Wildfire risk as a socioecological pathology

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Wildfire risk in temperate forests has become a nearly intractable problem that can be characterized as a socioecological "pathology": that is, a set of complex and problematic interactions among social and ecological systems across multiple spatial and temporal scales. Assessments of wildfire risk could benefit from recognizing and accounting for these interactions in terms of socioecological systems, also known as coupled natural and human systems (CNHS). We characterize the primary social and ecological dimensions of the wildfire risk pathology, paying particular attention to the governance system around wildfire risk, and suggest strategies to mitigate the pathology through innovative planning approaches, analytical tools, and policies. We caution that even with a clear understanding of the problem and possible solutions, the system by which human actors govern fire-prone forests may evolve incrementally in imperfect ways and can be expected to resist change even as we learn better ways to manage CNHS.

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Fire-prone temperate forests are becoming increasingly risky places for humans. Despite massive and increasing investments in firefighting, wildfire risk – the probability and potential losses associated with fire – is increasing. The problem is global in scale: Australia and countries in North America and the Mediterranean Basin have experienced substantial losses in life and property to wildfires in temperate forests in recent years (Chapin *et al.* 2008; Bowman *et al.* 2011; Dennison *et al.* 2014; Moritz *et al.* 2014; Stephens *et al.* 2014). Length of fire seasons and extent of land area burned have increased in these regions, as have economic losses from wildfire and expenditures on fire suppression (Jolly *et al.* 2015). In the US, economic losses from wildfires doubled and suppression costs tripled in the decade after 2002 as compared with the previous decade (Headwaters Economics 2013; Reuters 2013). Nevertheless, fire is an essential ecological process in many temperate forest ecosystems, playing a critical role in maintaining native plant and wildlife diversity.

In a nutshell:

- Wildfire risk in temperate forests can be considered a socioecological pathology: a set of interrelated social and ecological conditions and processes that deviate from what is considered healthy or desirable
- Finding solutions to the problem of wildfire risk requires a more complete specification of fire-prone temperate forests as coupled natural–human systems, and more attention to the complex interplay between the social and ecological conditions and processes that influence human decision making (ie the wildfire governance system)
- Building social networks of stakeholders and engaging stakeholders in scenario planning exercises can foster creative problem solving to reduce wildfire risk and restore fire to fire-prone temperate forests

The nearly intractable problem of wildfire risk in temperate forests can be characterized as a socioecological pathology: a set of interrelated social and ecological conditions and processes that deviate from what is considered healthy or desirable. Another example of a socioecological pathology is the desiccation of the Aral Sea in central Asia and the subsequent decimation of its fishing industry and coastal human communities, which resulted from a narrow societal focus on the rapid spread of irrigated agriculture for cotton monoculture that led to the overuse of water resources (Gunderson and Pritchard 2002). The wildfire risk pathology, which should not imply that all wildfire is undesirable, can be traced to a complex set of interacting factors. Conditions in forests have become more hazardous due to accumulation of abundant flammable vegetation, in many cases a result of disrupted traditions of indigenous fire management, practices of fire exclusion and suppression, establishment of weeds and other flammable plants, and a warming climate (Moreira *et al.* 2011; Williams 2013). Population change has also affected fire risk. In some regions, such as the western US, expansion of exurban areas has increased the probability of ignitions and placed more assets at risk in forested fire-prone areas. Accompanying demographic shifts have engendered new social values, policies, and decisions that favor reduction of short-term fire risk to homes and other structures at the expense of long-term risk to forest landscapes (Williams 2013). In other

