Integrating Subjective and Objective Dimensions of Resilience in Fire-Prone Landscapes

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Resilience has become a common goal for science-based natural resource management, particularly in the context of changing climate and disturbance regimes. Integrating varying perspectives and definitions of resilience is a complex and often unrecognized challenge to applying resilience concepts to social–ecological systems (SESs) management. Using wildfire as an example, we develop a framework to expose and separate two important dimensions of resilience: the inherent properties that maintain structure, function, or states of an SES and the human perceptions of desirable or valued components of an SES. In doing so, the framework distinguishes between value-free and human-derived, value-explicit dimensions of resilience. Four archetypal scenarios highlight that ecological resilience and human values do not always align and that recognizing and anticipating potential misalignment is critical for developing effective management goals. Our framework clarifies existing resilience theory, connects literature across disciplines, and facilitates use of the resilience concept in research and land-management applications.

Keywords: adaptation, ecological resilience, social resilience, social–ecological systems, wildfire, wildland

Resilience is an increasingly common goal for natural resource management (e.g., Scheffer et al. 2001, Folke et al. 2004, Rist and Moen 2013, Bone et al. 2016), primarily because it encapsulates some level of stability while acknowledging the dynamism, complexity, and uncertainty of coupled natural and human systems (Gunderson 2001, Preiser et al. 2018). Applying resilience as an explicit natural resource policy goal, however, has proven elusive, in part because different disciplines attach different meanings to the concept (Brand and Jax 2007, Berkes and Ross 2013, Davidson et al. 2016, Folke 2016, Quinlan et al. 2016). In ecology, for example, resilience is viewed as an inherent property of a system, determining its ability to persist after disturbance or to bounce back (Holling 1973, Walker et al. 2004), with no explicit value or desirability attributed to the properties or system conditions. In contrast, many social science fields consider resilience a positively valued attribute of individuals (Fredrickson 2001) or human communities (Norris et al. 2008). These differences in definition can lead to confusion, with important consequences for interpreting policy and setting common goals, especially in complex systems in which social and ecological domains strongly interact (Davidson et al. 2016). In the present article, we offer a new conceptual framing of resilience, which facilitates improved understanding and synergy between ecological and social theories and may be more readily applied in natural resource management. We develop our ideas around the increasingly relevant challenge of managing for the resilience of social–ecological systems (SESs) to wildfires (Chapin et al. 2003, Moritz et al. 2014, Spies et al. 2014, USDOI and USDA 2014, Fischer et al. 2016, Smith et al. 2016, Schoennagel et al. 2017).

In the ecological literature, Holling (1973) introduced the concept of resilience as an attribute of a system, conceptualized by a mathematical relationship predicting whether and when a system state would change in response to a disturbance. Ecological resilience is perhaps most clearly understood as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to *still retain essentially the same function, structure, and feedbacks*" (emphasis added; Walker et al. 2004). From this perspective, resilience is neither good nor bad, but simply an inherent property of complex systems. As an inherent property of a system, we consider resilience to be value free, although

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we recognize that the scientific study of resilience is itself an interactive and social activity (Wallington and Moore 2005). This value-free perspective of resilience is frequently applied to ecological systems (e.g., Angeler and Allen 2016) and less frequently to social or SESs (e.g., Kulig et al. 2013), as an objective assessment of current conditions and the likelihood of a state change after disturbance. When this perspective is applied to social systems, the focus is on understanding how individuals, networks, institutions, and social processes maintain system components and function following disturbance (Norris et al. 2008, Kulig et al. 2013).

Outside of the ecological literature, resilience is often seen from a value-explicit perspective as a desirable system attribute (e.g., resilience of communities and cities to human disasters; Pickett et al. 2004, Grimm et al. 2017). However, resilience, through the maintenance of structure and function, can also be undesirable for society, because it can limit progressive social change that might reduce existing power asymmetries or facilitate social transformation. Therefore, when applied to social contexts, resilience is often implicitly or explicitly value laden, because its goals are often oriented toward maintaining or achieving some desired state or states. From the value-explicit viewpoint, if the current system state is *desirable,* then managing for the resilience of the current state is a logical goal. However, if the current state is *undesirable*, managing to enhance the resilience of the status quo is counterproductive (Standish et al. 2014). Despite this, and the fact that perspectives on the desirability of a current state will vary among stakeholders, the perspective of resilience being good is often adopted uncritically (Standish et al. 2014). Ascribing desirability to resilience by default can cause significant confusion in theory and application (e.g., Côté and Darling 2010).

