SYSTEMS THINKING AND WILDLAND FIRE MANAGEMENT

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ABSTRACT

A changing climate, changing development and land use patterns, and increasing pressures on ecosystem services raise global concerns over growing losses associated with wildland fires. New management paradigms acknowledge that fire is inevitable and often uncontrollable, and focus on living with fire rather than attempting to eliminate it from the landscape. A notable example from the U.S. is the National Cohesive Wildland Fire Management Strategy, which aims to bring multiple agencies, landowners and stakeholders together to achieve three broadly defined goals: resilient landscapes, fire-adapted human communities, and safe and effective response to fire. Implicit in the structure of these three goals is the nexus of three systems: the ecological system, the social system, and the fire management system, respectively. This systems-based structure reflects a perspective that contextualizes fire as a disturbance process that influences and is in turn influenced by other agents and processes within a broader socio-ecological system. While the need for transformative system change is well-recognized, at least three central challenges remain: (1) the need for more parties to accept that how fires are managed is in many instances the limiting factor of system behaviour; (2) the need to improve our understanding of the characteristics and complexities of the fire management system itself; and (3) perhaps most fundamentally, the need to coherently apply systems analysis principles in order to improve system performance. In this paper we attempt to bridge these gaps by applying systems thinking to contemporary wildfire management issues in the U.S. We review in more detail what we mean when we say fire management system, describe observed system behaviours and patterns, and begin to unravel factors that may influence behaviour. We synthesize findings from various lines of fire-related research and identify how collectively they reflect systemic flaws stemming from feedbacks, delays, bounded rationality, misaligned incentives, and other factors. These flaws are manifest in what is known as the "fire paradox," whereby a legacy of fire exclusion in fire-prone forests has led to hazardous accumulations of flammable vegetation such that future fires burn with higher intensity and are more resistant to control; today's "success" begets tomorrow's failure. To conclude we offer some ideas for next steps and system redesign to better align behaviour with purpose, largely borrowing from risk and decision analysis. Our primary objective is to sufficiently frame and gain agreement on what we view as essentially a systemic problem.

Keywords: hazard; risk; uncertainty; decision making; complexity

INTRODUCTION

A changing climate, changing development and land use patterns, and increasing pressures on ecosystem services raise global concerns over growing losses associated with wildland fires. Although modern fire management organizations in the U.S. and elsewhere are highly effective at extinguishing the vast majority of ignitions before they can grow large and potentially cause losses (Calkin et al. 2005; Short 2014), the reality is that more fire on the landscape, not less, may be the key to reducing losses and restoring ecosystem conditions (North et al. 2012; North et al. 2015a).

Emerging research and evolving perspectives acknowledge that wildland fire is inevitable and often uncontrollable, and critique a dominant response of aggressive suppression as contributing to an unsustainable trajectory with increasing costs and losses (Calkin et al. 2015; Olson et al. 2015). These alternative paradigms instead deemphasize fire exclusion while focusing on fostering social and ecological resilience to fire (Moritz et al. 2014; Spies et al. 2014). Moreover, these paradigms view fire not as a disturbance process to be minimized but rather one that when used in the right places, under the right conditions, and for the right reasons, may reduce landscape hazard and risk. A similar set of factors – right places, right conditions, and right reasons – also dictates selection of responder strategies and tactics for engaging fires in a safe manner when suppression is warranted to protect communities and resources.

A notable ongoing effort in the U.S. is the National Cohesive Wildland Fire Management Strategy (Cohesive Strategy; https://www.forestsandrangelands.gov/strategy/index.shtml), which aims to bring multiple agencies, landowners and stakeholders together to achieve three broadly defined goals: resilient landscapes, fire adapted human communities, and safe and effective response to fire. Implicit in the structure of these three goals is the nexus of three systems: the ecological system, the social system, and the fire management system, respectively. This systems-based structure reflects a perspective that contextualizes fire as a disturbance process that influences and is in turn influenced by other agents and processes within a broader socio-ecological system (SES).