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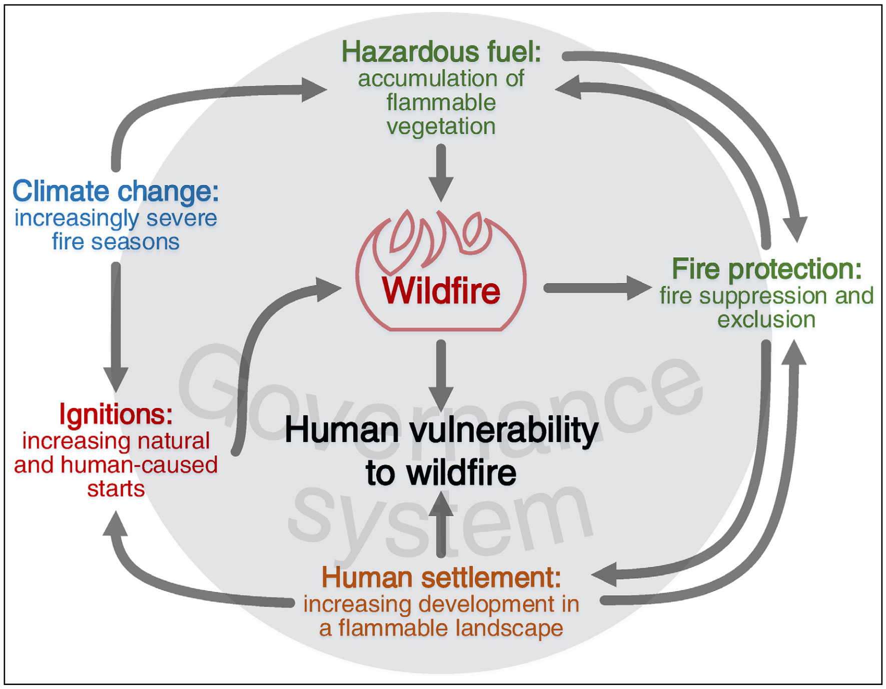

Figure 1. *Wildfire risk in fire-prone temperate forests is a result of interacting positive feedback loops that link wildfire and human vulnerability through key drivers of land use and natural resource management.*

areas, such as southern Europe, rural exodus has led to abandonment of land management activities and accumulation of hazardous vegetation (Moreira *et al.* 2011). These drivers have co-evolved over time, creating a maladaptive, positive feedback loop in which wildfire risk increases despite policies and practices designed to reduce it. As wildfires become larger and less controllable and forested areas become more vulnerable, society demands more fire protection, pushing agencies toward suppressing rather than using fire as a tool (North *et al.* 2015). The challenge of understanding the problem of wildfire risk and developing solutions is compounded by variability and complexity in: (1) fire regimes, not all of which exhibit the same positive feedbacks, (2) effectiveness of fuels management strategies, and (3) institutions involved in the governance of fire-prone forests (Price *et al.* 2015).

We use a coupled natural and human systems (CNHS) perspective (Liu *et al.* 2007) to understand the pathology of wildfire risk in fire-prone temperate forests and suggest strategies to mitigate it. Applying CNHS concepts to wildfire risk has been identified as a prerequisite for understanding the problem and framing appropriate policies (Chapin *et al.* 2008; Moritz *et al.* 2014; Spies *et al.* 2014). Although some researchers have attempted to address elements of the pathology, we submit that their effectiveness has been limited by incomplete specification of the CNHS, especially the interplay between the social and ecological conditions and processes that influence human decision making – what we call the wildfire governance system. By including governance in the CNHS framework, it is possible to identify key human components of the system that control attitudes, behaviors, and policies; it is also possible to develop strategies and analytical tools that human actors in the system can leverage to create more adaptive feedback loops in which wildfire risk reduction accompanies reduction in human and ecological vulnerability.

The nature of the pathology

Although global in scale, the socioecological pathology of wildfire risk is clearly demonstrated in the western US. During the 20th century, suppression and exclusion of fire (ie fire protection) allowed flammable vegetation to accumulate in this region's temperate forests, including scenic areas along the wildland–urban interface (WUI) where amenity-seeking migrants (people who relocate to areas based on non-consumptive values such as scenery and recreation) settled beginning in the 1970s, and increasingly in the 1990s (Theobald 2001; Johnson and Beale 2002). The extent of area burned and the social and ecological impacts of wildfire in the western US have increased as the climate has warmed over the past two decades (Dennison *et al.* 2014; NIFC 2015), although the proportion of high-severity fires that is increasing is debatable (Baker 2015). The result has been a destabilizing feedback loop in which spiraling fire losses are a direct consequence of policies intended to protect people and resources from wildfire (Figure 1).

