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Rethinking resilience to wildfire

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Record-breaking fire seasons are becoming increasingly common worldwide, and large wildfires are having extraordinary impacts on people and property, despite years of investments to support social–ecological resilience to wildfires. This has prompted new calls for land management and policy reforms as current land and fire management approaches have been unable to effectively respond to the rapid changes in climate and development patterns that strongly control fire behaviour and continue to exacerbate the risks and hazards to human communities. Promoting social–ecological resilience in rapidly changing, fire-susceptible landscapes requires adoption of multiple perspectives of resilience, extending beyond 'basic resilience' (or bouncing back to a similar state) to include 'adaptive resilience' and 'transformative resilience', which require substantial and explicit changes to social–ecological systems. Clarifying these different perspectives and identifying where they will be most effective helps prioritize efforts to better coexist with wildfire in an increasingly flammable world.

Globally, record-breaking fire seasons and loss of human life and property are becoming increasingly common, highlighting a critical need to develop new management approaches that enhance social–ecological resilience to wildfires. For example, the 2017 fire season was one of the most extensive and expensive in the United States and Canada. Over 4 million ha (10 million acres) burned in the western US, and US federal fire-suppression expenditures surpassed a record US$2.9 billion[1]. In British Columbia, 1.2 million ha (3 million acres) burned at a cost of US$493 million for fire suppression. The 2018 fire season was similarly devastating, with the largest (Ranch Fire—185,800 ha) and deadliest (Camp Fire—85 lives lost) wildfires in California's history. All told, recent wildfires have taken many lives, affected densely populated regions with smoke, destroyed tens of thousands of homes, and forced evacuation of hundreds of thousands of residents. In the US, these outcomes have directly belied national efforts to increase social–ecological resilience to wildfire (for example, the National Cohesive Wildland Fire Management Strategy[2]).

Supporting social–ecological resilience to wildfires

Efforts to promote social–ecological resilience to wildfires are falling short, in part, because they are limited in scope and scale, insufficiently funded, hindered by agency constraints[3] and lack urgency and broad public support[4,5]. An additional unrecognized weakness is a near singular intent to maintain social–ecological systems in static or historical states that are no longer sustainable given observed and predicted changes to the climate system and a legacy of fuel accumulation resulting from twentieth-century land management[6,7]. This commitment to maintaining or restoring unsustainable systems prevents effective response to rapidly changing climate conditions, human development patterns and socioeconomic vulnerability. As change is an inherent property of ecosystems, management interventions that aim to maintain the status quo are increasingly likely to fail; a more sustainable approach is to manage systems to restore the dynamic function and general attributes of non-degraded ecosystems[8]. Furthermore, because climate warming produces longer, drier fire seasons with more extensive burning[9], and trends in residential development are increasing human exposure to wildfires[10,11], restoring ecosystems and communities to pre-fire conditions is clearly unsustainable given current and predicted climate and land-use change.

A timely appeal has been laid out[6] for a new paradigm in which communities in western North America adapt and transform in light of inevitable increases in wildfire activity[13]. Here, we explore the application of adaptive resilience and transformative resilience[14–16] as options beyond basic resilience, and propose a framework for communities, natural-resource managers and policymakers to identify a range of actions that can better promote social–ecological resilience to wildfire. This framework is shaped by the history and legacy of wildfire and vegetation management in western North America, yet has implications for fire-susceptible communities worldwide. Our framework recognizes a diversity of resilience goals among communities and biophysical settings, based on human exposure to fire, novelty of the fire environment, and the social and ecological impacts of fire activity.

Resilience thinking in social–ecological systems

Resilience thinking has grown broadly from the well-established concept of ecological resilience[17], which focuses on the capacity of a system to maintain the same general structure, composition, and

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feedback processes following disturbances and other 'shocks' (hereafter referred to as basic resilience). In social systems, basic resilience is also used to describe the ability of people and communities to recover or 'bounce back' from disasters[18]. A second type of resilience, adaptive resilience, is now commonly used to describe how human communities or social systems adapt to new or dynamic conditions by changing fundamental characteristics of the system, for example through zoning or land-use planning[19,20]. Finally, transformative resilience is used to describe the creation of fundamentally new systems. A transformative-resilience approach requires a profound shift in the human relationship with wildfire—one that embraces the dynamic and rapidly changing role of fire in social–ecological systems. Adopting a transformative-resilience approach is sometimes referred to as bouncing forward, and it is typically required when conditions are changing rapidly (for example, due to climate change) such that returning to pre-disturbance conditions is untenable; this approach allows for an intentional transition to a new system that will be desirable under future conditions[8,21].