Despite the success of the Cohesive Strategy in establishing a common vision while recognizing divergent perspectives and purposes, solutions that would lead to meaningful change in decisions, actions, and outcomes remain elusive. Most SES-based analyses to date have focused on identifying pathways to better define and enhance community or landscape resilience to fire (Spies et al. 2014; Adams et al. 2016; Fischer et al. 2016), largely treating the fire management system as a black box of sorts that is malleable when change is desired. A common assumption seems to be that, contingent on changes in external factors such as public support or ecological condition, commensurate internal changes in fire management system planning and response will automatically occur. The evidential basis to support such an assumption is often limited or simply not provided. To the contrary, there is a substantial evidential base identifying internal factors that would promote resistance to change within the fire management system (Thompson 2014).

Herein lies the dilemma, as a change in management response to unplanned ignitions may be the factor most limiting broader SES change (Thompson et al. 2015). Absent a transition away from aggressive fire exclusion, hazard and risk would likely continue to increase, not only to communities and landscapes but to responders as well. As an example, while significant resources have been devoted to reducing hazardous fuel loads, significant financial, operational, and regulatory constraints along with limited demonstration of success and risk aversion preclude implementation of such activities at scales commensurate with the amount of area that burns from unplanned ignitions (Calkin et al. 2014a; Hudak et al. 2011; North et al. 2015b; Omi 2015). In sum, changes in land management and community actions that promote resiliency are necessary but perhaps insufficient to effectuate more desirable fire outcomes, requiring a sharper focus on prospects for change in the fire management system itself.

In this paper we discuss a range of factors governing fire manager behaviors and decisions using the lens of systems thinking (Meadows 2010), with the aim of better understanding factors that may be limiting the flexibility, responsiveness, and effectiveness of fire management organizations. We focus our analysis on federal wildland fire management in the western U.S., where fire managers face low-probability, high-consequence events with decision environments characterized by complexity, uncertainty, and the potential for conflict, and with the possibility of public and responder fatalities ever looming (Thompson 2013; Thompson et al. 2016a). While we recognize the importance of evaluating the fire management system in light of its position within a broader SES, our initial focus here is to shed light on what we feel is often a missing subsystem within fire-related SES analyses. Our analysis is centered on three premises that stem from the above discussion: (1) the need for more parties to accept that how fires are managed is in many instances the limiting factor of system behaviour; (2) the need to improve our understanding of the characteristics and complexities of the fire management system itself; and (3) perhaps most fundamentally, the need to coherently apply systems analysis principles to improve system performance. We review in more detail what we mean when we say fire management system, describe observed system behaviours and patterns, and begin to unravel factors that may influence behaviour. To conclude we offer some ideas for next steps and system redesign to better align behaviour with purpose, although we should be clear that our primary objective is not to be prescriptive but rather to sufficiently frame and gain agreement on what we view as essentially a systemic problem.

THE FIRE MANAGEMENT SYSTEM

Describing the System of Interest

The fire management system of the western U.S. is a complex web of multiple organizations with varying missions, responsibilities, and capacities. These organizations often coordinate, share suppression resources, and even co-manage incidents as conditions dictate. Differing objectives however can lead to conflict over how fires should be managed, especially when there is possibility of fire spreading across jurisdictional or ownership boundaries. At local and state-levels fire exclusion is almost universally mandatory, often to protect assets like communities, infrastructure, and commercial timber, but at the cost of foreclosing opportunities to managed unplanned fire for benefits when conditions would otherwise allow. Federal land management agencies by contrast have greater flexibility in policy that permits use of fire as a tool to restore, maintain, and protect landscapes; capitalization of this flexibility has typically been limited to ignitions occurring in remote wildlands far from human development, due in part to the uncertain potential of fires ignited closer to its boundaries spreading off federal lands.