The wildfire risk pathology can be viewed as the result of a set of social and ecological regime shifts (Figure 2; Folke *et al.* 2004). Forests that historically experienced frequent, low- and mixed-severity fires have been homogenized by widespread infilling with smaller-diameter, shade-tolerant tree species, and selective logging of large, fire-resistant tree species. These changes created new successional pathways and primed forests for large, uncontrollable fires under changing climatic conditions (Stephens *et al.* 2013; Stavros *et al.* 2014). New states and dynamics may be emerging in social systems as well. Expanded populations of WUI residents may be less tolerant of smoke from fire than their early 20th century natural resource-dependent counterparts and earlier native peoples, who relied on forests for consumptive and productive uses and often actively used fire as a management tool. Fires burning in forested areas raise legitimate concerns about effects on scenic beauty and human health. The potential for fires to escape containment, as well as debates about the effectiveness of controlled burning, impose particular constraints on the use of prescribed fire

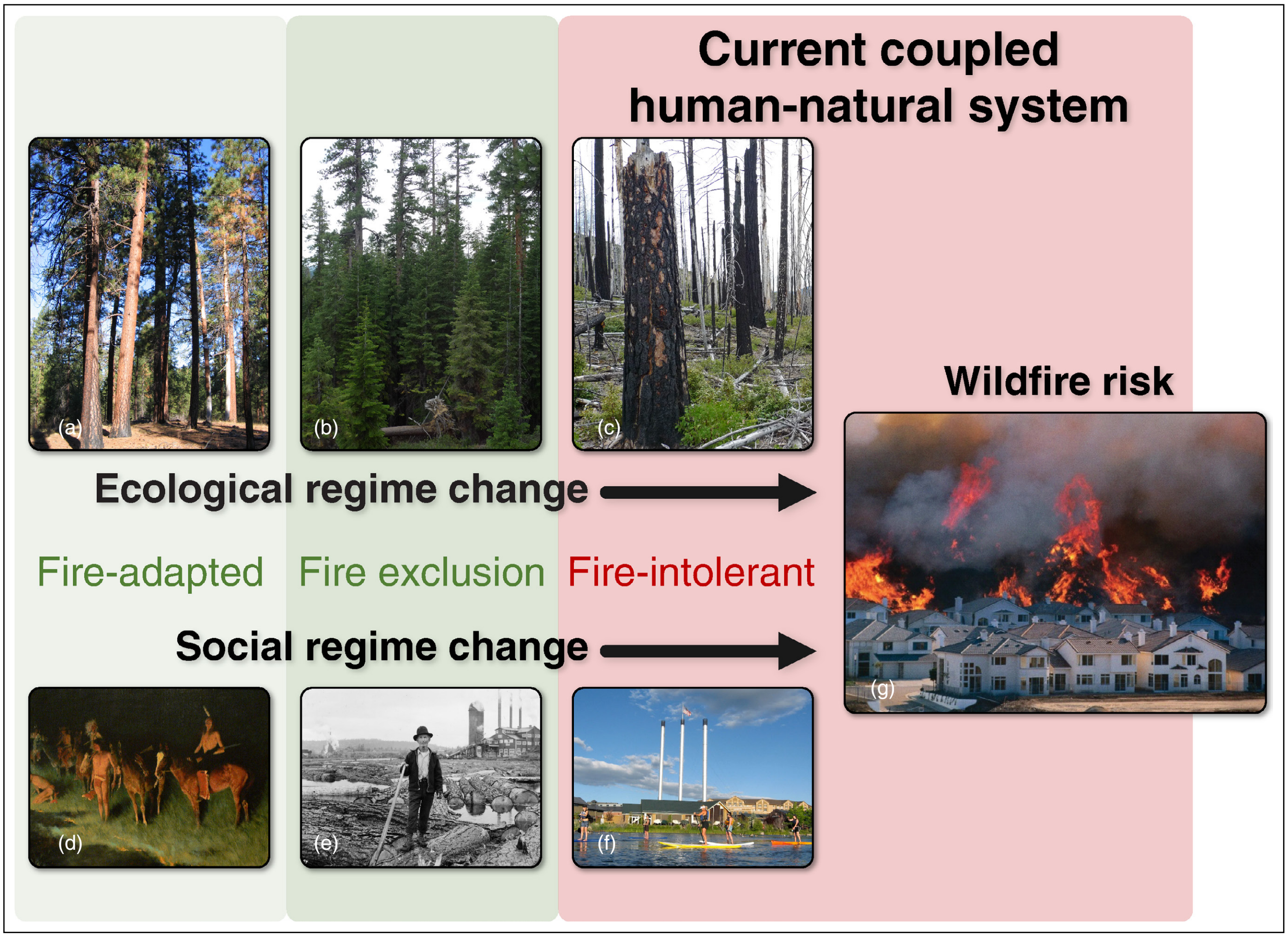

Figure 2. *Social and ecological regime shifts: transition of ecological system from fire-dependent ponderosa pine* (Pinus ponderosa) *woodland to fire-intolerant early-successional mixed-conifer forest (top); transition of social system from fire-dependent hunting culture to fire-intolerant amenity-oriented culture (bottom). Note the last two pictures in the social regime change series are from Mirror Pond, on the Deschutes River, in Bend, OR, where use has gone from wood processing to recreation and shopping. Courtesy of Amon Carter Museum, Fort Worth, Texas, Deschutes County Historical Society, Tumalo Creek Kayak & Canoe, and Elmer Fredrick Fischer/Corbis.*

