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Improving wildfire management outcomes: shifting the paradigm of wildfire from simple to complex risk

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Numerous wildfire management agencies and institutions rely primarily on simple risk approaches to wildfire that focus on technical risk assessments that do not reflect the complexity of contemporary wildfire risk. This review paper argues that such insufficiently complex conceptualizations of risk, which do not account for the social and ecological diversity of fire-prone areas, are key contributors to the continued wildfire dilemma. We discuss distinctions between approaching wildfire as a simple and a complex risk and illuminate the need for expanded and complimentary ways to further fire adaptation. We then share five principles to guide approaching wildfire as a complex risk to increase adaptation to and coexistence with wildfire. Such efforts are more likely to yield socially relevant and legitimate strategies for building wildfire adapted communities by recognizing and accounting for the complexities of wildfire governance amongst a variety of stakeholders who may operate at various scales using different knowledge systems.

Keywords: wildfire; wildfire risk; governance; complexity

1. Introduction

Fire is integral to both social and ecological systems worldwide. Many forest, shrubland, and grassland ecosystems are reliant upon fire, and humans inhabiting these environments have co-evolved with fire over millennia (Stewart 1963; Pyne 1996). Attempting to manage wildfire and its associated risks is, therefore, nothing new. In pre-colonial North America, Indigenous people used fire as a management tool to shape the landscape for a variety of purposes, including the establishment of transportation routes, promotion of favored plant species, and assistance in hunting (Kimmerer and Lake 2001; Carroll *et al.* 2010; Huffman 2013). In recent years, the growing challenges associated with many aspects of wildfire, including their impacts on human values (i.e. risk) in the United States (US) and many other fire-prone countries (e.g. Australia, Canada, Spain, Portugal, Greece), have highlighted the need to consider alternative management approaches (International Union of Forest Research

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Organizations 2018). However, many scholars have noted that wildfire management remains trapped in outmoded paradigms that perpetuate current dilemmas (e.g. fire suppression leading to increased fuel loads) and impede progress toward more adaptive coexistence with fire (Cheng, Steelman, and Moseley 2011; Calkin, Thompson, and Finney 2015; North *et al*. 2015; Stephens *et al*. 2016; Thompson *et al*. 2018; Schultz, Thompson, and McCaffrey 2019).

We propose that one reason for this inertia is the prevailing tendency to conceptualize—and therefore manage—wildfire as a simple rather than a complex risk. In recent years, scholars have begun to distinguish between simple and complex risk framings and identify how each may require different approaches or imply different outcomes (van Asselt and Renn 2011; Karlsson, Gilek, and Udovyk 2011; O'Neill and Handmer 2012; Renn *et al*. 2020). Predominant approaches to risk, including wildfire, often tend to adopt a relatively simple risk assessment approach that focuses on technical questions of probability of event occurrence. Such approaches often give limited consideration to details associated with specific contexts, including diverse drivers, impacts, or distributions of power and authority that will support the holistic action needed to address potential risks. Scholars suggest that focusing on a relatively simple risk conceptualization tends to narrow the range of options for addressing risk and fails to incorporate and account for the diversity of human actors affected by fire, including the varied experiences and concerns that influence collective adaptation. With regard to complex risk, Beck (2009b) argues that many risks can be most effectively addressed by considering: 1) who defines risk; 2) how risk is defined; 3) whether the risk should be addressed; 4) who should address it; and 5) the best processes and approaches to address it. Overt attention to these five risk considerations is argued to provide a more nuanced understanding of the varying perspectives and values affected by a particular risk and, in so doing, allows consideration of a wider range of possible actions to address it that may be more socially legitimate and relevant to those carrying out wildfire mitigation and adaptation activities.

Although wildfire management in the US has many characteristics of both simple and complex risk conceptualizations (see Section 3.0), a simple risk framing remains the predominant approach. However, such top-down, expert-focused approaches that might work if wildfire risk were, in fact, a simple risk do not align with the complexities of the contemporary wildfire context. They do not account for the diverse ways in which the issue of wildfire and wildfire risk management manifest and evolve in different fire-prone social-ecological systems, and therefore rarely lead to the site-specific strategies most likely to effectively address the specific risk (Paveglio and Edgeley 2020). We argue that more deliberate consideration of wildfire as a complex risk in fire management could lead to improved outcomes by better accounting for the context of individual places, including the diverse views held by individuals, and by supporting adaptation to, and restoration of, fire as a valuable landscape process that is connected to the actions of those implementing wildfire mitigation strategies. The suggestion here is not to discard simple risk approaches, but to consider them as part of a larger approach of treating wildfire as a complex risk—as one set of approaches that must coordinate with many others. Aspects of simple risk remain an important consideration, but only in specific contexts. The following review begins with a discussion of the distinctions between simple and complex risk, followed by an analysis of the respective applications for wildfire policies, practices, and research. We conclude by outlining

suggestions for how to better treat wildfire as a complex risk to build resilience to wildfire and promote constructive coexistence with fire.

