition to nonforest basin (higher green balls). Changes in the severity, frequency, and size of fire regimes and long-term regeneration following fire events reflect adaptive responses to changing fire regimes and climate conditions across broad scales.**

whereas managing for adaptive resilience considers how changing disturbance regimes may favor suites of traits that are better adapted to a future range of variability (FRV) (Fig. 3) (22). Alignment of fire regimes with adaptive regeneration traits of native vegetation defines a safe operating space (50). The HRV can still play a role by providing insight into how adaptive traits align with changing disturbance regimes to confer adaptive resilience, but under the FRV the safe operating space is shifting (Fig. 3) (50, 51, 52). In a social context, communities exhibiting adaptive resilience engage in ecological, psychological, social, and policy processes that set the community on a trajectory of change to reduce future vulnerability (Fig. 4) (53). Strategies may include changing building codes to make structures more fire-resistant, planning communities to avoid or withstand future wildfire, or providing incentives, education, and resources to reduce vulnerability to future wildfire (47). Adaptive resilience also involves institutional learning, where past management approaches to wildfire evolve.

When climate and wildfire trends are significantly altered from historical trends and/or variability, and planning horizons are long (century), transformative resilience may be necessary. “Transformative resilience” refers to planned fundamental change in response to drastically altered disturbances that have the potential to create broad-scale, systemic shifts in ecological states or radical shifts in values, beliefs, social behavior, and multilevel governance. Examples might include significant regional changes in ecosystem states and associated loss of ecosystem services and/or the relocation of communities of people away from wildfire-prone areas (44, 54). Rapid, planned social–ecological transformation is rare and difficult to implement because of uncertainties about future risk, inflexible institutions and behaviors, and the high cost of transformative action (55).

Although distinct, these approaches to resilience may be nested. Promoting specified resilience may make some forests better poised for adaptive resilience as climate changes, but in some forests or conditions specified resilience may not be effective as climate changes (e.g., refs. 56, 57). Allowing postfire shifts from forest to grassland or shrubland may increase adaptive resilience to changing wildfire and climate conditions. Approaches to adaptive resilience could reduce the need for transformation if efforts keep pace with climate and wildfire trends or may help pave the way toward inevitable social–ecological change. Embracing specified resilience may be the easiest, most familiar path with the least uncertainty, but this approach is short-sighted and could come at the cost of adaptation to future wildfire as climate change continues.

Taking an adaptive resilience approach now is critical, because specified resilience, although useful in some contexts, will become a less useful guiding principle as we exceed HRVs. Adaptive resilience means adjusting to changing fire regimes and climate—in both social and ecological systems—by taking advantage of opportunities to moderate potential impacts and cope better with the consequences. Adapting to wildfire sooner rather than later provides the widest benefits to society at the least cost. If we do not adapt to wildfire now, disruptive and unintended transformations of SESs in the West may ensue.

## How Policy and Management Can Promote Adaptive Resilience to Wildfire

Current approaches to managing wildfire focus primarily on controlling fire through suppression and secondarily focusing on managing fuels build-up in forests. Within the context of current and future trends in wildfire, we evaluate the following three approaches in terms of their promise for fostering adaptive resilience in ecosystems and residential communities living with more wildfire: (*i*) managing fire, (*ii*), managing fuels, and (*iii*) promoting adaptive capacity (Fig. 5).