to manage forest vegetation, although the public generally supports activities that mitigate forest fire risk (Shindler and Toman 2003; Maguire and Albright 2005; Wilson *et al.* 2011; McCaffrey and Olsen 2012). Furthermore, while managed wildfire (eg lightning-ignited fire allowed to run its course within well-defined and maintained perimeters) can contribute to reducing the fuels that support high-severity fires, economic and social factors and attitudes severly limit its use, despite policies that allow it (North *et al.* 2015).

The current wildfire governance system in the western US evolved as part of the positive feedback loop and accompanying regime shifts that comprise the wildfire risk pathology (Figure 1). Governance systems are "messy" collections of diverse parties with different levels of authority at different scales, whose aim is to create stable expectations, norms, and institutions to address complex problems (Duit and Galanz 2008). The wildfire governance system in the western US consists of many state and non-state actors with competing goals, policies, and practices. Long-standing federal actors such as the US Forest Service (USFS) and the Bureau of Land Management, as well as state-level departments of natural resources, administer divisions that simultaneously hold different and conflicting aims. For instance, one division within a natural resource agency may aim to restore ecological conditions and processes on historically fire-prone forestlands while another division will aim to suppress fire on those same lands. Departments of natural resources at the state level also provide fire protection to private industrial and nonindustrial landowners, and forest management assistance to nonindustrial owners. A variety of nonprofit organizations are also active in the wildfire governance system, advocating for ecological restoration and fire protection, and providing technical assistance to homeowners and nonindustrial private forest landowners.

While based on well-intentioned strategies, the current wildfire governance system has made changing the pathology extremely difficult. Despite the recognized importance of restoring ecological conditions and processes on historically fire-prone forestlands, including reintroducing fire, current forest management policies, as implemented, continue to prioritize fire protection (Steelman and Burke 2007). State and federal agencies continue to focus on fire suppression (North *et al.* 2015) and face numerous challenges that make it difficult to encourage use of thinning, prescribed burning, and managed wildfire to restore forests and reduce future fire risk (Maguire and Albright 2005; Wilson *et al.* 2011). Expanding state and federal fire suppression budgets creates a disincentive for agencies to shift toward thinning and use of fire as a management tool (North *et al.* 2015). Moreover, land-use policies and property insurance practices can subsidize the risk of settling in hazardous areas (Yoder and Blatner 2004; Donovan and Brown 2007), although there is no empirical evidence for the strength of this feedback. In addition, the combined influences of climate change and land-use change appear to be leading to longer fire seasons and increased wildfire activity in the western US (Westerling *et al.* 2006), strongly suggesting that ineffective greenhouse-gas emissions policies in tandem with regional land-use policies have amplified the problem. The result has been a set of complex interactions between fire protection behaviors, hazardous fuels, human settlement patterns, wildfire ignitions, and climate change, which have given rise to ever-increasing wildfire risk (Figure 1).

For better or worse, the wildfire governance system, in turn, reinforces the wildfire risk perceptions and management behaviors of individual property owners. Such owners often do not make short-term investments in reducing flammable vegetation to diminish their long-term exposure (McCaffrey 2004), in part because the probability of a wildfire damaging their property is relatively low in any given year, but also because they can benefit from the risk reduction activities of other landowners nearby (Busby and Albers 2010). Furthermore, the public generally expects government agencies to protect them when wildfires occur (Canton-Thompson *et al.* 2008). The resultant human decisions to reduce flammable vegetation (or not to do so) can influence risk at large spatial scales. Unlike other natural hazards, a fire can be ignited by a single individual and can cause widespread impact, and owners who fail to reduce hazardous vegetation around structures and along property lines can enable the spread of wildfire to larger areas (Calkin *et al.* 2014).