2. Background: Simple and complex risk

The following sections summarize both simple and complex risk conceptualizations, including their respective origins, assumptions, problem framings, and other key characteristics.

2.1. Overview of simple risk

The primary goal of simple risk approaches is to minimize the costs associated with hazards and their management. Simple risk approaches have their roots in actuarial insurance, risk management, and rational choice models. First developed to protect mariners from pirates looting financially valuable cargo, current notions of actuarial insurance are combined with contemporary notions of risk management and focus on calculating the likelihood of financial loss using an engineering-based systems framework (Rasmussen 1997). These simple risk approaches are informed by rational choice economic assumptions that entities (e.g. individuals, agencies) tend to 1) make rational decisions to optimize economic return, and 2) actively seek all available information (i.e. perfect information) within the market of choices available to them to make the "optimal choice" (Holdsworth 1917; Edler de Roover 1945; Brillinger 2003). Rational choice thinking also underpins the view that risk management is a *cooperation* problem (Berardo and Scholz 2010; McAllister, Taylor, and Harman 2015; Bodin *et al*. 2019), where decisions and actions of *individual* actors (e.g. an individual, a household, an agency) are seen to occur largely independently of one another. From this perspective, the main question is how individual actors minimize their own losses.

Simple risk approaches generally assume that the underlying cause and effects of a risk are clearly understood, agreed upon, and subject to optimal solutions designed by technical experts. This belief favors either (1) technocratic governance models that apply technical and scientific knowledge directly to decisions without stakeholder or end-user input, or (2) decisionistic governance models that also begin with purely technical and scientific assessments but are then supplemented with social and/or stakeholder input before informing decisions (Millstone *et al*. 2004; Renn 2008; Renn, Klinke, and van Asselt 2011; Brown and Osborne 2013). The role of experts in both models is to define, evaluate, and identify solutions to risks and then deliver associated results to decision-makers and others to build top-down mechanisms to institutionalize means of controllability, certainty, and security (Renn, Klinke, and van Asselt 2011). This view reflects an emphasis on eliminating complexity in the pursuit of universal solutions that can be administered from a central authority (Scott 1998), reflecting a notion of an apparently value-free science that provides singular "answers" that rational individuals are expected to "adopt" (Cash, Borck, and Patt 2006; Fernández 2016). When it comes to building solutions and making decisions to address wildfire risk, both of these governance models underscore the "guardianship model" (Goldstein 2008) where government maintains authority and legitimacy, for instance, to protect homes during a wildfire incident, but steers clear of directly addressing issues of private property rights. This model has been critiqued as representing an undemocratic "monopoly of interpretation" (Beck 1992, 192) in defining risk and effecting risk policy decisions, as it includes the power and authority to make judgements about the

Table 1. Key characteristics of simple and complex risk.

	Simple risk	Complex risk
Goal	Minimize risk	Adapt to risk
Origins	Actuarial insurance, risk management	Wicked problems, risk governance, second modernity risk
Model	Rational choice	Collective action
Problem framing	Individual entities (cooperation problem)	Interdependent entities (coordination problem)
Information flow	Unidirectional knowledge transfer	Multidirectional social learning
Decision-making model	Decisionistic, technocratic guardianship model	Inclusive governance
Knowledge valued/prioritized	Technocratic monopoly of interpretation	Knowledge pluralism
Generalizability	Acontextual/universal	Contextual

relative importance of addressing risk and determining viable solutions and the resources available for minimizing related losses (Beck 1992; Renn 2008; see Table 1).