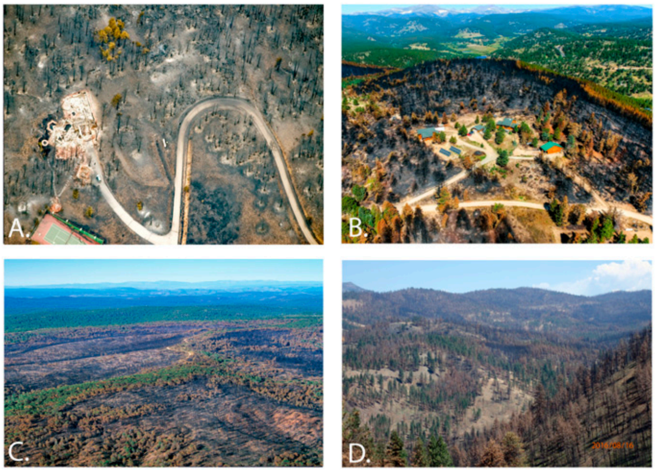


**Fig. 4. Wildfires are catalysts of change that promote adaptive resilience by communities and ecosystems to future wildfires. (*A* and *B*) Example of adaptation in communities. (*A*) A home burned in the 2010 Fourmile fire, Boulder County, CO, which at the time was the most destructive fire in Colorado history in terms of home loss. (*B*) A home that survived the 2016 Cold Springs fire, where many residents managed structural and vegetative fuels around their home to reduce fire hazard after the Fourmile fire through Boulder County’s Wildfire Partners program. (*C* and *D*) Heterogeneity in wildfire severity promotes diversity in postfire regeneration and fuels in the 2002 Rodeo-Chediski fire, Coconino and Navajo counties, AZ (*C*) and the 2016 Canyon Creek fire, Grant County, OR (*D*). Photographs courtesy of REUTERS/Alamy Stock Photo (*A*), Wildfire Partners (*B*), Tom Bean/Alamy Stock Photo (*C*), and M.A.K. (*D*).**

## Managing Wildfire

***Suppressing Fewer Fires and Prescribing More Burning.*** Increasing the use of prescribed fires and managing rather than aggressively suppressing wildland fires can promote adaptive resilience as the climate continues to warm. Many dry forests currently experience significantly less burning than in the period just before European settlement (8, 35, 58). In recognition of the fire-dependence of many ecosystems, the 1995 Federal Wildland Fire Management policy ushered in the first federal policy aimed at reintroducing more wildfire on public lands; that policy remains in effect today. US federal agencies actively managed an average of 75,000 ha of lightning-caused fires per year under the Wildland Fire Use policy from 1998–2008 and currently burn about 1 million hectares per year with prescribed fires (58). However, prescribed fires still constitute only about 10% of the treatments implemented by the US Forest Service in the West and burn about one-third of the area burned by wildfires (National Interagency Fire Center, https://www.nifc.gov/). In the United States and Canada, suppression remains the primary approach to wildfire, with more than 95% of all wildfires suppressed (28). Continued aggressive fire suppression is counterproductive to building adaptive resilience to increasing wildfire in the long term (13, 14).

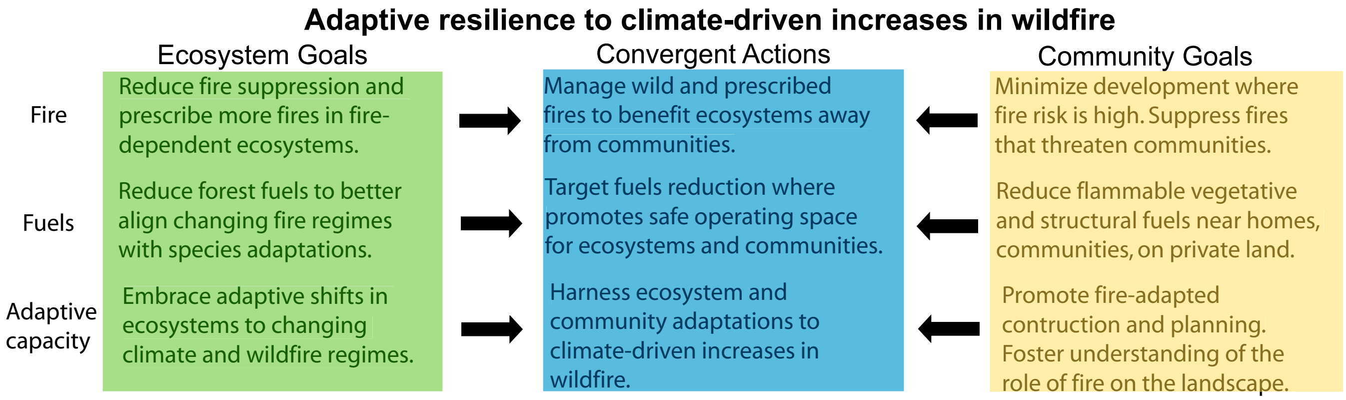
***Using Fire to Foster Adaptive Resilience to Climate Change.*** In some systems, fire today attenuates future fire effects, because flames that burn dead and live fuel limit where and how severely subsequent fires burn, at least for a time (59–61). Fires often create complex patterns of burn severity that create variation in postfire regeneration and fuels (62–67). As fire regimes shift over time, individual fire events filter for species adapted to changing fire and climate conditions (68). Strategic planning for more managed and uncontrolled wild fires on the landscape today (69) may help decrease the proportion of large and severe wildfires in the coming decades and may enhance adaptive resilience to changing climate. Prescribed fires, ignited under cooler and moister conditions than are typical of most wildfires, can reduce fuels and minimize the risk of uncontrolled forest wildfire near communities. In contrast to wildfires, prescribed fire risks are relatively low, and more than 99% of prescribed fires are held within planned perimeters successfully (58).