These varying perspectives on resilience have stimulated substantial discussion in research and management communities regarding its utility (or lack thereof) for bridging social and natural sciences and guiding natural resource management (Buma 2013, Sandler 2013, Standish et al. 2014, Olsson et al. 2015, Davidson et al. 2016). Confusion, ambiguity, and miscommunication about resilience among researchers, managers, and policymakers, who may adopt differing definitions of the term, have created tension among disciplines and hindered the productive operationalization of the concept for natural resource management. We suggest that neither a value-free nor value-explicit perspective alone is sufficient for managing coupled human–natural systems, because each offers important and complementary strengths. The value-free perspective is attractive for its objectivity and mathematical grounding, whereas a value-explicit perspective directly recognizes the role of human values and real-world management contexts. Although integrating these perspectives is necessary for effectively visioning and managing for resilience in different contexts, appreciating their distinction is critical.

Building on the rich history of resilience research from both the ecological and social sciences (Carpenter and Folke 2006, Folke 2006, Stone-Jovicich 2015), we present a framework that distinguishes and integrates the value-free and value-explicit perspectives of resilience, thereby taking an important step toward applying resilience concepts to understand and manage SESs. Our framework differentiates the inherent properties of SESs that maintain structure, function, or system states (e.g., following disturbance) from the human perceptions of which system structures, functions, or states are desirable. In doing so, it helps clarify existing theory, bridges ecological and social sciences, and facilitates the use of resilience concepts in future research and practice. Our framework orients SESs by coupling resilience as an objective attribute of a system to the subjective evaluation of the system conditions. As an objective attribute, resilience is a function of both biophysical and human characteristics, whereas the subjective desirability of system conditions is an entirely social construct. We suggest that explicitly recognizing these distinct dimensions can help alleviate the tensions and contradictions that have limited the application of resilience theory in policy and land management.

Recognizing distinct value-free and value-explicit dimensions of resilience provides a new way to frame SESs that can lead to clearer articulation of policy or management goals. To illustrate its utility, we apply our framework to the challenge of managing wildfires in fire-prone SESs, because the relationships between fire and humans can easily lead to the complex entanglement of value-explicit and value-free applications of resilience concepts. This focus orients our discussion, and we provide examples for landscape spatial scales (e.g., 10^2–10^3 square kilometers) and time scales relevant to postfire management and recovery, which span years (e.g., for humans to rebuild or redevelop after a wildfire) to decades or centuries (e.g., for tree regeneration after high-severity fires). We also discuss temporal dynamics of SESs in terms of changes associated with postfire recovery, when a system is resilient to wildfire, and changes associated with postfire state change or type conversion, when a system is not resilient to wildfire. Finally, we highlight remaining challenges for applying resilience concepts, including reconciling varying spatial and temporal scales relevant to social and ecological systems.

Distinguishing and linking value-free and value-explicit dimensions of resilience

Our framework represents the value-free likelihood of a state change as orthogonally related to the (value-explicit) acceptability of such a state change by stakeholders (figure 1). The quadrants that result from this ordination represent four archetypes of SES states, defined by both an objective, value-free assessment and a subjective, value-explicit evaluation. The location along the x-axis reflects the value-free probability of change after a disturbance such as wildfire, or the conditional probability of a state change given a fire occurs (i.e., the inverse of ecological resilience). The location on the y-axis reflects the explicit desirability of such a state change, or the acceptability of a state change. Provided the