Here for a number of reasons we focus on wildland fire management by the Forest Service, U.S. Department of Agriculture. Put simply these reasons relate to scale, timing, decision space, and synergy. First, the Forest Service accounts for approximately 70% of total federal wildland fire suppression expenditures. The magnitude of agency spending on wildland fire has grown over time, to the point where wildland fire expenses now consume over half of the agency's discretionary budget (U.S.D.A. Forest Service 2015). Second, as of this writing, all national forests and grasslands in the National Forest System are already or will in the near future be revising their land and resource management plans that will circumscribe and guide fire management planning and response for the coming decades (Meyer et al. 2015; Thompson et al. 2016b). Third, the greater policy flexibility that enables local management discretion in response to fire (insofar as response is consistent with land and resource management plans) provides a richer context for exploring factors that would promote fire exclusion or conversely fire expansion, relative to a decision context where fire exclusion is mandatory. Fourth, the branch of the Forest Service responsible for fire management is actively moving towards stronger adoption of enterprise risk management principles including systemic evaluation of business practices and assessment of risks, presenting an opportunity to broaden the systems perspective (Thompson et al. 2016a). A more comprehensive analysis incorporating additional fire management organizations could explore how varying purposes, relationships, and conflicts influence behavior, and is left for future research.

Wildland fire management in this context is largely the purview of two partially overlapping systems, the aforementioned National Forest System and the Incident Command System (Figure 1). Other relationships with for instance local law enforcement and municipalities related to evacuation protocols are excluded for simplicity of presentation. The Incident Command System is flexible, scalable, and response-driven, and builds organizational capacity according to the needs of individual incidents. These systems overlap in terms of personnel, in that many Forest Service employees hold qualifications to work on fire incidents, and the relationship between these two systems is formalized through a Delegation of Authority. When a fire incident occurs, the National Forest System Agency Administrator (local manager) is responsible for assessing risks and organizational needs, and describing strategic incident objectives based on existing plans and conditions. The Incident Commander is responsible for maintaining command and control of the incident management organization, and deploying tactical and operational decisions to achieve response objectives. The designed nature of the relationship between Agency Administrators and Incident Commanders is effectively that of principal and agent (Donovan and Brown 2005). This relationship structure assumes that the Agency Administrator (principal) has a deeper understanding of local conditions and land management objectives, while the Incident Commander (agent) has unique skills and expertise in the operational management of wildland fires.

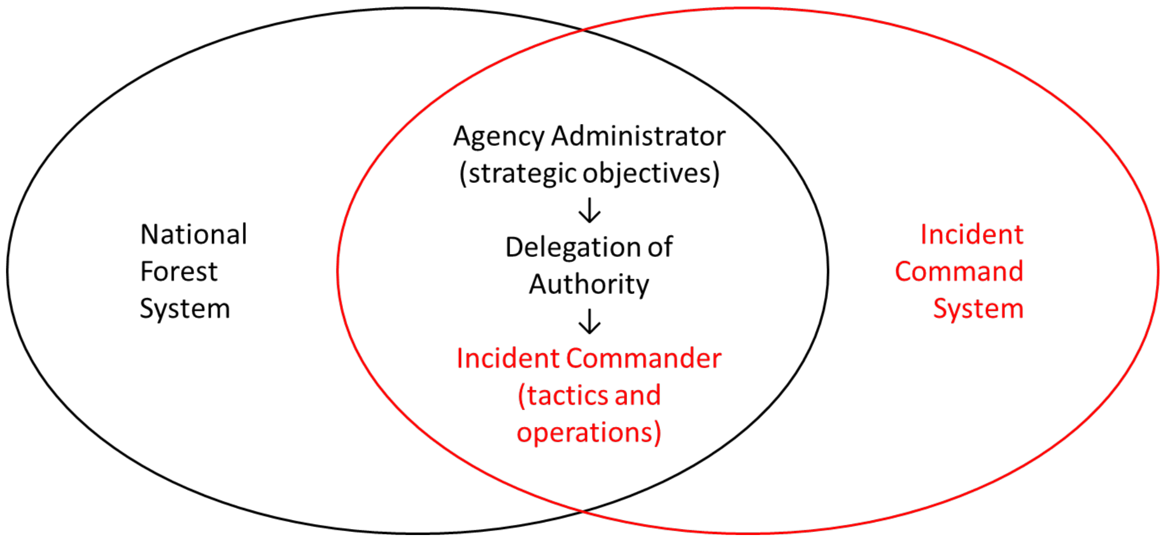

Figure 1. Relationship between the National Forest System and the Incident Command System