Challenges to increasing use of managed and prescribed fires vary from the public's limited experience with smoke and wildfire to significant direct health impacts of smoke on vulnerable populations, including children, the elderly, and low-income communities (40, 70, 71). Some smoke hazards can be reduced through careful planning and management of fire, public health monitoring, and provisioning of health services for vulnerable populations. Public perceptions of fire are also an important hurdle, given the success of Smokey Bear's fire-prevention campaign and because most urban and suburban residents have very limited experience with wildfire compared with rural residents of the early 20th century. Therefore, public education programs that demonstrate the inevitability of wildfire will be a key aspect of living with increasing fire in the West. We need to develop a new fire culture. Despite these and various legal and operational challenges (58), the benefits of prescribed fire and managed wildfires to ecosystems and communities are high (72). Promoting more wildfire away from people and prescribed fires near people and the WUI are important steps toward augmenting the adaptive resilience of ecosystems and society to increasing wildfire.

## Managing Fuels

***Limiting Reliance on Fuels Treatments to Alter Regional Fire Trends.*** Managing forest fuels is often invoked in policy discussions as a means of minimizing the growing threat of wildfire to ecosystems and WUI communities across the West. However, the effectiveness of this approach at broad scales is limited. Mechanical fuels treatments on US federal lands over the last 15 y (2001–2015) totaled almost 7 million ha (Forests and Rangelands, https://www.forestsandrangelands.gov/), but the annual area burned has continued to set records. Regionally, the area treated has little relationship to trends in the area burned, which is influenced primarily by patterns of drought and warming (2, 3, 20). Forested areas considerably exceed the area treated, so it is relatively rare that treatments encounter wildfire (73). For example, in agreement with other analyses (74), 10% of the total number of US Forest Service forest fuels treatments completed 2004–2013 in the western United States subsequently burned in the 2005–2014 period (Fig. 6). Therefore, roughly 1% of US Forest Service forest treatments experience wildfire each year, on average. The effectiveness of forest treatments lasts about 10–20 y (75), suggesting that most treatments have little influence on wildfire. Implementing fuels treatments is challenging and costly (7, 13, 76, 77); funding for US Forest Service hazardous fuels treatments totaled $3.2 billion over the 2006–2015 period (6). Furthermore, forests account for only 40% of the area burned since 1984, with the majority of burning in grasslands and shrublands. As a consequence of these factors, the prospects for forest fuels treatments to promote adaptive resilience to wildfire at broad scales, by regionally reducing trends in area burned or burn severity, are fairly limited.