2.2. *Overview of complex risk*

Concepts of complex risk stem from scholarship on wicked problems, risk governance, and Second Modernity Risk (described below) (Rittel and Webber 1973; Beck and Lau 2005; Renn 2008; van Asselt and Renn 2011). The complex risk framework accounts for and expands on simple risk ideas and approaches by explicitly considering the multiplicity of contexts, knowledges, and definitions regarding a particular hazard. The primary goal of complex risk approaches is not to minimize or eliminate immediate risk (as in simple risk approaches), but to adapt to the risk over time (Folke *et al*. 2005; van Asselt and Renn 2011). This approach is informed in part by a wealth of natural hazards research demonstrating that attempts to eliminate a hazard are rarely successful but instead lead to larger-scale, often more catastrophic, disturbances; wildfire suppression is a good example of this phenomenon (Arno and Brown 1991; McCaffrey *et al*. 2020). In this context, effectively adapting to a complex risk will involve a broad array of efforts that rely not only on technical inputs but also on individual and institutional changes through social learning and institutional adaptation. Using a diverse set of approaches to adaptation more readily accounts for the regularly changing circumstances of risk related to social (e.g. policies, agencies) and ecological conditions.

Rittel and Webber (1973) argued that societal problems addressed by planners are qualitatively different from the linear problems addressed by engineers, which could be adequately resolved with equations guided by principles of efficiency. In contrast, planners are often faced with addressing what are conceptualized as wicked problems: problems that are ill-defined, influenced by subjective political pressures or decisions, and that require iterative evaluation (Head 2008; Head and Alford 2015; Innes and Booher 2016). Working within these complex arenas requires addressing situations

rich with uncertainty, ambiguity, and interactive effects. This contrasts with the clearly understood and agreed upon definitions, and technically optimized solutions associated with simple risk. Key questions in complex risk focus on how risk is defined, how decisions about risk are made, who makes them, and who is affected by them (Renn 2008; van Asselt and Renn 2011). It specifically seeks to address inclusivity, differential distribution of risk, equity, justice, multidirectional social and organizational learning, and the need for collective action and innovation (van Asslet and Renn, Klinke, and van Asselt 2011; Klinke and Renn 2012). Thus, rather than minimizing costs, the goal of complex risk management is not only to adapt to the risk over time, but also to make risk governable and to make approaches to addressing risk socially legitimate (Lidskog, Uggla, and Soneryd 2011).

Augmenting discussions about wicked problems and complex risk, especially in a hazard context, is Beck's (2009a) notion of Second Modernity Risk. Beck and Lau (2005) recognize that contemporary society is characterized by a blurring of the lines that traditionally distinguished categories such as public/private and nature/society. Complex risk builds upon these ideas by emphasizing that single actors, such as government agencies or individuals acting alone or at a single scale, are often unable to sufficiently address contemporary risks. Instead, responsibility and authority for how society anticipates and prepares for different catastrophes are increasingly ambiguous and seen as a *coordination* problem, where desirable outcomes are based on decisions and actions of a suite of *interdependent* public and private entities. In this context, decisions must be socially negotiated among governing networks where power and authority are distributed across these individual and institutional actors.

In sum, complex risk shifts away from the simple risk focus on controllability, predictability, certainty, and security – hallmarks of risk management using actuarial approaches. While the complex risk framework can include these notions, it broadens the focus to underscore the emergent nature of systems (i.e. the regularly changing and hard to predict circumstances of risk related to social and ecological conditions) and adopts inclusive approaches to crafting problem definitions and the solutions that flow from these definitions (van Asslet and Renn, Klinke, and van Asselt 2011). Such processes are designed to allow decision making that values knowledge pluralism among actors, each of whom may contribute different knowledge whether technical, experiential, cultural, or some mix (i.e. hybrid knowledge). The fact that definitions and management of risk are not separable from social, political, and historic context, also highlights why there are few successful, universal strategies or solutions to addressing risk (Renn 2008).

Adopting a complex risk perspective also presents substantial challenges that are important to recognize. Committing to inclusive risk governance may take more time than top-down approaches and may therefore be more costly in the short term. This may be a noteworthy barrier in an era of limited budgets. There is also a danger of fragmenting the process among too many actors or the process becoming dominated by select interests (Steelman 2016; Bixler *et al*. 2016). Furthermore, decentering traditional government actors from the task of risk definition may complicate traditional modes of democratic accountability (Renn, Klinke, and van Asselt 2011; for a more detailed discussion of accountability, see Christensen and Butler 2019).

3. Wildfire: Simple and complex risk

The following discussion considers several aspects of how existing policy, practice, and research surrounding wildfire currently fit within simple and complex risk

conceptualizations and their potential implications. While most of the examples below are taken from the US, we believe the insights can be applied to many fire management contexts around the globe.