Describing System Behavior

To describe system behavior we introduce a stylized causal loop diagram that focuses on three central themes: (1) an ecosystem's natural fire regime; (2) a fire exclusion management paradigm; and (3) a fire expansion management paradigm (Figure 2). This depiction is most relevant to an ecosystem characterized by frequent, low-intensity fire, as was historically common in many low-mid elevation dry conifer forests of the western and southeastern U.S. Fuel load is a proxy for flammable vegetation, which includes live and dead trees, shrubs, grasses, etc. As fuel load increases, fire intensity increases, thereby consuming more fuels. As intensity increases the area burned also tends to increase, leading to additional fuel consumption. The natural fire regime can be conceptualized as two complementary balancing loops that regulate the amount of flammable vegetation on the landscape and therefore future fire activity.

The principal effect of excluding fire from the landscape through suppression is reducing area burned. Although suppression actions can directly reduce intensity, through for instance dropping water or retardant on actively burning areas from aircraft, fire intensity is more often a constraining factor that determines what suppression actions and tactics would be safe (Andrews et al. 2011). Over time, reducing area burned has the effect of accumulating higher fuel loads than would have otherwise occurred due to more frequent burning, leading to higher intensity in future fires (Weaver 1943, 1947, 1955). In turn, higher intensity increases resistance to control and places greater constraints on how and where suppression resources can safely engage fires, leading to increases in area burned. Increased fire intensity and resistance to control can also lead to greater damage to the ecosystem as well as human communities and infrastructure. This phenomenon has been referred to as the "fire paradox," whereby "success" today begets failure tomorrow (Arno and Brown 1991; Calkin et al. 2015). When exclusion remains the dominant paradigm, the increased resistance to control results in demand for additional suppression effort, resulting in a reinforcing feedback loop (Collins et al. 2013).

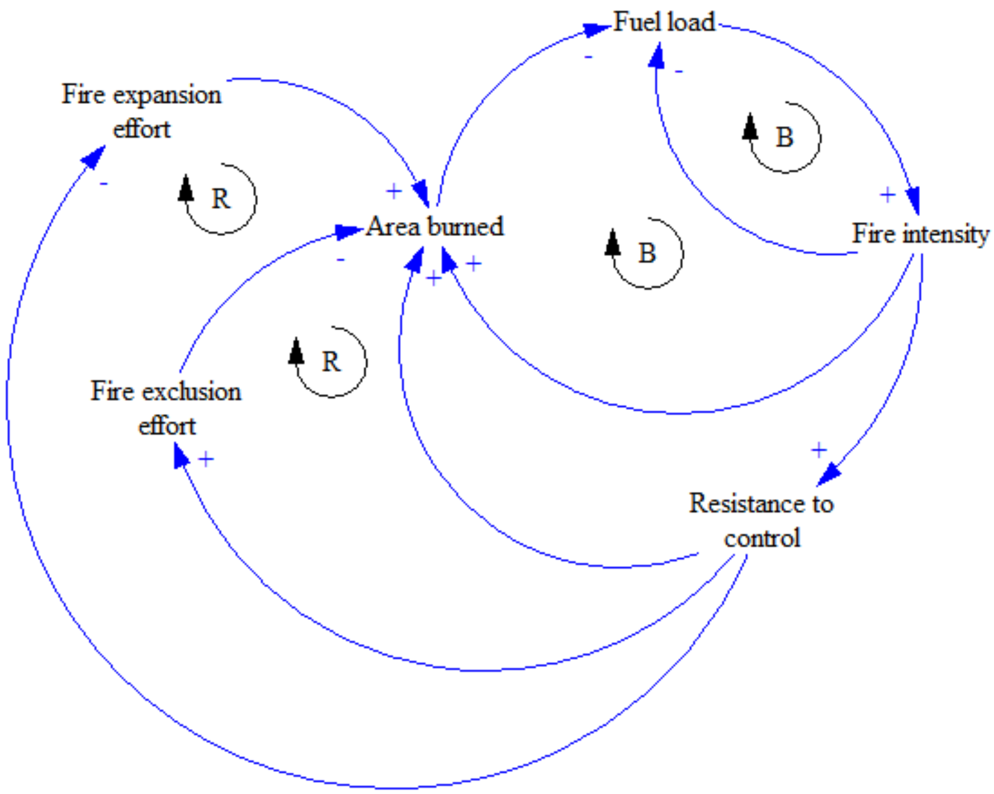

Figure 2. Causal loop diagram of a natural fire regime and how it is affected by alternative fire management paradigms