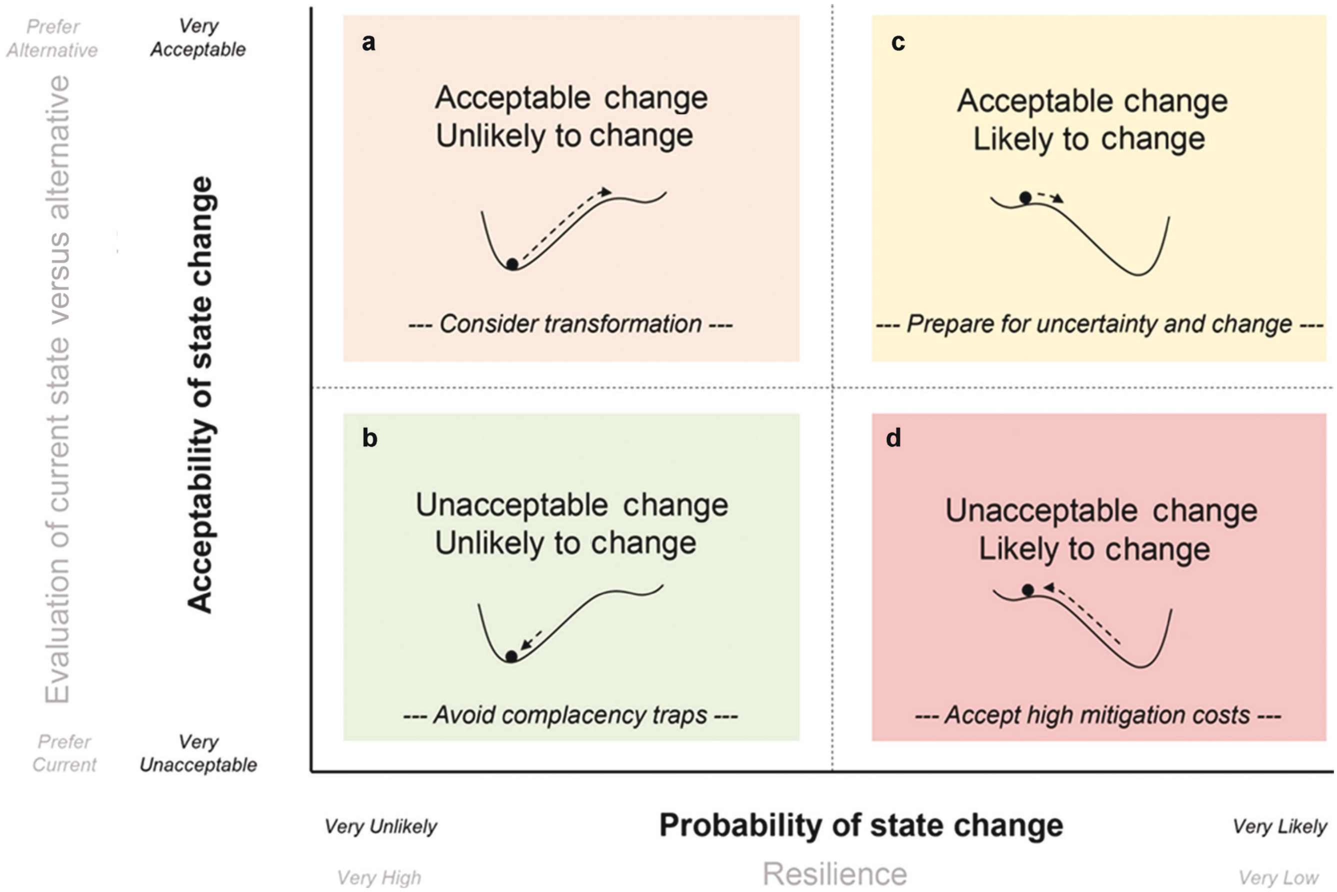

Figure 1. The value-free—value-explicit framework and archetypical scenarios. The conditions are characterized by their probability (x-axis) and acceptability (y-axis) of a state change after a disturbance such as wildfire. The probability of a state change is inversely correlated with resilience. The acceptability of a state change is a social evaluation of whether stakeholders prefer to shift to an alternative condition and is inversely correlated to the desirability of the current condition. The traditional ball-and-cup diagrams (sensu Holling 1973) illustrate greater resilience with deeper cups. The dotted lines indicate the desired postdisturbance trajectory, with arrow length proportional to the energy required for recovery. The panels' shading indicates a threat level with respect to the probability and acceptability of state change (increasing from green, yellow, orange, to red). Finally, the location of a system in any quadrant reflects a snapshot in time and should be routinely reassessed as the system changes over time.

conditions of the future state are known, this axis can also indicate the preference for the altered state over the current state. Therefore, we can view resilience from both value-free and value-explicit perspectives simultaneously. The location a system occupies in figure 1 reflects a snapshot in time and should be routinely reassessed as the system changes over time. Likewise, SES properties (including the effects of fire on ecosystems and humans) and management actions vary across spatial scales; although these archetypes could be applied to individual components of a landscape (e.g., a single forest stand), we describe them first as representing a landscape as a whole. We highlight how management scenarios and goals differ in an archetypical fashion across the four quadrants.

Value-free dimensions. The horizontal (x) axis represents the components of resilience that are value-free attributes of a system. It is similar to Holling's (1973) definition of *ecological resilience* but can also be applied more broadly to *all* components of an SES, including explicitly social components such as institutions and management regimes. The location of a system along this axis is determined by the likelihood of state change in response to a disturbance of a given magnitude. The ability to understand, quantify, and predict the likelihood that disturbances will occur or whether a disturbance will drive a system to a new state is continually improving (e.g., Westerling et al. 2011, Kulig et al. 2013, Angeler and Allen 2016, Ratajczak et al. 2016), making this an attractive metric for operational purposes. The important measure in this context is the likelihood that a disturbance (of a given severity) will cause a persistent state change over a defined time period and spatial scale, which combines disturbance likelihood and disturbance impacts.

Importantly, although the attributes of a system that determine these outcomes are themselves value free, we point out that choices of what attributes to focus on, and the associated spatial and temporal scale, are themselves subjective and in part reflect what humans value (Cote and Nightingale 2012, Quinlan et al. 2016).