3.1. *Wildfire as a simple risk*

Much of the current approach to wildland fire management reflects a simple risk paradigm focused on identifying hazards and calculating fire risk and deploying resources to efficiently protect values at risk that have been determined by a select group of technical experts. In the US, although federal resource managers recognize the need to fundamentally shift wildfire management strategies and have some flexibility with regards to fire tactics, full suppression remains the default response. Likewise, larger fires are generally managed under centralized emergency response protocols (Cheng, Steelman, and Moseley 2011; Calkin, Thompson, and Finney 2015; North *et al*. 2015; Stephens *et al*. 2016; Thompson *et al*. 2018; Schultz, Thompson, and McCaffrey 2019). For example, although the USFS has a stated goal to use a flexible approach to managing wildfire incidents (including using naturally ignited fires for resource benefits) (Hoover and Bracmort 2015; Thompson *et al*. 2018), the agency reported that the size of its budget associated with activities to increase resilience has decreased rather than increased due to the costs of fighting wildfires (USDA 2015). Similarly, while the content of the National Cohesive Wildland Fire Management Strategy (CS) incorporates some aspects of a complex risk framing, particularly its emphasis on initiating discussions across stakeholders, implementation often continues to follow a simple risk approach. For instance, the National Science Analysis (NSA), developed to inform the CS, primarily used technocratic, quantitative scientific approaches to define risk and make judgements about the relative importance of addressing risk and possible solutions to minimize losses. This approach—where technical experts define, evaluate, and identify solutions to risks and then deliver results to decision makers and other stakeholders—is a clear example of a simple risk approach. Hallmarks of a simple risk approach are also evident in institutional incentive structures and performance metrics used to analyze the "success" of wildfire response by focusing on short-term outcomes such as minimizing immediate risk associated with acres burned or home losses via successful suppression rather than possible long-term benefits of fire reintroduction such as increased ecological health (Donovan and Brown 2005; Schultz, Thompson, and McCaffrey 2019).

Research influencing wildfire risk management also often defaults to a simple risk approach, defining risk explicitly in terms of the relationship between specific quantifiable variables associated with probability and consequences (e.g. benefits and losses) to values at risk based on expected net value change (Thompson *et al*. 2016). Some definitions focus on wildfire risk as including a stable and predictable relationship between wildfire probability and effects (Finney 2005) or burn probabilities and number of structures (Massada *et al*. 2009). Wildfire is sometimes depicted as a "risk triangle" where each segment of the triangle represents a calculable variable. Most specify these variables as wildfire likelihood, intensity, and effects (Ager, Finney, and McMahan 2006; Calkin *et al*. 2010; Thompson *et al*. 2011; Miller and Ager 2013), while others focus on wildfire likelihood, intensity, and susceptibility (Scott, Matthew, and Thompson 2013). Although there are some exceptions (see, e.g. Bonazountas *et al*. 2005), a consistent thread throughout these definitions is the use of an actuarial approach to addressing risk – computational probability models of benefits and losses.

Overall, these papers communicate the need to identify and adopt a single common definition or framework for wildfire risk to be applied to all subsequent wildfire research and management that will directly inform policy and practice (Bachmann and Allgöwer 2001; Finney 2005; Hardy 2005; O'Laughlin 2005; Thompson *et al*. 2011; Thompson *et al*. 2016). While such models are an important tool for informing *specific* management choices, they are often calculated at large and expansive scales or extents (e.g. Western US, entire US). Accordingly, they may miss meaningful differences in local social context and are not often re-calculated when applied to functional or actionable planning units outside the initial management scale they were designed for. They also tend to constrain discussion around the variables that are included in the model and limit consideration of alternative risk definitions, priorities, or preferences that may be held by different stakeholders (e.g. residents, recreationists, environmental groups, local officials, politicians).

Technical approaches to wildfire as a simple risk are also reflected in several contemporary wildfire policy initiatives. For instance, the US national risk map (Scott *et al*. 2020) mandated by the 2018 Omnibus spending bill (H.R. 1625, Section 210) required completion of a nationwide wildfire severity map that can 1) inform communities about the probability of wildfire occurring within or near their borders and the magnitude of impact such an occurrence may have on values at risk (primarily homes), 2) aid in prioritizing wildfire fuel treatments, and 3) inform wildfire suppression operations. One apparent assumption underpinning the resourcing and completion of this map is that the expert calculation and dissemination of standardized risk metrics based on probabilities and quantitative optimizations is the primary information communities need to decide to mitigate fire risk around homes. Such a one-way flow or dissemination of scientific outputs aligns with the information deficit model (Cash, Borck, and Patt 2006; Fernández 2016) most often associated with simple risk and is also an example of top-down definitions of both the problem (i.e. communities do not have the right information about their risk and that the only risk communities care about is homes) and the preferred way to address it (i.e. a quantitative spatial assessment of risk). The metrics considered by this model emphasize loss prevention (e.g. reduction in acres burned, suppression expenditures, reduced home losses) as a means of standardizing risk measurement nationwide. Although the resulting information may indeed be valuable to many stakeholders, the generalized spirit behind this approach does not take into account different notions of risk and associated priorities of distinct communities of place or practice. Ultimately, this monopoly of interpretation may fail to resonate with priorities and risk perceptions across the diversity of communities affected by fire.