Conversely, the principal effect of a fire expansion paradigm is to increase area burned. This regulates fuel loads and reduces future fire intensity and resistance to control, thereby setting the stage for increased application of fire on the landscape (a reinforcing loop). The two primary pathways for expanded fire are to intentionally ignite fires in specific locations in accordance with prescribed weather conditions, or to manage naturally ignited fires in such a way that suppression efforts to retard fire growth are limited and mitigation is primarily intended to directly protect highly valued resources and assets. Though not depicted in our diagram, both types of activities typically occur under non-extreme weather conditions, such that the intensity of the contemporaneous fire is typically lower. This has the result of burning grasses, shrubs, and juvenile trees that can be the primary carriers of fire spread, while limiting mortality to older trees, and is more consistent with the natural fire regime (Graham et al. 2004; Ryan et al. 2013).

There are many factors that influence system dynamics not represented here, including climate and weather, land management activities like grazing, hazardous fuel reduction, and timber harvest, expanding human development in fire-prone areas, and sociopolitical pressures. These factors have been discussed elsewhere and our aim is not to rehash those findings here (e.g, Theobald and Romme 2007; Stephens et al. 2013; McCaffrey et al. 2013; Jolly et al. 2015; Omi 2015; Parks et al. 2016a). Rather, we focus on internal, systemic factors that affect choices between fire exclusion and expansion as singular incident-level decisions and as patterns of decisions over time. In reality fire response is not binary (exclusion versus expansion) but is rather a continuum where for instance incident management teams may aggressively attempt suppression along one edge of a fire to protect a community while devoting little resources or suppression effort along others for reasons of safety, hazard reduction, or resource benefit.

There exist numerous success stories of fire used as a land and resource management tool – in fact as of this writing the lightning-caused Jack Fire on the Coconino National Forest in Arizona and the lightning-caused North Fire on the Cibola National Forest in New Mexico are being actively managed for multiple resource objectives, both of which are well over 10,000 hectares and will likely continue to grow in size. On a broader basis however fire records and management actions suggest the continued preeminence of exclusion. Aggressive control of fires as small and as quickly as possible is typically successful for 95-98% of all ignitions (Short 2014), with little data to indicate changing trends in initial response decisions at local or national scales. Programmatic decisions have focused on increasing suppression capacity through for instance procurement of additional aircraft (Keating et al. 2012), and reaction to increasing fire activity has been largely to increase the scale and scope of existing management organizational approaches. Of the limited empirical data available on fire operations, findings suggest that weather rather than suppression effort can be the primary determinant of control (Finney et al. 2009), that incident management teams exhibit wide variation in suppression resource use on incidents with otherwise similar characteristics (Hand et al. 2016), that suppression resources are often used for missions outside of their recommended role (Thompson et al. 2013a; Calkin et al. 2014b), and that suppression resources are often used under conditions outside of recommended guidelines for effectiveness (Stonesifer et al. 2016). Pursuing ineffectual actions, perhaps in response to sociopolitical pressures, is of particular concern as responder fatalities mount, prompting a renewed focus on putting life first and reducing unnecessary exposure.

A high-impact outcome of these accumulated decisions is growing expenditures on wildland fire management, with concerns that landscape hazard and risk are increasing as well, pointing to a future of increasing costs and losses (Calkin et al. 2015; Olson et al. 2015). The negative impact of suppression expenditures on the Forest Service's budget, long recognized, has become critical, and continues to erode funding for other natural resource programs, including those that could be complementary to reducing risk such as restoration and planning (Stephens and Ruth 2005; Thompson et al. 2013b). These trends continue despite amassing evidence that large fire can act as a self-regulating mechanism (Parks et al. 2014; Parks et al. 2015; Parks et al. 2016b), and has been suggested to enhance incident response efficiencies (Salazar and González-Cabán 1987;Thompson et al. 2016c). Hence the growing calls for expansion of fire, where appropriate (North et al. 2012; North et al. 2015a; Stephens et al. 2013).