One SES that would typically be located to the left on the *x*-axis in figure 1 is a Rocky Mountain lodgepole pine ecosystem. These systems have been highly resilient to large, infrequent wildfires, because traits such as serotinous cones (which require heat to open and release seeds) result in a high likelihood of tree regeneration after fires (Turner et al. 2016). Therefore, under conditions within the historical range of variability, this system has a low likelihood of postfire state change. In contrast, an SES located to the right on the *x*-axis in figure 1 would have a high likelihood of state change. One such system might be a dry forest that, because of human exclusion of fire, has developed a dense understory and ladder fuels. In this situation, a high-severity wildfire is likely and, because the component tree species lack adaptive traits to cope with high-severity wildfires, there is a high likelihood of postfire change to a nonforested state (e.g., Guiterman et al. 2018).

Value-explicit dimensions. The vertical (*y*) axis represents the components of resilience related to human evaluations of conditions within an SES. Subjective perceptions, which span a continuum of desirability, reflect whether the current system state supports or undermines specific human values, goals, or preferences (Rittel and Webber 1973, Costanza et al. 1997). Therefore, although the *x*-axis—or the likelihood of a state change—is a function of system processes, desirability on the *y*-axis is a function of human values and whether they align more with current conditions or an alternative state (Stedman 2016). As human values are highly diverse, desirability should be understood through conversations with relevant stakeholders (Balint et al. 2011, Gregory et al. 2012). In the context of fire management, stakeholders may hold different values or prioritize values differently. For example, some stakeholders may prioritize postfire salvage logging, whereas others may place more value in opportunities for recreation or conservation of biodiversity.

In some instances, potential state changes may be deemed undesirable, placing an SES low on the *y*-axis. For example, persistent failure of vegetation regeneration after wildfire may cause undesirable impacts to water quality, recreational opportunities, aesthetics, or economic opportunity. In other situations, people may welcome state changes, placing the system high on the *y*-axis of figure 1. For example, where trees have encroached into rangelands, wildfires could reverse this trend, changing the system to a more desirable state (Smit et al. 2016).

Integrating perspectives. Taken together, the location of a system along the two axes of figure 1 helps separate the likelihood of change in system conditions from the subjective evaluation of whether the potential changes are desirable. The four archetypes (quadrants) characterize how well social preferences align with system realities. These archetypes can be thought of as scenarios, each associated with distinct, generalized strategies for management. Importantly, system resilience is aligned with social acceptability of state change in only two of the four scenarios (figure 1a, 1c), and therefore, *a goal to increase or maintain resilience of current system states is socially acceptable in only half of the scenarios.*

Archetypes of social–ecological resilience in fire-prone systems

Below, we briefly describe the four archetypes, or SES scenarios, that emerge from figure 1, and subsequent management implications. Although these scenarios reference an entire SES, the same two dimensions exist for specific components within a single SES (figure 2).

Low probability of change–low acceptability of change (figure 1b). In this scenario, the acceptability of change is low (implying that the current state is desirable) and the likelihood of change is also low. Most management programs are designed to promote or protect these desirable SESs, which effectively provide services valued by people and are unlikely to change state after a wildfire. Examples include fire-maintained savannas, open woodlands, and prairies, where humans use frequent prescribed fires to maintain the system state (e.g., by preventing tree encroachment; Briggs et al. 2005). Managers in this scenario should avoid the trap of complacency because exogenous forces (e.g., climate change) could increase the likelihood of state change, thereby moving the system to quadrant (d) (figure 1).

High probability of change–low acceptability of change (figure 1d). This scenario arises when desirable conditions exist, but the likelihood of postfire state change is high. An example is in low-elevation dry forests of the western United States, where for personal or economic reasons individuals choose to live in forested landscapes (e.g., the wildland–urban interface), often because they value privacy, affordability, or aesthetics. The current state is, on the whole, desirable. However, land use and land management practices since the early twentieth century have led to increased fuels and fire hazard (Peterson et al. 2005), and climate conditions are increasingly conducive to extreme fire behavior and also limiting to postfire tree regeneration (Guiterman et al. 2018). When a fire does occur, it can burn with high intensity and severity, differing from the fire behavior and effects experienced under the historical range of variability (Keane et al. 2009). These conditions, a product of social and ecological dynamics, make it more difficult for people to protect valued infrastructure such as homes, and decrease the likelihood of postfire tree regeneration (e.g., Stevens-Rumann et al. 2018). In this scenario managers and landowners must