In recent decades, the repeated occurrence of some natural disasters (for example, floods and hurricanes) has motivated communities, managers and policymakers to adopt goals focused more on adaptive or transformative resilience rather than on basic resilience; facilitating recovery by intentionally averting the return of a community or ecosystem to a maladaptive pre-disaster state. This decision acknowledges that supporting basic resilience in some contexts may exacerbate persistent vulnerabilities, especially when and where changing conditions increase the probability of repeated disasters in the future. For example, the Dutch shifted from resisting repeated flooding of land below sea level, and instead acknowledged their vulnerability by adopting large-scale adaptive planning strategies and redesigning infrastructure to accommodate rising seas[22]. There are three key analogies we can draw from this in the context of living with wildfire: first, acknowledge that fire is a natural phenomenon that poses inherent hazards to an increasing number of communities wherever there is vegetation that can burn; second, shift our primary response from reactive fire-fighting and rebuilding replica communities to proactive planning, management and infrastructure strategies that embrace goals of adaptive and transformative resilience; and finally, respond to wildfire activity at the appropriate scale, which, in many regions of the western US and Canada necessitates coordinating adaptive-resilience strategies across multiple communities and land ownerships[23].

Adopting, and even championing, a broader approach to resilience thinking allows managers, stakeholders and policymakers to consider adaptation and transformation as appropriate and desirable responses to wildfire, especially when the current system is degraded or misaligned with historical conditions that are unlikely to return[6]. Adaptive and transformative responses modify and change conditions of ecosystems (for example, fuel conditions and vegetation) and social systems (for example, institutions) to support desired system attributes under anticipated future conditions, rather than a return to a previous state.

Promoting resilience in fire-prone landscapes

Understanding the social and biophysical context of a landscape is critical for identifying specific resilience strategies that can most effectively support sustainable coexistence with wildfire[24] (Fig. 1). We argue that appropriate adaptive and transformative-resilience actions will depend upon the specific social–ecological context along three gradients: (1) human exposure and vulnerability to wildfire; (2) wildfire severity and human impacts; and (3) degree of change in fire activity and fire impacts from historical patterns (hereafter referred to as fire novelty).

Human exposure and vulnerability to wildfire varies considerably across gradients in valued resources and ecosystem services (Fig. 1, 'Human exposure' axis). For example, homes densely situated within or near a matrix of flammable vegetation increase the direct exposure of humans to fire and changing fire regimes. However, the impacts of wildfires on humans extend beyond the footprint of homes, as valued ecological and cultural resources in remote areas (for example, municipal water supplies and threatened species) can also be vulnerable to fire effects (for example, soil erosion and habitat change). The likelihood and frequency of fire (today and into the future) among different ecosystems also determines human exposure to wildfire; for example, low-elevation dry forest, chaparral and montane mixed-conifer ecosystems are generally susceptible to fire and fire effects more commonly than are high-elevation cold, moist subalpine and sub-boreal and boreal forest ecosystems[12]. Additionally, many human communities, or populations within communities, are particularly vulnerable to wildfire due to low socioeconomic status or limited access to the resources necessary for responding to wildfire and its secondary impacts (for example, smoke)[25]. These vulnerabilities amplify the need for the development of resources and social institutions that broadly promote economic wellbeing, mental and physical health, community connectedness and individual and community hazard preparation and response plans[22].

Fire severity refers to the immediate ecological impacts of fire (for example, amount of biomass consumed, vegetation mortality and soil erosion). Here we extend this term to apply to the immediate impacts of fire on humans and their communities. Fire severity also varies across biophysical gradients in vegetation, fuels and weather and climate (Fig. 1, 'Fire severity' axis).

Fire novelty is the degree that specific landscapes experience fire activity (for example, frequency and behaviour), impacts (that is, severity), or responses (for example, post-fire vegetation regeneration) that are unlikely, or rare, in the context of historical experience[26]. Novelty also varies with local vegetation, fuels, management activities and weather and climate before, during and after fires (Fig. 1, 'Fire novelty' axis).

Defining where a landscape falls along these three gradients is critical for understanding social–ecological resilience in different contexts and determining how resilience can be best supported through policy, management and community organization and planning. Below, we discuss how these different management strategies might be applied in different settings.