Policy innovation in a complex coupled system

Ultimately, the remedy to the wildfire risk pathology is a governance system that transforms maladaptive feedbacks into adaptive feedbacks. Creating such a governance system requires policies that influence human–land–forest and fire-management behaviors and that account for socioecological interactions at multiple scales: spatial (ownership, landscape, ecoregion), temporal (short- and long-term), and organizational (individuals, groups, institutions). Recent US federal policy innovations such as Stewardship End Result Contracting and the Collaborative Forest Landscape Restoration Program, both permanently authorized in 2009, have, to some extent, moved toward this ideal. These initiatives encourage local variation in planning and management such that actions can be coordinated and adapted across larger spatial scales and longer time frames than are typically seen in forest management (Table 1). Similarly,

Table 1. Examples of US policies that account for socioecological interactions at multiple scales

Policy	*Intent*	*Demonstrated ability to account for key types of cross-scale interactions*		
		Spatial	*Temporal*	*Organizational*
Collaborative Forest Landscape Restoration Program (CFLRP) of 2009	Promotes landscape-scale restoration on national forests by making long term financial investments where stakeholders are already working together	Engages managers and stakeholders in landscape in planning and management	Fosters longer planning horizons than typical in forest management	Integrates decision making at local, state, and regional scales
Stewardship End Result Contracting (first passed in 1999, permanent authority in 2014)	Creates mechanisms for forest management that allow for integration of timber removal and restoration activities to benefit local communities	Integrates forest management projects across landscapes	Fosters longer implementation horizons than typical in forest management	Integrates considerations of local economic, social, and ecological benefits with forest management and wildfire protection goals
The National Cohesive Wildland Fire Management Strategy (mandated as part of Federal Land Assistance, Management and Enhancement [FLAME] Act of 2009)	Promotes fire-resilient landscapes, fire-adapted communities, and effective and efficient wildfire protection through multi-scalar strategy development and implementation	Integrates responses by federal and state agencies, state and local government, and tribes across regional, state, and local scales	Will be revised at least every five years to consider changes with respect to landscape, vegetation, climate, and weather	Engages federal and state land management and fire protection agencies, state and local governments, tribes, and other stakeholders in analyzing alternatives

the intent of the National Cohesive Wildland Fire Management Strategy of 2009 – mandated as part of the Federal Land Assistance, Management, and Enhancement (FLAME) Act – is to balance local, state, and federal fire protection goals with the need to restore fire-adapted landscapes and create human communities that can plan for, respond to, and recover from wildfires.

Policy innovation has already occurred on multiple scales of social organization. A growing number of networks of non-state actors have emerged to address wildfire in the western US by supplementing the work of long-standing state and federal actors. Across the wildfire governance system, networks of diverse stakeholders are operating at various spatial and organizational scales. These include collaborative activities at the national level, such as in the area of interagency wildfire response, and at the local level, as with neighborhood organizations seeking to reduce wildfire risk. Federal agencies are heavily involved with many of these efforts, such as the Fire Learning Network, a USFS-funded project of The Nature Conservancy (an environmental nonprofit organization). Other efforts have been initiated with limited government intervention, as with prescribed fire councils where local landowners, land managers, and other stakeholders are organizing to increase social and political support for using fire as a management tool and building capacity to implement it across jurisdictional lines.