Finally, the command-and-control structure and approach to responding to wildfires when they do occur also reflects a simple risk approach. The hierarchical, top-down nature of wildfire management in the US is perhaps nowhere more apparent than in the institutions that guide fire response. Both the Incident Command System (ICS) and the National Incident Management System (NIMS) are examples of command-and-control governance structures that feature judgments made by trained experts via a "chain of command" designed to increase efficiency. While such a centralized approach may indeed be appropriate and highly effective during immediate emergency responses when lives are at risk, it can break down in complex incidents (e.g. large scale or high severity—such as Hurricane Katrina) and scholars have suggested that in those conditions problem-solving, decentralized approaches can provide more effective disaster response as they are better able to quickly adapt to changing conditions and needs (Tierney 2009).

3.2. *Wildfire as a complex risk*

While elements of a simple risk approach to wildfire have persisted in the US, there has been increasing recognition that current wildfire management is a wicked problem (Carroll *et al*. 2007; Chapin *et al*. 2008) that may necessitate increased focus on a complex risk approach. Challenging wildfire seasons in the 1960s led to wildfire beginning to be treated as a complex risk as recognition grew of both the technological limits to strict fire suppression and the beneficial ecological role fire played in many ecosystems (Pyne 2015). Laws, such as the 1964 Wilderness Act which US agencies (largely) interpreted as barring suppression activities in federally designated Wilderness areas, and the Multiple-Use Sustained-Yield Act of 1960 which created a more diverse suite of values to consider than just timber (e.g. recreation, wildlife, range, and watersheds), created incentives for allowing fire on the landscape and for taking into greater account the needs and perspectives of diverse stakeholders in wildfire-related decisions and activities (Coggins 1981).

Several recent policies, practices, and initiatives also include approaches that align with complex risk frameworks. These policies demonstrate complex risk approaches in their efforts to enable more collaborative methods to addressing risk across federal and private lands. The Fire Adapted Communities Network (FAC Net), funded by federal agencies, is a network of local professionals, residents, and other stakeholders who share knowledge about ways to more effectively live with fire and adapt them to different circumstances. The Indigenous Peoples Burning Network (IPBN) is an inter-tribal organization that partners with federal and state institutions to re-establish cultural burning in indigenous communities by sharing traditional ecological knowledge and protecting indigenous rights (Robbins, McConnell, and Stauffer 2016). Both FAC Net and IPBN are examples of a governing model that accounts for shared power and responsibility for wildfire risk across actors and is informed by local contexts and diverse knowledges. Likewise, Rangeland Fire Protection Associations (RFPA), dynamic partnerships between local ranchers and land management agencies, provide an example of a specialized coordination mechanism and policy innovation that facilitates the ability to integrate the experiential knowledge, expertise, and resources of local actors into the ICS and NIMS systems—potentially leading to an increased use of local knowledge and greater overall adaptation (Abrams, Davis, and Wollstein 2017). Thus, RFPAs exemplify how a complex risk perspective can modify what was a linear, simple risk "solution" by building upon site-specific knowledges and resources (McCormick and Wuerzer 2016; Stasiewicz and Paveglio 2017). Finally, although each program has slightly different management goals and operating approaches, the Collaborative Forest Landscape Restoration Program, The Joint Chief's Landscape Restoration Partnership, and the Tribal Forest Protection Act all share a contextual, place-based approach (Lucero and Tamez 2017; Butler and Schultz 2019; Cyphers and Schultz 2019). In some cases, national forest managers have taken initial steps toward co-management of fire-prone landscapes with native communities incorporating traditional ecological knowledge (Long and Lake 2018). These efforts all provide evidence of policies and programs that use a networked and decentralized approach to defining priorities, identifying strategies, and implementing activities in line with the interests and ecologies specific to social-ecological landscapes.