Support basic resilience. Allow and support ecosystem recovery from wildfires; help individuals and communities manage the impacts of fires and recover from fire events.

Promoting basic resilience is appropriate where the impact of changing climate and wildfire activity poses few hazards to important social and ecological assets; that is, where fire novelty is (or can be) low, and exposure of valued human and cultural resources is generally low. Basic resilience may be promoted through active or passive management (for example, natural vegetation succession) in systems where fire regimes have not been highly altered or degraded. Where the need to protect human property and infrastructure from wildfires is low and cultural resources and ecosystem services have low exposure, a primarily passive management response to disturbance may be the most efficient and desirable means to promote basic resilience (Box 1; Fig. 1a,b)[6,27]. Emphasizing basic resilience in these types of systems confers several benefits. For instance, allowing ecosystems to burn and recover from fires maintains critical natural processes and functions, including reducing the abundance of woody fuels, mediating the probability of future fire ignition and spread, facilitating nutrient cycling and promoting structural diversity. Fostering basic resilience to wildfires in social systems involves helping communities prepare for, cope with, and manage the impacts of wildfires, including bolstering fire planning and response, supporting those needing to rebuild after fires and managing the secondary impacts of wildfires (for example,

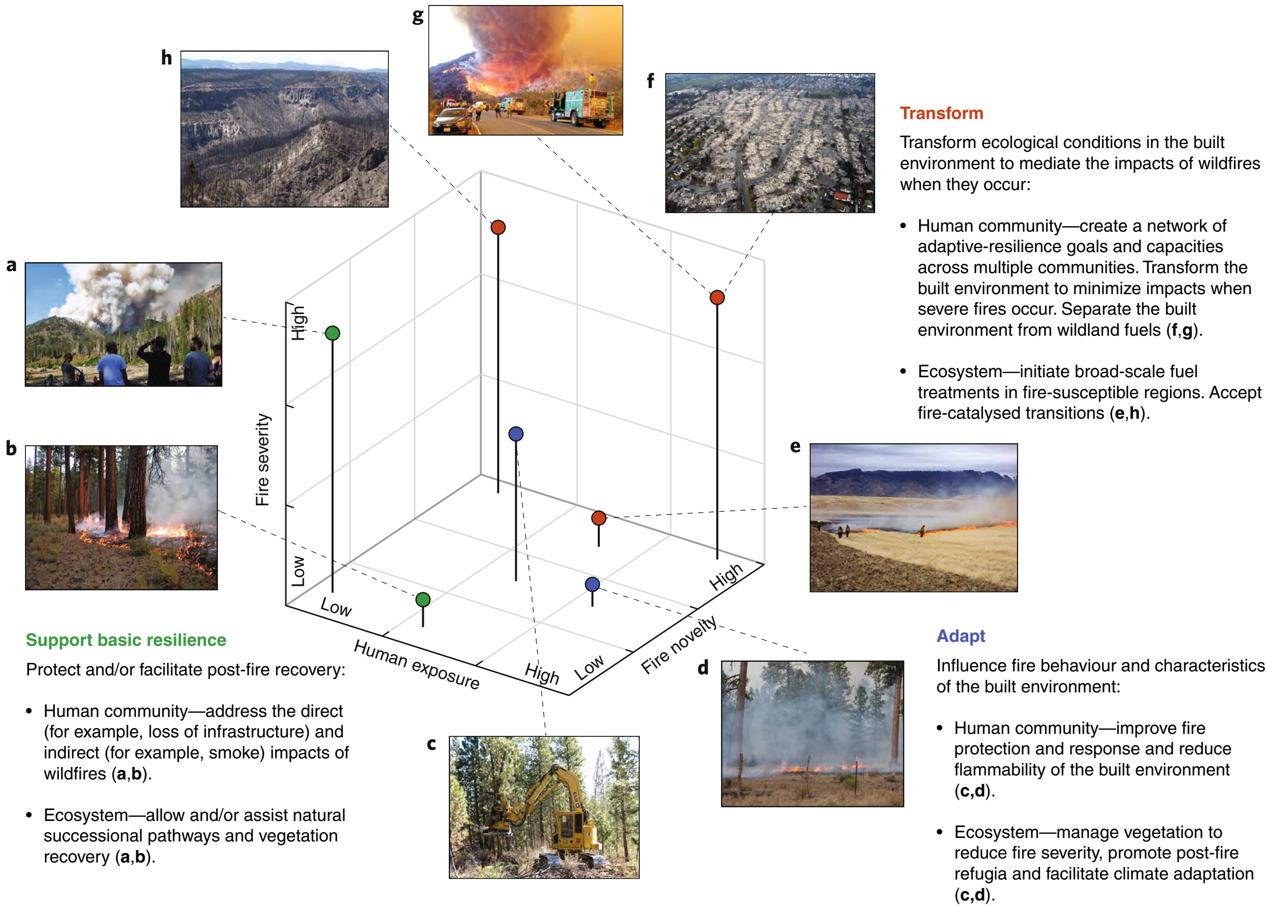

Fig. 1 | Specifying basic, adaptive and transformative-resilience goals based on social–ecological context. **a**,**b**, Actions that support basic resilience include allowing fire and vegetation succession to occur in settings where the exposure of valued resources is low. Examples include: high-severity fire, in the Bob Marshall Wilderness, Montana (**a**); and low-severity fire, in Ponderosa pine (*Pinus ponderosa*) forest in the Metolius Research Natural Area, Oregon (**b**). **c**,**d**, Actions that support adaptive resilience include implementing intensive vegetation management to reduce fire risk where human exposure to wildfire is high and changing climate and fuel conditions are moderate. Examples include: thinning forest fuels to reduce ladder fuels (**c**); and coupling of timber harvest, fuel reduction and prescribed fire treatments to reduce fire risk in Ponderosa pine forest (**d**, prescribed fire on Kaibab National Forest, Arizona). **e**–**h**, Actions that support transformative-resilience goals include implementing a network of adaptive-resilience goals across multiple communities, redesigning the location, character and flammability of the built environment in landscapes with high exposure of valued resources to repeated severe wildfires, and accepting and managing fire-catalysed transitions where climatic and land-use conditions result in novel fire activity. Examples include: managing for a new fire regime where cheatgrass has become the dominant land cover, Izzenhood, Nevada (**e**); reimagining patterns and characteristics of residential development and community fuel management following extreme fire behaviour of the Tubbs