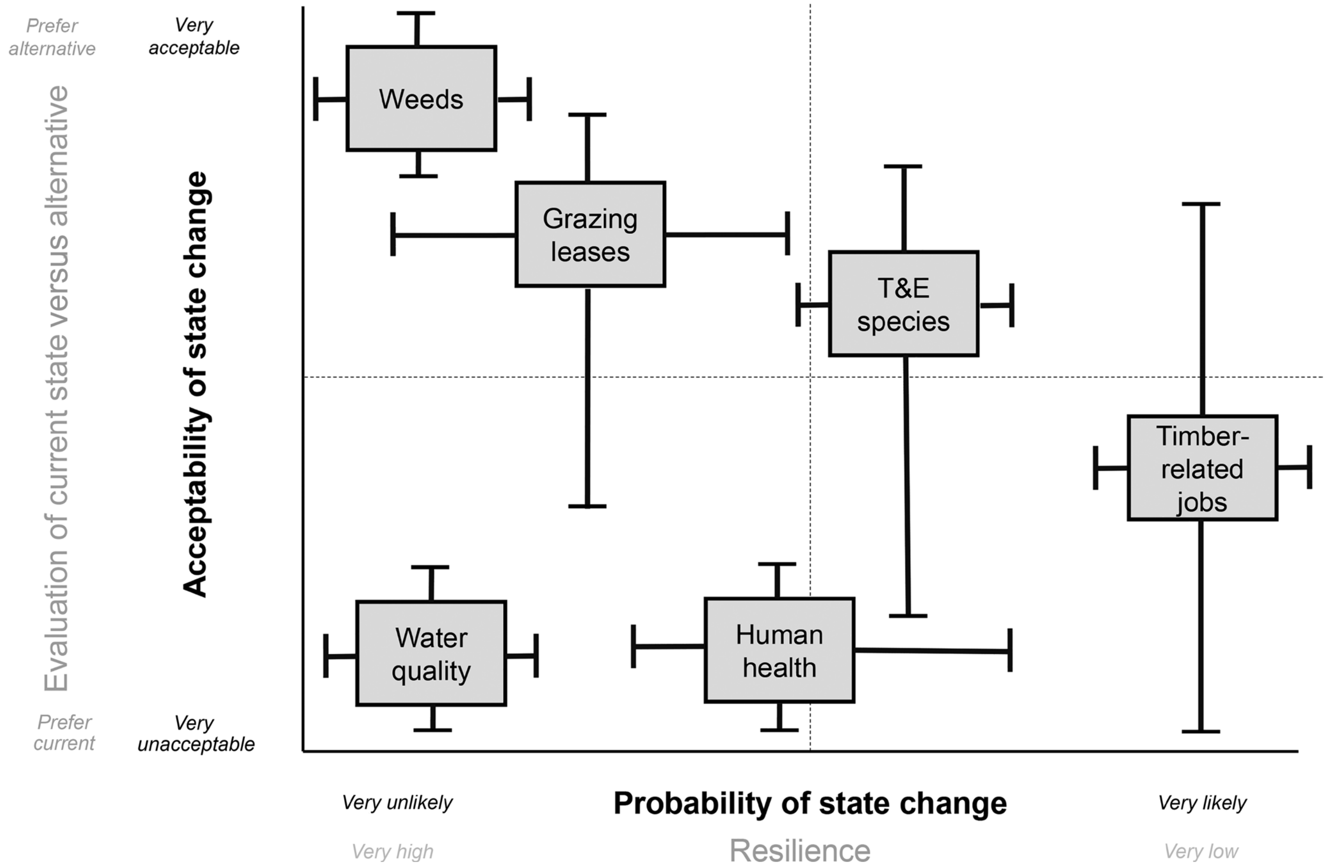

Figure 2. Probability of state change (x) as a function of acceptability of state change (y) for components in a hypothetical social–ecological system. The horizontal error bars represent the hypothetical lack of precision in estimating the probability of a state change, whereas the vertical error bars correspond to the hypothetical diversity of subjective evaluations among stakeholders, with narrower bars reflecting higher levels of consensus. For example, stakeholder agreement may be higher for components affecting water quality than for those affecting timber-related jobs. The specific components evaluated would vary among different SESs. Abbreviation: T&E, threatened and endangered species.

reconcile unstable conditions, in both social and ecological elements, with the social desire for stability: Exhibiting resilience comes at high costs. For example, preventative actions, such as reducing surface fuels and crown bulk density through silvicultural treatments and prescribed fire (Agee and Skinner 2005) to reduce the likelihood of postfire state change, would require ongoing investments by people and social institutions. Rebuilding homes or infrastructure after wildfire losses would likewise require significant economic input and social commitment. Across social, ecological, and social–ecological dimensions, individuals, managers, and stakeholders in this scenario should be prepared to accept high mitigation costs to avoid transformation to an unacceptable state.