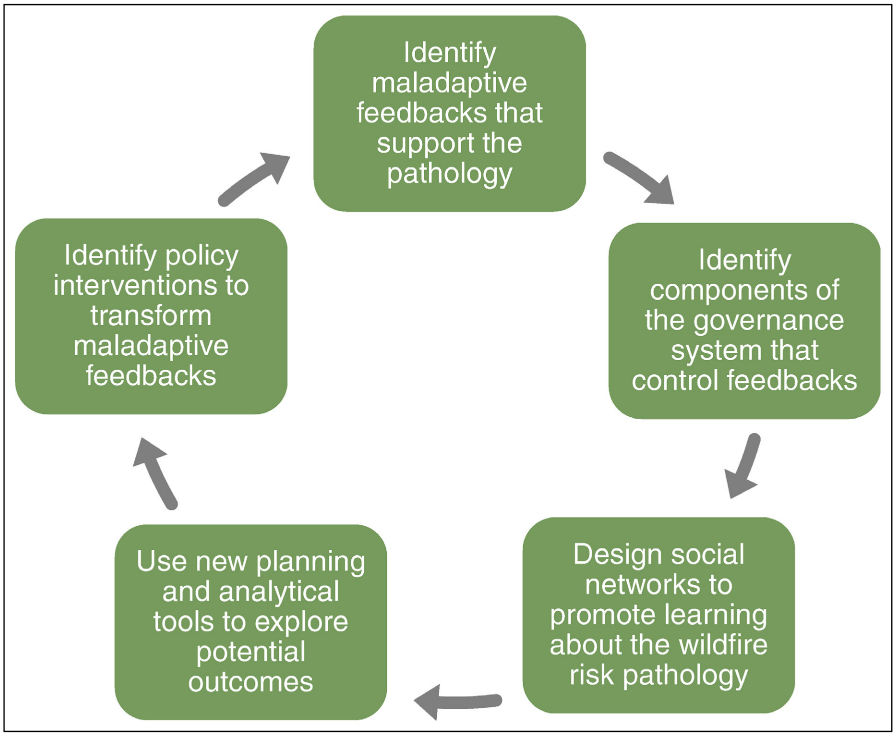

Figure 3. *Components of a framework for addressing the pathology of wildfire risk in fire-prone temperate forests through broad human engagement in complex thinking about multi-scalar policies and adaptive planning and management.*

While these new cross-scalar policy interventions have created opportunities to weaken maladaptive feedbacks between wildfire and human vulnerability, their effects are not yet visible. Property losses from wildfires continue to grow and the annual rate of restoration needed to reduce risk remains well beyond current treatment rates (Stephens *et al*. 2013). With projected climate change and further development in the WUI, the problem of wildfire risk is outpacing the human capacity to adapt. Perverse incentives continue to encourage not only residential development in fire-prone forests in the WUI but also fire suppression instead of management to reduce risk in forested areas (North *et al*. 2015). Moreover, jurisdictional heterogeneity has added new layers of complexity to the governance system, making progress uneven.

How these recent policy interventions affect human behavior and landscape fire risk is unpredictable. New policy does not operate in a vacuum; rather, it is integrated into the complex, path-dependent wildfire governance system that itself operates at multiple organizational scales. Furthermore, formal policies do not change human behavior in straightforward ways. Change is often resisted, as in the case of the Federal Wildland Fire Management Policy of 1995, which formally moved federal policy away from absolute fire suppression. In practice, however, suppression remains the default choice of wildfire management, even as federal agencies experiment with more complex strategies (Steelman and Burke 2007). What is needed is a more fire-adapted governance system that leads to reduced fire risk through better-targeted fuel treatments, coordinated efforts, and restoration across whole landscapes.

CNHS planning approaches and analytical tools

In a fire-adapted governance system, actors from across spatial, temporal, and organizational scales would be engaged in interactive, collaborative efforts to develop solutions to the wildfire risk pathology (Figure 3). Social network analysis offers an efficient path to understanding the complex social structure of a governance system. The patterns of interaction within a network of actors – how centralized or densely interconnected they are – influence the functioning of a governance system and the extent to which it may enable or constrain communication, coordination, and creative problem solving (Bodin and Crona 2009).