Fire, Santa Rosa, California (**f**), and the Thomas Fire, California (**g**); accommodating novel regeneration pathways following high-severity Las Conchas Fire, New Mexico (**h**). Credit: Lily Jane Clarke (**a**); Forest Service, USDA (**b**,**d**); Oregon Department of Forestry under a Creative Commons license CC BY 2.0 (**c**); Bureau of Land Management (**e**); US DOD, (**f**; the appearance of US Department of Defense visual information does not imply or constitute DOD endorsement); Ray Ford, Noozhawk.com (**g**); Craig D. Allen / USGS (**h**).

smoke exposure, closure of public lands and economic impacts on tourism). Importantly, as vegetated landscapes become more vulnerable to severe wildfire under a warming climate, we expect that examples of landscapes where managing for basic resilience is possible or desirable will decrease[28].

Support adaptive resilience. Focus intensive fuel management and community planning to influence fire behaviour and improve fire preparedness and response.

In landscapes of moderate-to-high human exposure and vulnerability, and low-to-moderate fire novelty and severity, management should strive to promote adaptive resilience to wildfire[6,29]. Adaptive resilience to wildfire centres on managing both the human-built and non-human environment in response to changing climate and fire regimes, and increasing wildfire risks and exposure of human communities. Among forest ecosystems, dry low-elevation forests are the most likely to burn in any given year, and historically were characterized by frequent low- and moderate-severity fires (that is, mean return intervals of years to a few decades with low fire-caused adult tree mortality). In these forests, decades of effective fire suppression have resulted in a significant increase in the abundance and continuity of woody fuels which, with more fire-conducive weather and climate, can contribute to high-severity fires that threaten people and structures, induce extensive tree mortality and promote little, delayed, or no post-fire tree establishment[1,30,31] (Fig. 1c,d). While there is active debate over which forest types have experienced the most pronounced changes to fuel and fire conditions, restoring forest structure (that is, tree density, diameter and spacing) and fuel loading to pre-suppression ranges is clearly warranted in some forests, which confers benefits to forest ecosystems and to protecting valued resources from fire impacts. We suggest that managers prioritize efforts in low-elevation dry forests that have experienced

Box 1 | Basic resilience: Greater Yellowstone area

- Historical fire regime: ~100–300-year average fire-return intervals between typically large, high-severity (stand-replacing) fires.
- Novelty of fire activity and impacts to communities: low, but increasing.
- Human exposure: low.
- Climate: continental subarctic.
- Vegetation type: subalpine forest dominated by lodgepole pine (*Pinus contorta* var. *latifolia*), Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*).
- Level of degradation or departure of vegetation and fuel conditions from historical: low departure, but evidence increasingly suggests increased fire frequency.
- Social context: small- to medium-sized towns near protected areas and working forests that support both tourism and forest-products industries.