High probability of change–high acceptability of change (figure 1c). This scenario is currently the least common among the four, because it requires human communities that are willing to adapt or transform the SES. This scenario may also only be relevant over short time windows, just prior to a period of significant change. Highly unusual or novel fire events, such as those during the 2017 and 2018 fire seasons in California and western Canada that included record-setting fire size, structure loss, human impacts, and loss of lives, may catalyze such transformative changes in some SESs. Under climate change and human development patterns, the likelihood of change in similar settings is high. If individuals and communities acknowledge this likelihood, then they may increasingly desire large-scale changes in both human development patterns and infrastructure, along with vegetation conditions in and near the wildland–urban interface. This scenario would arise if and when human communities become unwilling to accept the short-term social and economic costs of fire, despite mitigation efforts, and instead prefer transforming to another state, with the expectation that long-term social costs will decrease (e.g., transforming from figure 1c to figure 1b). In such scenarios, managers and policymakers may harness windows of opportunity for change and focus on creating desired aspects of the SES throughout the transition (Chaffin et al. 2016). Generally, managers and stakeholders in these systems should prepare for uncertainty and change.

Low probability of change–high acceptability of change (figure 1a). In this scenario change is desired, but a stable system makes it unlikely to change. This is challenging from a management perspective, because managers must disrupt a stable state and replace it with a more desirable state. Cheatgrass invasion and the resulting grass-fire cycle in Great Basin of the western United States (Balch et al. 2013) is an example, where the postinvasion ecosystem is highly resilient to wildfires, but this state is unacceptable to many people. To induce change that is desirable, management might trigger compound disturbances to reduce resilience in some settings (Paine et al. 1998, Suding and Hobbs 2009, Larson et al. 2013); immediate postdisturbance action may also be required, such as aggressive planting (Buma and Wessman 2013). Alternatively, in some cases social perception of the system can change (moving down on the y-axis), potentially increasing the recognized value of the current, stable system state. In either case, managers and stakeholders facing this scenario and desiring change to an alternative state should consider transformation, ecological or social, but likely with a high cost and uncertainty (Chaffin et al. 2016).

Applying the value-free–value-explicit framework

Managers, policymakers, and scientists can employ this framework to understand systems in their entirety, or specific elements of the system independently. Management goals will differ substantially across the value-free–value-explicit space, and maintaining resilience will be socially acceptable in only two out of four quadrants. Although entire systems may fall into a single quadrant, elements within a system may occupy different quadrants, therefore requiring divergent management approaches and revealing specific opportunities and challenges. For example, in figure 2, social and ecological system components may be more or less likely to change after a disturbance (x-axis), and change may be more or less acceptable to different stakeholders (y-axis). Empirical assessments, by social or ecological scientists, would determine the placement of system elements on the x-axis, with a mean and variance indicated by its horizontal central location and horizontal bars (e.g., Keane et al. 2018). The location of system elements on the y-axis would be derived from subjective evaluations by stakeholders. These evaluations should be established using inclusive engagement procedures that allow for collaborative scrutiny of the social and ecological system elements (e.g., deliberative dialogue among managers, scientists, and stakeholders). This value-explicit metric also has a mean and variance, reflecting the average assessment by stakeholders and the level of agreement among them, indicated by the element's vertical central location and vertical bars. Placing systems or system elements in the value-free–value-explicit space alerts managers and stakeholders to opportunities (e.g., undesired system elements that are vulnerable to disturbance), challenges (e.g., valued system elements that are vulnerable to disturbance, or undesired system elements that are likely to persist), and areas in which monitoring may be more important than management (e.g., long-term measurements of valued system elements). In addition, large horizontal bars highlight areas in which more research is needed or in which uncertainty is high, when systems are highly stochastic, or variable over space or time. Managers may be able to more accurately and confidently gauge stakeholder support when system elements have narrow ranges of variability, such as the elements in figure 2 with smaller vertical and horizontal bars. Finally, this framework can facilitate communication among and between stakeholders and land managers about planning scenarios and tradeoffs.

Social–ecological dynamics over time

Our examples and discussion thus far have largely focused on the likelihood of wholesale state changes after wildfire. However, even when systems exhibit resilience to wildfire, the rate and trajectory of return to prefire conditions vary considerably, as a function of factors including the historical fire regime, fire-adaptive traits of constituent species, characteristics of human communities, and degrees of human intervention. For example, recovery may only require several years after a low-intensity surface fire in a ponderosa pine stand, because species traits of the dominant trees minimize fire-caused mortality (figure 3a); likewise, after cheatgrass invasion, an invaded system can quickly return to prefire condition (figure 3b). In contrast, postfire recovery after a crown fire in a subalpine forest will require decades, because of the high mortality rates of thin-barked trees and slow growth rates of regenerating vegetation (figure 3c). In all three examples, the ecological components of the SES are considered resilient to wildfire, but over different time scales. Perhaps because of these scale differences, the social acceptability of conditions while the system recovers may vary (i.e., y-axis in figure 3). These examples differ from other scenarios in which a single high-severity fire, or multiple fires in short succession, may catalyze state changes (Johnstone et al. 2016). For example, the Las Conchas Fire in New Mexico resulted in large patches of (near) 100% tree mortality, uncharacteristic for these dry mixed-conifer forests (figure 3d). Without a nearby seed source and under harsh postfire climate conditions, resilience to this fire is in question; recovery will either happen very slowly, or the fire truly catalyzed a state change and the prefire state will never return.