While these last examples provide a sense of how wildfire risk in the US can be treated as a complex risk, other elements indicate that more work may be needed to advance a complex risk paradigm. First, the continued focus on immediate wildfire

suppression, including the size and importance of the wildfire suppression budget, reflects the more reactive model of simple risk that focuses on building a workforce, budgets, equipment, and perspectives that largely react to the potential of immediate wildfire losses, effectively perpetuating and justifying a simple risk approach in lieu of innovating complex risk approaches. Second, the focus on quantitative wildfire risk maps, especially those for large spatial extents, rely on a technocratic monopoly of interpretation that can impede democratic interaction and artificially limit the decision space to identify and innovate strategies that address wildfire risk that account for the social and ecological diversity of a specific fire-prone area. While technocratic approaches for mitigating risk are an essential part of addressing fire risk, investments in these approaches alone are unlikely to yield desired outcomes, such as decreased suppression costs or decreased losses, and may in effect serve to perpetuate the status quo and constrain opportunities for change (Goldstein and Butler 2011; Abrams *et al*. 2021).

We recognize that there are other explanations for the continued persistence of a simple risk framework for wildfire. For instance, scholars have identified how some large and established institutions (e.g. USFS, Bureau of Land Management), despite sometimes being imperfect, are "sticky" (Young 2010, 379) and remain unchanged for long periods. Despite this, these institutions can shift to other, more effective forms comparatively quickly once reaching a tipping point. Schultz *et al*. (2021), for example, contend that managing disturbance in the face of declining capacity is now the principal driver of US federal forest policy and governance innovations. We contend that paradigms informing wildfire management may be similarly sticky and raise the question of whether such a tipping point has been reached where the paradigm may be ripe for a shift (Calkin, Thompson, and Finney 2015; Cosens *et al.* 2021). We offer complex risk as such a paradigmatic shift to consider.

4. Diversifying to complex risk

Throughout much of the twentieth century, wildfire in the US was treated by federal and state entities as a detrimental process that needed to be met with a singular response: full suppression. Such an approach informed by simple risk precepts has over time clearly been shown to be an inadequate means of considering and accounting for the vast social and ecological diversity found in fire-prone areas, and the consequent diversity of social-ecological interactions with fire.

Although centralized, simple risk approaches are an often necessary part of addressing wildfire risk, greater emphasis on wildfire as a complex risk brings attention to the reality that decisions and outcomes at various temporal points, including mitigation, preparedness, response, and recovery, are linked to place-based networks, processes, activities, decisions, and outcomes of other temporal points. What follows are five principles to reflect lessons from the literature synthesized in this manuscript. These principles could help guide increased treatment of wildfire risk as a complex risk and begin to transform wildfire governance: 1) embrace knowledge plurality and purposefully integrate perspectives other than technical expertise; 2) use inclusive, accountable, and transparent engagement strategies that incorporate collaborative learning processes; 3) include underrepresented groups in wildfire risk governing networks; 4) account for potential uneven distributions of risk and resources to address risk; and 5) re-focus or re-balance investments across spatial, institutional, and temporal scales.

Although principles one and three are similar, given the complex risk emphasis on equity and justice, we believe it is important to give specific space and attention to including underrepresented groups. Together, the principles can help to structure strategic actions that advance shared, collective adaptation to wildfire risk that is inclusive of diverse individuals, institutions, and the specific contexts they help create.