Given the mandate of the National Park Service to support natural processes like wildfire while also making parks accessible to the public, the social–ecological context in and around Yellowstone National Park is an example of where managing for basic resilience is well supported. The high-elevation subalpine forests of the Greater Yellowstone area are typified by high-severity fire regimes, which, at watershed scales, exhibit natural regeneration of seedlings resembling pre-fire forest structural characteristics. For example, three decades following the 1988 fires in Yellowstone National Park, densities of regenerating lodgepole pine stands were within the historical range of variability, especially at higher elevations and wetter sites[28,49]. This return to pre-fire conditions in and around Yellowstone, generally unaided by management, implies that basic ecological resilience to wildfires is maintained in some settings. Basic social resilience to wildfires in communities adjacent to higher-elevation forests (for example, West Yellowstone and Gardiner) is supported through well-developed fire planning and connecting community members with services that address the secondary effects of wildfires (for example, short-term evacuations, personal air-quality measures and health services); however, when fire behaviour becomes extreme, institutions and services that support basic resilience often become stressed.

While the social–ecological system proved resilient following the 1988 Yellowstone fires, recent research shows that even places like Yellowstone have their limits to using basic resilience as a guidepost, as warmer and drier conditions may begin to inhibit post-fire tree regeneration[28,50,51]. Even if the self-sustaining capacity for the current ecosystem is not viable in the future, actively managing for the properties of basic resilience may be appropriate in order to protect critical ecosystem services or properties deemed valuable by society (for example, soil, water quality and threatened species such as whitebark pine—*Pinus albicaulis*). For example, building seedbanks, planting seedlings and promoting rapid revegetation following severe fires with the express goal of stabilizing post-fire soils may be necessary. In an increasing number of landscapes, however, these actions may, at best, offer only temporary stability to systems undergoing inevitable transformations in response to rapid change.

multiple (for example, more than two) high-severity fires over the past several decades and in chaparral shrublands.

Despite the prominent differences in fire ecology, low-elevation forests and chaparral shrublands are two ecosystems where human development occurs at some of the highest densities, and where strategic fuel treatments, community planning and other management actions are most likely to facilitate adaptive resilience to wildfire. In chaparral ecosystems, strategic and coordinated fuel management focused around homes and communities, and control of flammable and invasive species, could minimize the likelihood of fires burning homes under extreme fire weather (for example, fires fuelled by Santa Ana wind events). In dry forest ecosystems, strategic implementation of landscape fuel treatments through thinning and prescribed fire and targeted fire suppression could minimize the likelihood of severe fire, thereby promoting adaptive resilience when fire events occur. Removing small, shade-tolerant trees in lower-elevation forests and treating fuels heterogeneously across topographic gradients may also promote fire refugia, thereby enhancing post-fire recovery and protecting key ecological and cultural resources (for example, rare and diverse ecosystems)[32–34]. With careful thought into the placement, frequency and nature of fuel treatments, high carbon emissions associated with severe fires can be avoided[35], while also conferring resistance to drought, insect infestations and disease[36].

From an ecological perspective, promoting adaptive resilience will necessarily require a portfolio of management activities tailored to specific biophysical conditions, cultural and ecological resources, and societal goals for a given landscape or watershed[15]. In forests with lower probabilities of fire (for example, cool and moist forests and often high-elevation forests), efforts could be focused on treating locally drier sites based on aspect and landscape position, thinning less drought-tolerant trees, and replanting and reseeding with species better adapted to projected future climate conditions. An adaptive management approach can be used to compare ecosystem responses in treated and untreated landscapes to determine whether treatments confer climate-adaptation benefits such as resistance to drought or insect outbreaks[36], and to determine how best to meet management goals as conditions continue to change.