Describing Factors that Influence System Behavior

Wildland fire management is highly dynamic, time-pressured, and uncertain (Thompson and Calkin 2011; Thompson 2013). Fire managers have imperfect information regarding a multitude of factors, including future weather and associated fire behavior, near- and long-term socioeconomic and ecological consequences of fire, suppression resource productivity and effectiveness, and suppression resource availability during periods of high fire activity, among other factors. Conditions can change rapidly, and require frequent reassessment of conditions and organizational needs. In such decision environments, cognitive biases and reliance on suboptimal heuristics can become commonplace, leading to systematic errors interpreting and combining information (Maguire and Albright 2005). In fact many biases and heuristics have been identified as relevant to the wildland fire management context (Table 1). Their collective influence tends to induce reversion to fire exclusion as the status quo response as well as potential overuse of suppression resources.

Table 1. Fire Management Cognitive Biases and Decision Heuristics

Identified Issues	Source(s)
Status quo bias, loss aversion, discounting	Wilson et al. (2011)
Risk aversion, nonlinear probability weighting, susceptibility to information framing	Hand et al. (2015); Wibbenmeyer et al. (2013)
Systematic biases in estimates of fire outcomes	Donovan and Noordijk (2005)
Sunk cost bias, optimism bias, overutilization of resources bias	McLennan et al. (2006)

Beyond the difficulty of the decision environment, internal factors that set the stage for decisions also contribute to emergent behaviors, corresponding feedbacks, and unintended consequences. Here we use a version of the events-patterns-system structure-mental models frame (i.e., the iceberg model) to evaluate factors influencing the behavior of the Forest Service fire management system (Table 2). Events relate to decisions, actions, and outcomes from individual fire incidents. Some of the emergent patterns across events were discussed above, including escalating expenditures and concerns regarding unnecessary exposure of ground and aerial suppression response forces. Moving to the bottom of the iceberg, mental models include a culture that has evolved to "fight" fires, to "put fires out," and to view fires as controllable, although we should be quick to point out that this culture is not monolithic and that there has been a long and rich history of localized management efforts to reintroduce natural fire (Pyne 2015). As alluded to in the introduction, these viewpoints appear to be broadly changing, as evidenced by the vision put forward in the Cohesive Strategy and in the language of the Forest Service. Where the largest resistance to but also opportunity for change might be found then is in system structure.

Table 2. "Iceberg" Model Applied to Fire Management System Behavior

Factor	Observations and Attributes
Events	Fire sizes and intensities, strategies, expenditures, fire consequences, responder injuries and fatalities
Patterns	Risk-aversion, aggressive suppression, unnecessary expenditures and responder exposure

System Structure	Incentives, performance measures, monitoring, planning architecture, decentralized decision making
Mental Models	Culture, notion of fire as controllable, notion of need to always "fight" fire

In Table 3 we expand on concepts and findings related to system structure (Table 2), primarily synthesizing a range of studies that have identified internal factors affecting Forest Service decision processes. One prominently featured issue is a misaligned incentive structure thought to encourage aggressive suppression, over-utilization of suppression resources, and expenditures incommensurate with values-at-risk (Canton-Thompson et al. 2008; Donovan et al. 2008; Donovan and Brown 2007, 2005; Calkin et al. 2005b; MacGregor and Haynes 2005). In a choice experiment study, fire managers actually favored higher cost suppression strategies when selecting what they felt was expected of them given community, leadership, and political expectations (Calkin et al. 2013). While this undoubtedly cannot be decoupled from sociopolitical pressures (Collins et al. 2013; Donovan et al. 2011; Stephens and Ruth 2005), the critical point here is that there are limited internal mechanisms in place to counterbalance those pressures. This is largely due to suppression expenditures being funded from national accounts and the fact that any theoretical cost savings can't be reinvested by the manager locally, such that there are very little opportunity costs for deploying additional resources and minimal local budgetary impacts of excessive expenditures. Neither are there incentives in place that managers feel reward innovation or risk-taking (Kennedy et al. 2005).