People in systems that are on a slow trajectory toward postfire recovery may not be able to discern whether current conditions are in an intermediate step on the path to recovery or, instead, indicative of a new state. More salient to managers and stakeholders alike is whether conditions will be desirable within the time frame of planning processes. Therefore, potential mismatches in temporal (or spatial) scales of resilience between the ecological and social realms may be an inherent feature of many SESs; clearly articulating

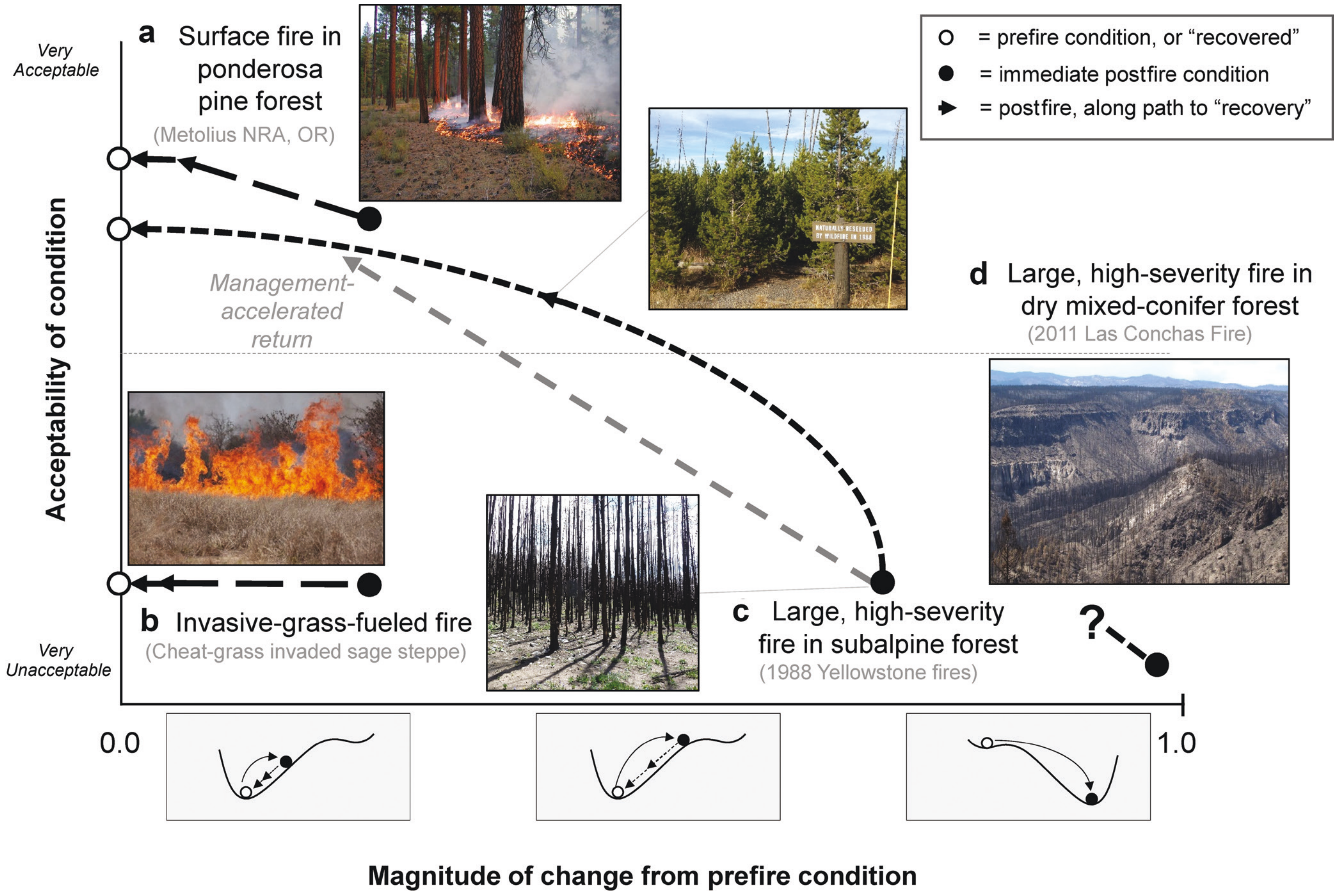

Figure 3. Examples of changing system conditions and social acceptability over time, after a fire occurs. Three general scenarios are considered, illustrated by the ball-and-cup diagrams in the grey boxes below the x-axis, each with one or more example(s) (i.e., photograph insets above each scenario). All examples inherently start at 0 on the x-axis; the thin grey dashed line half way along the y-axis represents neutral acceptability (as in figures 1 and 2). An end point of 0 on the x-axis indicates a return to the prefire state (i.e., recovery), whereas a value of 1.0 indicates a state change; each dash in the thick dashed lines represents approximately uniform time increments, indicating faster (e.g., a, b) or slower (e.g., c) rates of change. (a) Relatively rapid recovery after a low-severity surface fire in a ponderosa pine forest (photograph: Metolius NRA, USFS) and after (b) an invasive-grass-fueled fire in sage steppe (photograph: USDA/NRCS); in both cases, there is little fire-caused change in the system or in social acceptability of the condition. (c) Slow postfire recovery after a high-severity, stand-replacing fire in subalpine forest, illustrated immediately after fire, and along the trajectory to recovery (photographs: Brian J. Harvey). As the system recovers, social acceptability of the system state increases; the thick, grey dashed line illustrates the potential for managers to accelerate postfire recovery and social acceptability. (d) Potential conversion from forest to nonforest state after a large, high-severity fire in dry mixed-conifer forest (Photograph: USGS/Craig D. Allen). The question mark indicates an uncertain trajectory and potential for a state change.

mismatches (e.g., via figure 3) is a step toward resolving seemingly intractable differences.

Managers, stakeholders, and policymakers can also work to induce or accelerate changes in a system. For example, in the aftermath of the 1988 fires in Yellowstone National Park, public perception shifted from thinking of high-severity fire as destructive and undesirable, to seeing high-severity fire as ecologically characteristic and necessary for that system; this shift was in part because of communities accessing research findings that emerged from extensive study of fire history and post-1988 ecosystem dynamics in Yellowstone (Romme et al. 2011). More broadly, policies, incentives, or social movements may allow stakeholders or managers to see value in new, postfire conditions, or to find novel ways to reach long-held goals while on a path to recovery. In such scenarios, an SES moves up on the *y*-axis of figure 3, independent of changes in the ecological conditions.