From a social perspective, supporting adaptive resilience of communities to increased fire activity in areas with high human exposure would include a suite of activities: applying fuel treatments to reduce ember production and reduce flame lengths around roads to facilitate evacuations; regulating and incentivizing building approaches and landowner practices that reduce structure flammability or exposure to fire and smoke; designing communities with arterial pathways to improve ingress and egress; moving power lines underground to avoid widespread ignition events; establishing decentralized locally distributed power resources[37] (for example, household solar and battery cells); and establishing communication networks to facilitate evacuations and emergency responses when fires occur. Surprisingly, few of these approaches have been adopted consistently across fire-susceptible communities. Despite repeated calls for fuel management in and around developments that are most vulnerable to severe fires, only a small fraction of these areas has received federal fuel treatments[27], and only a few of the treated areas have been exposed to subsequent wildfires[6,38].

The efficacy of these types of responses depends on collaboration at multiple levels: individual property owners, builders and developers, local and regional decision makers, and broader government and agency decision makers[39]. Such approaches require political and collective action to do more than just quickly respond to the last crisis, including proactive and sustained investment and outreach to manage for long-term risks. Few communities in the US have had the political and fiscal will to implement these approaches, and even fewer have been subsequently tested by fire; an exception, however, is the community of Montecito, California (Box 2).

Prescribed fire is an important but underutilized tool for promoting adaptive resilience to wildfire in many ecosystems. In social–ecological contexts that support prescribed fire, this tool can be used to reduce future fire risk to human communities[40]. Intentional, regular burning was a staple of indigenous land-use practices across North America[41], and it has been maintained in the southeastern

Box 2 | Adaptive resilience: south-central coast of California

- Historical fire regime: ~20–30-year average fire-return intervals between typically stand-replacing, moderate- to high-severity fires[52]; vegetation notably includes many woody species that re-sprout.
- Novelty of fire activity and impacts to communities: moderate.
- Human exposure: high, due to extensive development in and near wildland fuels.
- Climate: Mediterranean.
- Vegetation type: fire-maintained coastal chaparral shrubland and oak and pine woodlands—mix of native and non-native species.
- Level of degradation or departure of vegetation and fuel conditions from historical: increase in grassy fuels from invasive annuals, moderate levels of increased woody fuel accumulation in treed areas.
- Social context: densely developed communities (Montecito, Santa Barbara and surrounding communities) within fire-susceptible ecosystems.

Following a series of destructive and fatal wildfires that began in the 1960s in Santa Barbara County, California, the Montecito Fire Protection District (MFPD) implemented a long-term community partnership effort to reduce wildfire risk and protect residents from the worst impacts of severe fires[53]. The MFPD acknowledged that wildfire was inevitable in the community and that due to increased development, property owners had taken on more risk. The MFPD adopted a primary goal of developing community relationships to reduce resident wildfire exposure, emphasizing partnerships as key to developing adaptive strategies. They implemented strategies that centred on reducing fire intensity through vegetation removal, improving fire-response effectiveness through infrastructure planning (ingress and egress, and community protection zones), replacing flammable chaparral shrubs with grass to reduce the intensity, and reducing flammability of the home and built environment through the creation of defensible space and retrofitting home exteriors. The MFPD utilized community education, thinning projects, a neighbourhood chipping program, a dead-tree removal program and roadside vegetation reduction as part of the broader community partnership effort to develop an extensive fuel-treatment network. In conjunction with existing low-flammability irrigated lands and recently burned areas, this fuel-treatment network significantly reduced fire intensity, supported successful structure defence, and likely led to the protection of small, unburned fire refugia that may already be aiding post-fire recovery. Together, these practices exemplify adaptive resilience to wildfires. In 2017, the community of Montecito was tested by the Thomas Fire, and only seven homes burned, rather than the 400–500 homes it was projected to lose[54]. The MFPD effort illustrates adaptive resilience: the community prepared itself using partnerships and integrating resident-specific and community-wide actions to achieve resilience to inevitable wildfire.

US, where fire is widely applied to reduce rapidly accumulating fuels and wildfire risk, maintain ecosystem function, and support timber production[42]. While prescribed fire is known to help reduce the severity and impacts of wildfires, implementing prescribed fire across a broader footprint in the US hinges on developing cultural acceptance of the risk–benefit trade-off.

The examples described above support adaptive resilience by altering human-built and natural environments to reduce human exposure to, and interaction with, high-intensity, potentially catastrophic fires. Rather than aiming to return ecosystems to previous, pre-fire or historical conditions, these management actions are designed to help communities adapt to changing climate, fuel and land-use conditions by directly shaping the human and natural template in ways that acknowledge the present and future inevitability of fire.