1. A key step for addressing wildfire risk management as a complex risk is to *embrace knowledge plurality* and seek expertise beyond the technical. Including other types of expertise (and thus complexity) can increase the local relevance and legitimacy of the output which can be critical to local implementation. Questions about what and who defines risk for a locale also are often overlooked by assessments where local stakeholders' definition of risk and key values of concern are absent. In some rural areas, for instance, instead of being concerned with structures, residents may be more concerned about the loss of fencing, grass, or forests that are critical to their culture or livelihood, yet many risk management approaches focus solely on structure loss (Kent *et al.* 2003; Paveglio *et al.* 2015). To avoid giving primacy to any one form of knowledge and foster a shared understanding of wildfire risk, complex risk approaches take into account the range of different knowledges of public, tribal, and private affiliated actors, practitioners, researchers (social and ecological), and residents who may be differently affected by wildfire risk. Such conversations can bring valuable alternative insights to the conversation and help shape the technical and other methodological choices that lead to risk-related outputs. Processes where technical inputs are just one of many inputs in a larger, inductive process and incorporate place-based understandings through facilitated dialogue more readily align with complex risk and likely help develop risk management efforts tailored to a variety of local conditions (Paveglio *et al.* 2018; Charnley, Kelly, and Fischer 2020; McCaffrey *et al.* 2020). One action that could be taken guided by this principle would be to revisit the NSA portion of the CS, potentially as regionally- or state-specific components, in a way that meaningfully incorporates a range of different values and knowledges absent in prior analysis.
2. Effectively embracing knowledge plurality will require use of *inclusive, accountable, and transparent engagement strategies* that incorporate collaborative or social learning processes, where a suite of interrelated public and private actors participate in an iterative process to find a common understanding of a situation that yields pathways to desirable and feasible situational improvements (Daniels and Walker 1996; Suškevičs *et al.* 2018). Such discussions must address the distribution and allocation of power and authority, and also consider the values associated with different knowledges (Keen and Mahanty 2005). Scholarship on adaptive governance has shown the benefits of inclusive, accountable, and transparent engagement and collaborative learning processes for encouraging more adaptive wildfire planning (Almstedt and Reed 2013; Abrams *et al.* 2015). Rather than managing for the stable output of a narrow range of goods (an approach typically associated with the attempted suppression of all disturbances), adaptive governance takes into account the inherent dynamism and complexity of social-ecological systems and the need to promote social learning and flexible institutions as a means of learning to live with dynamic complexity (Dietz, Ostrom, and Stern 2003; Folke *et al.* 2005; Chaffin, Gosnell, and Cosens 2014). In some cases, new restoration and fire risk reduction policies have successfully engaged diverse

partners in ways that improve legitimacy and capacity (Schultz, Coelho, and Beam 2014; McIntyre and Schultz 2020); however, the persistence of institutions relying on top-down control can hamper these changes (Cheng, Steelman, and Moseley 2011; Wurtzebach *et al*. 2019). Research has shown that efforts focused on this type of shared planning, such as community wildfire protection plans, can help build trusting relationships and capacity that serve as critical foundations to more successfully govern wildfire risk (Brummel *et al*. 2010; Williams *et al*. 2012; Fairbrother *et al*. 2013) and facilitate adaptation.

3. A key part of ensuring that both the full range of values and power allocations are taken into account as part of a shift toward addressing wildfire as a complex risk is to *strategically invest in the inclusion of underrepresented stakeholders* in collaborative processes and networks. By forgoing assumptions that experts fully understand the experiences or abilities of underserved populations (e.g., Latine, Black, Indigenous and People of Color), more inclusive processes invite more diverse perspectives and, by so doing, can better reflect the differential adaptation abilities of populations and organizations. For instance, technically focused efforts do little to incorporate Indigenous knowledge and associated practices of cultural burning which are increasingly recognized as providing valuable insights on different ways to manage fire risk (Marks-Block and Tripp 2021). While an initial step here would be for existing networks to ensure "seats at the table" for underserved groups, networks must also share the power and authority to mitigate wildfire risk while building resilience and helping to build trust and mutual understanding. In addition, investing in understanding the ways that underserved groups both perceive and or are affected by wildfire, beyond structure loss, including impacts to employment or to social networks that might help facilitate adaptation and recovery, provides new avenues for incorporating such considerations in a broader portfolio of criteria used to obligate resources to mitigate wildfire risk.
4. Another important way to bring complex risk perspectives into wildfire management is to *account for potential uneven distributions of risk or risk management support* (e.g., fuels treatment funds; see e.g., Adams and Charnley 2020). For instance, the growing number of competitive approaches for funding natural resource and associated wildfire management efforts (Schultz, Jedd, and Beam 2012; Abrams 2019) can favor groups or entities with resources and capacities needed to obtain grants and/or whose resource levels and conceptions of wildfire risk match the predominant (e.g., simple risk) policy priorities of the time (Cheng and Dale 2020). That may leave the circumstances of groups or communities who have less access to resources and capacity unchanged or even diminished, furthering an already uneven distribution. Although more recent funding efforts may seek to support activities related to complex risk by promoting work managed by private or public sector institutions at different spatial, temporal, and institutional scales, care needs to be taken to ensure that what is funded is not limited to the simple and easy, or low hanging fruit. Consequently, assessing patterns among previously funded projects and developing more diverse sets of funding opportunities that can strategically boost adaptation capacities, not only for those with existing capacity but also for those with much less, would be more representative of a complex risk perspective. In addition, disaster relief funding mechanisms, (e.g., Federal Emergency Management Agency monies) can be designed to target recovery and mitigation efforts among underserved groups and areas.