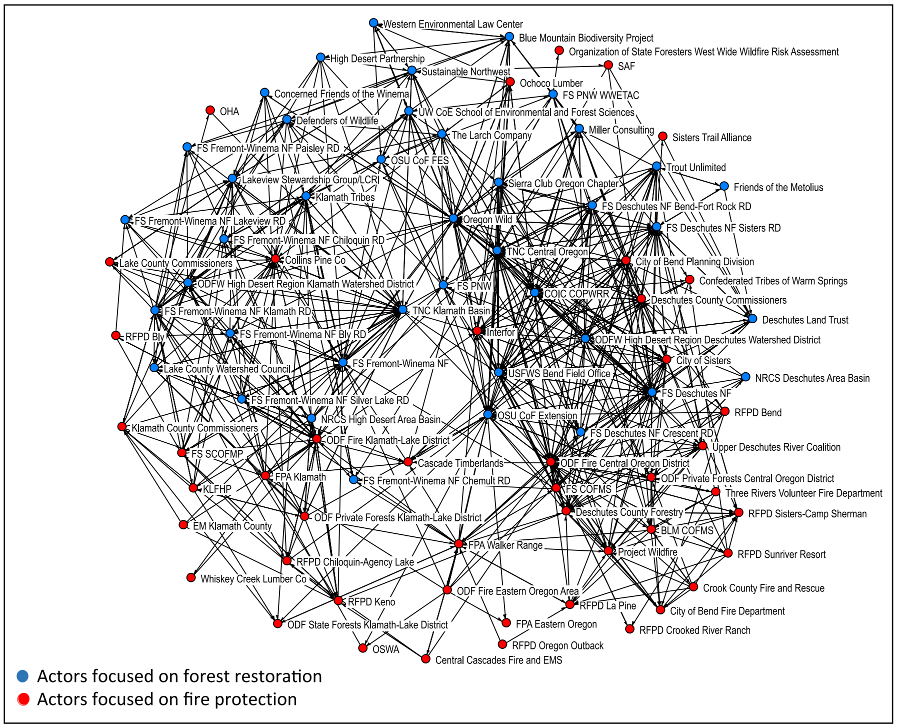

Figure 4. *A map of actors in a wildfire governance network in Oregon, in which groups that interact with each other are closer to each other than to groups that do not interact. Actors that focus on forest restoration are mainly located in the upper hemisphere of the figure, whereas those that focus on fire protection are largely located in the lower hemisphere. This pattern suggests that interaction between actors from the two groups may be constrained. Policy interventions could create new institutions to bring forest restoration and fire protection actors into more frequent and sustained interactions.*

As an example, network analysis was used to map and quantify relationships among a set of organizations involved in forest and wildfire management in Oregon. The analysis indicated that network structure was strongly shaped by the tendency of people to associate with those who possess similar management goals, geographic emphases, and attitudes toward wildfire (Figure 4) (Fischer *et al.* 2016; Fischer and Jasny in review). In particular, organizations with fire protection and forest restoration goals comprised distinct subnetworks despite a shared concern about the issue of increasing wildfire risk. The lack of cohesion in the overall network could potentially constrain interactions among organizations with diverse information and resources, limiting opportunities for learning and complex problem solving regarding the wildfire risk pathology.

Network analysis can also inform interventions to enhance the structural characteristics of social networks so as to better support critical exchanges of information and resources among key actors (Valente 2012). The Fire Learning Network mentioned earlier is an example of a network intervention that has built connectivity among land management organizations to further restoration of fire-dependent ecosystems through landscape-scale collaborative planning (Butler and Goldstein 2010). Network maps and statistics can reveal highly connected or influential organizations whose strategic positions could be leveraged to improve communication and cooperation, or to pinpoint sets of organizations that could benefit from greater communication and cooperation. Network analysis may reveal that conservation groups in the western US are augmenting the limited capacity of land management agencies to engage in collaborative landscape planning and social–ecological thinking by contributing additional labor, skills, and, at times, financial resources. Similarly, network maps may identify scientists as emerging actors in the wildfire governance system because of their increasing role in using, and providing interpretations of, complex models. Indeed, the analysis of organizations involved in forest and wildfire management in Oregon revealed that several conservation groups and academic institutions had much more extensive and heterogeneous networks relative to all other organizations (Fischer and Jasny in review). The large and diverse networks of such organizations could be leveraged to improve communication, coordination, and joint problem solving.

Once social networks are identified, scenario planning (also referred to as alternative futures modeling) offers a systematic method for actors to anticipate uncertain future social and ecological conditions resulting from potential shifts in social and environmental trends, or new policies and technologies (Peterson *et al.* 2003). Scenario planning provides a tool for actors to project social and ecological interactions and outcomes under different scenarios (Hulse *et al.* 2000; Hulse *et al.* in press; Spies *et al.* in review). Although scenario planning is not new, emerging stakeholder networks and state-of-the-art, spatially-explicit, agent-based models (simulation models that describe autonomous individual agents, eg landowners who make decisions that modify vegetation or built structures) create new opportunities for actors to explore socioecological feedbacks and interactions in real landscapes. Such exercises can serve as a discussion aid for actors to collectively identify possible pathways for remedying the wildfire risk pathology. For example, scenario planning is facilitating development of more effective and ecologically based forest landscape restoration projects by collaboratives in central Oregon (Figure 5) (Spies *et al.*

in review). As part of these efforts, stakeholder-generated scenarios are being used with an agent-based model to demonstrate how fuel treatment designs might affect the extent of area burned in the future by high- and mixed-severity fire and the trade-offs among managing for wood, fire risk, and biodiversity. Collaborative groups in central Oregon have shown interest in applying the models to specific landscape-scale projects that help them move beyond forest stand-scale and short-term perspectives, which can inhibit breaking out of the wildfire risk pathology.