***Targeting Fuels Treatments in Ecosystems with Fuel Build-Up and on Private Lands.*** Strategically targeting treatments in areas where fuels build-up has increased the expected burn severity may augment the adaptive resilience of those ecosystems to increasing wildfire. For example, treating drier forests, where the likelihood of fire is



Adaptive resilience to climate-driven increases in wildfire

| | Ecosystem Goals | | Convergent Actions | | Community Goals |
|---|---|---|---|---|---|
| Fire | Reduce fire suppression and prescribe more fires in fire-dependent ecosystems. | → | Manage wild and prescribed fires to benefit ecosystems away from communities. | ← | Minimize development where fire risk is high. Suppress fires that threaten communities. |
| Fuels | Reduce forest fuels to better align changing fire regimes with species adaptations. | → | Target fuels reduction where promotes safe operating space for ecosystems and communities. | ← | Reduce flammable vegetative and structural fuels near homes, communities, on private land. |
| Adaptive capacity | Embrace adaptive shifts in ecosystems to changing climate and wildfire regimes. | → | Harness ecosystem and community adaptations to climate-driven increases in wildfire. | ← | Promote fire-adapted contruction and planning. Foster understanding of the role of fire on the landscape. |

**Fig. 5.** **Convergent actions that promote adaptive resilience to climate-driven increases in wildfire in the West by ecosystems and communities, based on goals related to management of fire, fuels, and adaptive capacity.**

high, may also increase opportunities to modify wildfire behavior and postfire recovery. Burn severity has increased because of past fire suppression and fuels build-up in low-elevation dry forests adapted to predominantly frequent, low-severity surface fires (8, 11, 22, 25, 78, 79). In these forests, fuels treatments that remove midstory and understory fuels through thinning and prescribed fire can reduce fire intensity, severity, and rate of spread and may promote adaptive resilience to more frequent fire. Such forests were preferentially treated under the National Fire Plan in 2004–2008 (80). Thinning may effectively restore more frequent, low-severity fire in some dry forests, but when thinning is combined with the expected warming, unintended consequences may ensue, whereby regeneration is compromised and forested areas convert to nonforest (56, 57, 81). Strategic placement of treatments to promote low-severity fire at ecotones between dry and mesic forest distributions may help facilitate postfire migration of species better adapted to warmer, drier conditions.

Midelevation mixed conifer forests, or mesic forests, which typically experienced broad variance in fire frequency and severity, may also benefit from fuels treatments that reduce the likelihood of large patches of high-severity fire and facilitate the migration of species adapted to drier, warmer conditions (77). In contrast, cold/wet forests, such as high-elevation subalpine forests, are adapted to high-severity fire that historically recurred at relatively long (∼100–300 y) intervals (19, 82, 83) and have not experienced unprecedented fuels build-up in recent decades. Severe wildfires have occurred for millennia across a broad range of forests and shrublands, and in many ecosystems species are adapted to severe fire (17, 19, 84, 85), although postfire regeneration may be comprised by drier, warmer conditions (86).

Fuel-reduction treatments also hold promise for locally reducing wildfire hazard around WUI communities if treatments are strategically located to protect homes and the surrounding vegetation. Fuel reduction on federal lands and in municipal watersheds is a primary management tool that has limited application in the WUI, where the majority of land is privately owned (87). Home loss to wildfire is a local event, dependent on structural fuels (e.g., building material) and nearby vegetative fuels (88, 89). Therefore, fuels management for home and community protection will be most effective closest to homes, which usually are on private land in the WUI where ignition probabilities are likely to be high (37). Programs that facilitate the targeted removal of fuels from private land, such as community chipping programs, have been highly successful in some areas, at relatively low cost. The Wyden and Good Neighbor authorities and federal programs, such as the US Forest Service Collaborative Forest Landscape Restoration Program, take an "all-lands" approach to forest management through collaboration with landowners and communities. These policies and programs are roadmaps for augmenting fuel-management efforts across land ownerships. These and other more ambitious policies that facilitate significant fuels management on private land, on a par with fuel-reduction efforts on federal lands, are needed. New policies that facilitate private-land fuels management are critical to augment significantly the adaptive resilience of communities to increasing wildfire.