When postfire conditions remain unacceptable to communities and stakeholders for long periods of time, decisions are more complex. Managers may work to accelerate a return to prefire conditions. For example, silvicultural treatments could accelerate ecological succession or facilitate more desired conditions, and postfire management could accelerate revegetation through planting or tree thinning. In both cases, a system would potentially move left on the *x*-axis and up on the *y*-axis of figure 3.

Remaining challenges and future opportunities

Many challenges remain for applying resilience theories in real-world scenarios. Although progress has been made in assessing the resilience of ecological attributes to wildfires (e.g., Lehmann et al. 2014, Smit et al. 2016), understanding ecological responses to disturbance alone is not enough: SES resilience is a function of ecological *and* human dynamics. As SES science is still developing, there is much to learn about how human and natural systems are coupled and respond to disturbances (Carpenter et al. 2012, Moritz et al. 2014, Mockrin et al. 2015, Wigtil et al. 2016, Chang et al. 2018). Furthermore, understanding the resilience of SESs inherently involves dynamics over multiple scales; although we briefly touch on this issue (figure 3), significant challenges arise when considering varying spatial or temporal scales. For example, because focal scales (in space or time) do not operate independently, but are instead nested and interact (Gunderson 2001), an evaluation of SES resilience at one scale, as is depicted in figure 1, may be quite different when viewed at a different scale. More challenging, the relevant ecological and social scales of resilience may not align; for instance, systems may be ecologically resilient over long time frames or large spatial scales, but postfire conditions may not be socially desirable in the short term or at smaller, locally relevant spatial scales (figure 3). In addition, human perceptions change through time and acceptability of state change is subject to feedback loops and other social changes that could shift the degree of acceptability. More study of the dynamics and interactions between social and ecological components of resilience is needed, particularly across varying spatial and temporal scales (e.g., Cumming et al. 2015).

Precisely because of its ambiguity, multiple dimensions, and variation in application, resilience can be seen as a boundary concept (Brand and Jax 2007), which allows multiple groups to coalesce around broad goals in SES governance while maintaining divergent objectives and interpretations. Identifying and distinguishing between value-free and value-explicit dimensions of resilience can improve our understanding of SESs, and clarify when divergent management and policy directions are needed. Our conceptual framework and graphical model (figure 1) provide a useful starting point for discussions of SES dynamics among interdisciplinary researchers, as well as citizens and communities in fire-prone landscapes. This framework should also be applicable and relevant to other natural disturbances and natural hazards – for example, bark-beetle-driven tree mortality (e.g., Morris et al. 2018) and flooding (e.g., Adger et al. 2005). Although we have demonstrated how this framework could be applied to hypothetical systems, future work should explore the governance processes that are used for translating these concepts into practice, and use quantitative data to populate the framework along both dimensions of resilience to reveal implications for policymakers and land managers.

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