Figure 5. *Representatives of organizational actors within a wildfire governance system in Oregon developing a conceptual map of a wildfire risk scenario.*

Land managers, planners, and other actors in the wildfire governance system can model scenarios that test plausible interventions by exploring uncertainties and risks associated with implementing alternative future policies. These could include using fire to a greater degree as a management tool on public and private lands, shifting responsibility for fire protection from agencies to homeowners, or zoning land use and development based on fire risk. Scenario planning can be used to explore the limits of human adaptation – for instance, to investigate at what point increasing wildfire risk might compel WUI residents to move to less fire-prone areas or, alternatively, take wildfire management into their own hands. Such advanced models may not yet exist, but recent innovations in the implementation of complex agents, social networks, and learning mechanisms may soon bring them within reach. As a case in point, the potential to endow agents with increasingly human characteristics (Tweedale *et al.* 2007) now includes algorithms for deliberative reasoning to avoid undesirable situations (Davidsson 2003; Doniec *et al.* 2008); proactive, forward-thinking behavior (So and Sonenberg 2004); and confounding factors such as spread of misinformation (Acemoglu *et al.* 2010).

The capacity to generate hundreds of spatially explicit alternative futures that explore variability and uncertainty within and among scenario sets can be particularly informative when change is likely to occur outside the bounds of historical variability (Hulse *et al.* in press). In this vein, Hulse *et al.* characterized eight alternative futures for a fire-adapted oak–conifer system composed of multiple sets of contrasting climate, development, and fire hazard management scenarios and generated simulations of each scenario over a 50-year period. The authors used the results to explore the mechanisms through which fires of unprecedented size could spread through the landscape in response to, and sometimes contrary to, the expected effects of land management actions. They then demonstrated how this analysis could be used to anticipate when, where, and how potentially unexpected fires may burn. Further advances in such simulation tools may offer increasingly useful insights into managing the complex feedbacks of the wildfire risk pathology, and serve as important aids in policy development.

Conclusions

Although temperate forest regions in the US, southern Australia, and the Mediterranean Basin have different landscape histories, their political systems and approaches to fire management all exhibit the socioecological pathology of wildfire risk. In Greece, for example, the decision to shift responsibility for wildfire management from the Forest Service, located in the Ministry of Agriculture, to the Fire Service, located within the Ministry of Public Order – combined with new European Union policies intended to reduce wildfire occurrence – increased focus on the main symptom of the wildfire risk pathology (uncontrollable wildfires) rather than the cause (land-use and population change) (Kalabokidis *et al.* 2008). In Australia, post fire disaster recovery has typically included rapid rebuilding, making it difficult to adapt building practices and landscape design to increasingly fire-prone conditions. In each of these countries the pathology will continue to be exacerbated by climate change (Flannigan *et al.* 2013). The need to adapt is driving rapid policy development, with increasing recognition of the importance of collaborative partnerships in some regions. The 2015 decision in Victoria, Australia, to use greater community consultation and partnerships to help identify areas for fuel management to reduce risk, instead of relying on mandated annual targets, is an example of such a shift. As we have demonstrated for the western US, overthrowing all current policies may not be required to mitigate the wildfire risk pathology; revising existing policies could be sufficient.

While research, evaluation, and monitoring are required to determine whether policy innovations will be effective and enduring, applying a CNHS framework may help to ensure that policies are well-grounded ecologically and socially. We hypothesize that engaging actors in anticipatory thinking can help reveal how the transformation of maladaptive feedbacks into adaptive feedbacks can come from within the network of actors within a CNHS. As policies are implemented, managers, planners, and other actors can use scenarios and modeling not only to identify social and ecological processes that continue to exacerbate wildfire risk but also to test further strategies to reverse such positive feedbacks. Through adaptive actions and learning, actors in the wildfire governance system can become aware of what parts of the system resist change, and where new policies, networks, or organizations may make a difference. Such a framework may help expand the problem-solving capacity needed to address the pathology of wildfire risk at appropriate spatial, temporal, and social scales.

Changing a pathological system is difficult because the conditions and processes that engender the pathology are highly resilient. We caution that even with clear understanding of the wildfire pathology and possible solutions, governance systems may evolve incrementally and in imperfect ways, continuing to resist change even as we learn better ways to manage CNHS. Nevertheless, a fire-adapted governance system that engages a wide array of human actors in social networks and planning processes that promote complex thinking about the future offers the best chance of mitigating the wildfire risk pathology, whether in the US or in fire-prone temperate forests elsewhere in the world.

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