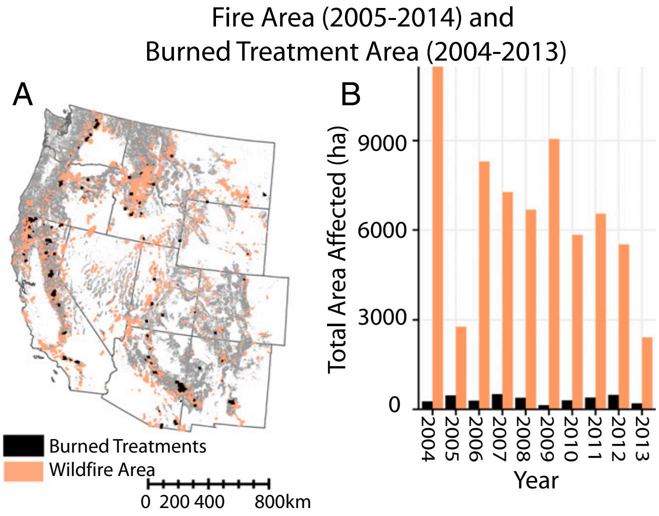


**Fig. 6.** (*A*) Spatial distribution and area of US Forest Service fuels treatments from 2004–2013 and wildfire from 2005–2014 across forests and woodlands in the western United States. About 3% of the total treated area and 10% of the total number of treatments burned in the period 2005–2014. (*B*) Annual total wildfire area and total burned treatment area. Data are from the following: (1) US Forest Service fuels treatments: Hazardous Fuel Treatment Reduction Polygon (https://data.fs.usda.gov/geodata/edw/datasets.php), (2) Wildfires >1000 ac: Monitoring Trends in Burn Severity Burned Areas Boundaries (www.mtbs.gov/dataaccess.html), (3) Wildfires ≤1000 ac: GeoMAC Historic Fire Perimeters (https://rmgsc.cr.usgs.gov/outgoing/GeoMAC/historic_fire_data/).

## Promoting Adaptive Capacity

***Fostering and Embracing Adaptive Shifts in Ecosystems.*** Management of fire and fuels will help some ecosystems withstand more frequent fires and possibly may reduce the risk of larger, more severe fires that may compromise forest recovery. Such efforts will be significant in high-value ecosystems or locations, in helping slow the pace of change and providing a chance for ecosystems and species to adapt to changing fire regimes. The HRV concept can guide management in identifying ecological vulnerabilities and adaptation strategies to changing disturbance regimes (Fig. 3) (50, 51, 52). However, quantifying ecological objectives outside the HRV will be increasingly important in guiding management as fire regimes and climate continue to change (90, 91). Given such uncertainties, management must be adaptive and iterative, and monitoring will be critical to assessing progress. Given the vast area of fire-prone forests in the West, management can directly affect only a small portion of forests. In the majority of forested ecosystems beyond our effective reach, we will have to accept and even embrace changing ecological conditions. While some forests may be entering decades of significant change with high tree mortality in response to drought, wildfire, insect outbreaks, and legacies of past management (86, 92), they also are in the process of adjusting to new conditions to which they will be better adapted and that may challenge our existing philosophies of and approaches to conservation.

***Creating Fire-Adapted Communities.*** The majority of home building on fire-prone lands occurs in large part because incentives are misaligned, where risks are taken by homeowners and communities but others bear much of the cost if things go wrong. Therefore, getting incentives right is essential, with negative financial consequences for land-management decisions that increase risk and positive financial rewards for decisions that reduce risk. For example, shifting more of the wildfire protection cost and responsibility from federal to state, local, and private jurisdictions would better align wildfire risk with responsibility and provide meaningful incentives to reduce fire hazards and vulnerability before wildfires occur. Currently, much of the responsibility and financial burden for community protection from wildfire falls on public land-management agencies. This arrangement developed at a time when few residential communities were embedded in fire-prone areas. Land-management agencies cannot continue to protect vulnerable residential communities in a densifying and expanding WUI that faces more wildfire (12). The US Government Accountability Office questioned the US Forest Service's prioritizing protection of WUI communities that lie under private and state jurisdictions and has argued for increased financial responsibility for WUI wildfire risk by state and local governments (93). This shift in obligation would enhance adaptive governance and could increase the motivation to pursue adaptive resilience of WUI communities to increasing wildfire (94).