Support transformative resilience. Implement a network of adaptive-resilience goals across multiple communities and land ownerships, accept fire-catalysed transitions in ecosystems, and change patterns and characteristics of social organization (for example, residential development, transportation, infrastructure and regulations) to reduce the overlap between extreme fire impacts and the human-built environment.

Whereas basic resilience allows fire-adapted ecosystems to recover naturally, and adaptive resilience helps reduce the potential for wildfire disasters, transformative resilience fundamentally alters the human relationship to wildfire—by embracing the dynamic and rapidly changing role of fire in social–ecological systems. Purposively choosing the goal of transformative resilience may be the most rational option to avoid a constant state of vulnerability and costly responses to wildfire. However, adopting this approach will require fundamental shifts in how we envision social–ecological systems. Transformative resilience can be achieved by: (1) scaling up and integrating adaptive-resilience approaches across multiple communities and land ownerships[23,29,43]; (2) redesigning the character and pattern of development to minimize community risk from wildland fuels[14]; and (3) accepting fire-catalysed transitions in social–ecological systems. Initiating transformative resilience of social–ecological systems to wildfire is the most proactive response in settings with high human exposure and vulnerability. The key factor motivating transformative resilience is that novel conditions make a return to previous states (that is, basic resilience) undesirable, unsustainable or even impossible. For example, the conversion of dry mixed-conifer forest to open woodland–savanna and shrubland ecosystems following recent high-severity fires in the southwestern US (for example, the 2011 Los Conchas Fire in New Mexico) provides opportunities to accept, and in some cases support, ecological-type conversions, especially in drier settings where a changing climate makes the return of forests unlikely.

Specific approaches for supporting transformative resilience will differ across communities and landscapes[29]. In some instances, the most efficient management response may be to accept any reshaping and reorganization of ecological communities from shifting fire regimes (for example, transitions to open woodland–savanna or shrubland ecosystems, or to new species assemblages that currently have no analogue, Fig. 1e,h). Where the risk to valued resources is low, managers might deliberately allow fire-catalysed ecological transitions driven by novel fire activity. Where the risk to valued resources is high, managers may actively modify fuels (for example, via prescribed fire or other fuel treatments) to promote transitions while minimizing negative consequences to communities and ecosystem services (Box 3).

Wherever humans and valued resources are exposed and highly vulnerable to fire, maintaining current patterns of development will likely be increasingly disastrous (Fig. 1f,g). Recent fires in California illustrate how communities positioned in flammable landscapes can be impacted when exposed to extreme fire weather. Rebuilding equally vulnerable structures after such catastrophic fires, in pursuit of basic resilience, is likely to increase social and economic costs, while undermining the persistence and sustainability of social–ecological systems. In some locations, adaptive resilience may not be enough to mitigate undesirable effects of fire on human infrastructure or natural ecosystems. Instead, promoting transformative resilience to novel fire activity could be more effective and sustainable,

Box 3 | Transformative resilience: low-elevation ecosystems of the southeastern US

- Historical fire regime: ~1–35-year average fire-return intervals between low-severity fires.
- Novelty of fire activity: moderate.
- Human exposure: high due to widely dispersed wildland–urban interface.
- Climate: humid subtropical.
- Vegetation type: fire-adapted coniferous forests, mixed broadleaf–coniferous forest, coastal prairies and mixed grasslands.
- Level of degradation or departure of vegetation and fuel conditions from historical: prior to the 1930s, a substantial departure due to extensive colonial land clearing followed by twentieth-century fire exclusion, resulting in substantially more dense fuels across ecosystems[55].
- Social context: low-to-high density human-built environments; predominantly rural communities with a broad range of socioeconomic conditions.