5. Finally, shifting the treatment of wildfire risk to a complex risk calls for a *re-focusing and re-balancing of investments across spatial, institutional, and temporal scales*. Current wildfire investments are concentrated primarily on hazardous fuels reduction, preparedness (hiring and training firefighters) and response (incident management). Investments could be re-focused across temporal scales to provide more opportunities for building adaptation through the allocation of more resources to a wider range of mitigation work long before any fires occur and ensuring that those affected by a fire can recover quickly and in a more adaptive manner. This means investing in systems of wildfire governance, the social architecture that will support collective action and innovation in ways that are more likely to be responsive to the changing circumstances of on-the-ground fire risk. For instance, complex risk informed investments would further target inclusive governance processes, such as those made by learning networks, that support context-specific capacity building before and after a fire (see e.g., Edgeley and Paveglio 2017; Tedim *et al*. 2020) and support local individuals in professional positions who focus on coordinating the diverse suite of actors in each locale (McCaffrey 2006; Wyborn *et al*. 2020). This reinforces and builds on the call from Charnley *et al*. (2015) to redistribute wildfire suppression funds focused on reducing fuel loads to also focus on a dynamic social framework needed to carry out wildfire mitigation in legitimate and relevant ways.

The five specific principles outlined above could guide more effective adaptation to the wicked nature of the wildfire problem, support development of flexible wildfire management approaches, and improve the "fit" of place-specific actions that match both existing and evolving social-ecological contexts of fire-prone areas. Together, they account for the fact that the problem of wildfire risk is unlikely to be "solved," but instead will change over time, requiring adaptation approaches to be iteratively revised based on frequent, regular opportunities for multidirectional social learning across scales and in ways that equally value different knowledges. Actualizing those principles means building an approach to wildfire risk "that involves history as well as geography, that must meld culture with nature" (Pyne 2018, 99) to enable wildfire to play its inevitable and necessary cultural and ecological role while accounting for the diverse and important ways notions of fire risk and ways of addressing it manifests in contemporary society. An integral part of these collective principles is the need to consider how existing institutions, research paradigms, practices, funding structures, and relationships surrounding wildfire management can evolve and flex to facilitate better living with fire. In other words, instead of trying to reduce the complexity inherent in the system, a more realistic approach would be to account for it.

5. Conclusion

The calculated probability and severity of wildfire risk for any given area or value is important and an inherent part of a complex approach to risk. However, questions about how risk is conceptualized and what to do about that risk—including whether it should be addressed, who should address it, and the process or approaches to address it—are equally important and often not robustly considered by current management approaches. Past research, practice, and policies to address wildfire risk have primarily centered on building technical knowledge of wildfire risk and disseminating that knowledge to others. While this work has provided important insights, we argue that, in

contemporary society, complex risk is a better conceptual guide for addressing wildfire risk and provide suggestions for how complex risk practices can be applied more in the context of wildfire management.

Expanding the repertoire of approaches around wildfire management will necessitate a normative shift to be more inclusive, just, and dynamic. That is not to say current approaches are necessarily unjust, but it simply recognizes that an approach that treats wildfire as a complex risk explicitly accounts for such considerations in the foreground rather than assuming they will be tended to in the background. Ultimately, more inclusive activities and processes can help build an approach to wildfire risk more likely to improve future outcomes by explicitly recognizing the complexity of the problem, acknowledging the essential ecological and cultural role of fire, and responding to the diverse ways wildfire manifests in contemporary society.

Moving forward, more work could be done to understand how to most effectively focus on building the social architecture of a coordinated, collective network of interrelated actors where different knowledges are valued, and that supports adaptive and innovative decisions, activities, and outcomes that account for the social and ecological diversity of wildfire prone areas. Such work could help illuminate how existing fire management systems might more fully adopt a complex risk approach, including consideration of who will be "at the table" and what role (i.e. power) they will have as key wildfire decisions are made. A key challenge will be incorporating all of these things in ways that move away from monopolies of interpretation to more democratic ways of addressing risk and more readily account for the values and needs of indigenous, people of color, or other underserved groups. We do not suggest that we have articulated here all the answers or solutions to address these gaps or other important questions that will surface to make such a monumental shift. Instead, we hope to spur further dialogue that could contribute to strategic action to support such a shift over short- and long-time horizons.

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