Another promising approach for increasing adaptive resilience of WUI residents to wildfire is the promotion of fire-adapted planning in communities. Providing incentives for counties, communities, and homeowners to plan fire-safe residential development for both existing and new homes and discouraging new development on fire-prone lands will make communities safer (89, 94–96). Communities can use land-use and development codes that encourage developers to set aside open space and recreational trails as fuel breaks and require ignition-resistant construction materials in fire-prone settings. For example, San Diego, California enforces strict brush management regulations; the Flagstaff, Arizona fire department uses a WUI development code to protect properties; and Santa Fe, New Mexico applies stringent fire-safe regulations on new developments to protect its watershed (97). Programs such as the Community Planning Assistance for Wildfire (CPAW; planningforwildfire.org), funded by the US Forest Service and private foundations, offer assistance to communities in the form of advice on land-use planning and detailed mapping of wildfire risk. Another example is California, which employs a statewide Fire Hazard Severity Zone map to guide development plans and building codes that reduce wildfire risk. With 84% of potential WUI lands in the West still undeveloped (98), land-use planning now has high potential to reduce the vulnerability of communities to future wildfire. Furthermore, fire-adapted planning may increase management options in terms of how, where, and when fire can be used as a tool for reducing the spread of wildfires into communities and rejuvenating fire-dependent ecosystems, thus increasing the adaptive resilience of communities and ecosystems to more wildfire.

Strengthening and expanding programs such as Fire Adapted Communities, Fire Adapted Communities Learning Network, Firewise Communities USA, and FireSmart Canada will also help communities become more fire-adapted. Capacities to assume these responsibilities will vary significantly among homeowners, communities, and local jurisdictions with markedly different risks and resources (99–101). For example, home hazard mitigation programs and community planning tools are more successful in communities at the fringe of urban areas that have more financial resources and often have a greater trust in government than in more isolated, resource-dependent WUI communities, immigrant non–English-speaking communities, or tribal and First Nations communities (101). Although some tax incentives and rebates are available for wildfire risk mitigation on and around homes, more comprehensive programs that include broader incentives and support are needed for meaningful and widespread impacts. Efforts that combine wildfire-specific efforts with other community capacity-building efforts may leverage the networks that enable communities to act on shared notions of risk (102).

Overall, a shift in resources from the defense of the WUI from wildfire to the mitigation of wildfire hazards and risks in advance of events will build a safe operating space for fire-prone communities that increases adaptive resilience to wildfire. Encouraging development away from fire-prone areas, reducing fuels on private lands in and near communities, and retrofitting and building homes to withstand ignition will increase the adaptive capacity for managing more wildfire (89), similar to adaptive approaches for other natural hazards such as flooding and earthquakes (12). Communities and institutions are long-lived, and disruptive events such as wildfires create windows of opportunity that can shift rules, norms, and expectations to increase adaptive resilience to future wildfires.

## Conclusions

Policies that foster adaptive resilience enable WUI communities and fire-prone ecosystems to adjust to increased wildfire risk and reduce future vulnerability. Adaptive resilience provides a realistic framework as the climate warms and wildfires increase, but how will we know if we are achieving adaptive resilience to future fires? On the societal front, minimizing the costs of suppression in the WUI, the number of homes lost to wildfire, the area burned in the WUI, and the number of smoke-related health problems are some metrics. Developing state- or county-wide maps of fire hazard, home survivability rating, and the adaptive capacity of communities would be useful tools in developing this framework.

Some ecosystems will survive and thrive as they adapt to novel future conditions, but not all will. Embracing rather than resisting ecological change will require a significant paradigm shift by individuals, communities, and institutions and will challenge our conservation philosophies. Wildfire is an important catalyst of responses to climate change by communities and ecosystems. Patterns of wildfire are changing with rising global temperatures, and will accelerate in the future. What we can do now is focus management efforts on the places where intervention is needed to slow the pace of change and thereby give particular species and ecosystems a chance to adapt. We also can change how we build, live, and work in fire-prone landscapes to keep our communities safe, healthy, and vibrant.

## Acknowledgments

This work emerged from a wildfire science communication workshop organized by COMPASS and the Wilburforce Foundation in 2014. We thank all fire and social scientists who participated and two anonymous reviewers who helped improve the paper.

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