Adopting a transformative-resilience approach requires profound changes to the structure and feedbacks of the social–ecological system across broad regions and/or across broad social and political groups[56]. There are few examples of where transformative-resilience goals have been implemented across populated regions where social exposure and vulnerability to wildfire is high. The social–ecological context and management of low-elevation ecosystems of the southeastern US, however, provides one example of a transformative-resilience approach that could be adapted to landscapes in western North America. Prior to European colonization, extensive indigenous fire use supported frequent, low-severity fires. European settlers introduced high-severity fire to clear large tracts of forested lands for agriculture. By the late nineteenth century, a fire-exclusion policy was in place, facilitating substantial vegetation growth and build-up of fuels. This lasted until the 1940s, when scientists and land managers pushed for reintroducing fire broadly across southern landscapes to support mature pine forests and open vegetation for game habitat[42]. Over the last eight decades, returning to the pre-colonial fire regime of frequent, low-severity fires has transformed the landscape back to one that resembles historical conditions, characterized by mature forests, diverse ecosystems, abundant game habitat, with wildfires that rarely become human disasters. As the wildland–urban interface has expanded and the effects of climate change have increased, fire managers have responded by increasing prescribed fire use across the region, with the support of communities that generally accept intentional burning as an important management tool. Today, land managers complete over two million ha of prescribed burning across the southeastern US annually[57], maintaining a fire-dependent system, mitigating wildfire disasters while maintaining benefits for wildlife and ecosystem function.

and perhaps the only viable solution for moving communities out of a constant state of vulnerability, especially as climate continues to change. Transformation requires a shift in social values and perceptions of fire such that individuals and communities move towards a more sustainable coexistence with fire (for example, through increased acceptance and support of fuel treatments including prescribed fires and allowing more fires to burn) as the most effective strategy for achieving resilience to wildfire. In communities that are the most vulnerable to wildfires[44], transformation also requires addressing the underlying social and economic conditions contributing to or exacerbating their vulnerability.

Promoting transformative resilience requires acknowledging that we are intentionally altering social–ecological systems. This should be desirable when it is consistent with societal goals, but it is also extraordinarily difficult and contentious when inconsistent with social goals and preferences[45]. In particular, rebuilding in places exposed to catastrophic natural hazards is common and unlikely to change; rebuilding sustainably to mitigate future catastrophes will require tremendous social agreement and political effort[46]. Nevertheless, this does not mean we should shy away from transformation in instances where it may be necessary. The home-to-home ignitions that occurred during recent fires in California[47] demonstrate how creating defensible space by managing vegetation around individual homes may not be sufficient alone to protect communities when fire weather is extreme; instead, the use of housing materials to resist ignition from ember showers will become increasingly essential. For existing developments that are vulnerable to these types of fires, much larger 'community defensible zones' on the order of tens of hectares (for example, playfields and large parking lots), could be designated or created to offer refuge for neighbourhoods during extreme fire events. Where fire exposure is greatest, structures can be built underground or physical barriers could be installed to protect homes[14]. A significant challenge in reimagining the structure and character of communities is recognizing that many individuals living in fire-susceptible areas often lack the means (or do not want) to relocate or live elsewhere. These individuals currently also receive substantially less governmental support following disasters[48]. Consistent with historical transformation around other natural hazards, reducing our vulnerability to wildfire will inevitably require tackling a host of associated social, political and economic factors. Such is the nature of true transformation.

Living with wildfire in the future

Increasing fire activity resulting from climate and land-use change is causing negative impacts on human lives and infrastructure, and motivates new approaches to living with wildfire. Projections suggest that extreme-fire years will become ever more common in upcoming decades, providing a stark warning: where fuels are present, wildfire activity will continue to increase across vast fire-susceptible landscapes of North America and elsewhere. Responding to increasing fire activity and maintaining the viability of social–ecological systems requires new approaches that include significant allocation of resources to strategic fuel management and community development, and a shift in how we think about living in fire-susceptible landscapes. In many cases, fire itself may be the catalysing force that helps promote social–ecological resilience to wildfires. Ultimately, decades of fire science strongly indicate that fuel management, prescribed fires and allowing wildfires to burn under moderate fire weather conditions will protect and promote ecological and cultural resources, and communities, far more effectively and efficiently than trying to eliminate fire from landscapes.

Given the reality of more fire-conducive climate conditions, harsher post-fire growing environments, and an expanding human presence in fuel-rich systems, current management focused predominantly on basic resilience will become increasingly less tenable in many settings, requiring a shift to adaptation and transformation. Catastrophic wildfires should motivate us to rethink what social–ecological resilience to wildfire means, and accept that more diverse approaches to resilience thinking are needed to facilitate human coexistence with wildfire. We face inherent trade-offs between our desire to live in flammable landscapes, and the social and economic costs of living with increased fire risk in these landscapes. Our potential success in living with wildfire hinges on society's acceptance that climate has changed the fundamental underlying conditions controlling wildfire activity. Living with wildfire challenges us to embrace change and reimagine our relationship with fire and its role on Earth.

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Competing interests

The authors declare no competing interests.

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