Other elements of the decision environment similarly contribute to suboptimal conditions for high quality decision making. A lack of integration across program areas combined with limited investments in pre-fire assessment and planning inevitably lead to increased uncertainty and time-pressures facing the Agency Administrator. Further, the culturally ingrained and long-held model of decentralized decision making is likely poorly aligned for the types of decisions that incident response requires. Whereas decentralization is premised on strong local knowledge, the Agency's promotion system tends instead to favor frequent transfers to broaden the experiential base. And while this could yield substantial benefits across many management domains, with respect to fire the Agency Administrator is not likely have the requisite understanding of local landscape conditions and fire history to provide sufficient guidance on what strategies might be safe and effective, developed the requisite trust with local communities to pursue alternative options, nor might they remain in any location long enough to see the impact of their own past decisions. Resultant reliance on Incident Management Teams to fill in the gaps is susceptible to the same problems, as these teams may travel from far away and have little to no experience with the local fire regime or the social-political-ecological landscape in which local fire management occurs, and the relative rarity of large fire assignments suggests that conditions for reliance on expert judgment and intuition are not met (Kahneman and Klein 2009). Hand et al. (2016) for instance identify that over 2007-2011 incident management teams averaged less than 4 fire assignments, which lasted on average less than twelve days.

Limited oversight and the need to increase the accountability of Agency Administrators and Incident Commanders have long been identified as concerns (U.S.D.A. Office of the

Inspector General 2006; U.S. Government Accountability Office 2007). Closing the accountability loop is premised on the ability to measure fire manager performance through tracking of decisions, actions, and outcomes. Few information systems are set up to provide research quality data, however, with concerns over sufficiency, consistency, availability, and interoperability across reporting systems. Thus the Agency has a very limited ability to understand what works and what doesn't, and a commensurate limited ability to credibly answer questions required for true organizational learning to feed into future decisions.

Table 3. List of Issues Relevant to System Structure and the Decision Environment

Identified Issues	Source(s)
Misaligned incentives, limited scrutiny and accountability for excessive suppression costs and possible unnecessary fire responder exposure	Donovan and Brown (2005); Calkin et al. (2011); Thompson et al. (2013); Calkin et al. (2015)
Lack of integration across programmatic and project planning	Schultz et al. (2015)
Perceived low rewards for innovation, risk-taking, independence, and concern for future generations	Kennedy et al. (2005)
Low investment in planning	U.S.D.A. Forest Service (2015)
Performance measures tend to track outputs not outcomes, and may be counter to desired conditions	Donovan et al. (2008)
Misalignment between criteria for effective decentralized decision making (localized expertise and knowledge) and promotion track for line officers (frequent transfers)	Robinson (2013)
Limited availability and sufficiency of fire operations data, and limited interoperability of reporting and accounting systems	Thompson et al. (2016b); Stonesifer et al. (2016)
Limited definition and monitoring of operational objectives and effectiveness	Plucinski et al. (2013)
Lack of organizational clarity on key concepts like risk and resiliency	Bone et al. (2016); Thompson et al. (2016)
Limited guidance from pre-fire assessment and planning, leading to uncertain and time-pressured decision environments	Thompson et al. (2013c); Thompson et al. (2016a)

DISCUSSION

Wildland fire management can be complex, uncertain, and conflict-ridden, presenting challenges to effective decision making and attainment of desired outcomes. Studies suggest a risk-averse decision structure constrained by perceptions and pressures and susceptible to suboptimal decision biases and heuristics. This can lead to emphasizing fire exclusion, which can disconnect fire management objectives from the underlying resource management objectives they are supposed to reflect. Analysis of Agency organization, process, and operations suggests that these factors influence decision making in the same direction. System structure may therefore present a limiting factor to effectuating broad change in fire management system response to fires, which in turn may be a factor limiting broader SES resiliency on fire-prone landscapes.

A number of partial solutions for incremental change are readily apparent, focused around three key areas of leadership, education and capacity, and assessment and planning (Thompson et al. 2016a). First, leadership can take ownership of and endorse change, including advocating for and using more robust systems of accountability. A fundamental element of enhanced accountability will be ensuring that performance measures link more directly to strategic objectives and do not create misaligned incentives. Second, education and capacity includes steps to help managers gain skills in risk analysis and structured decision making, and to reprioritize investments in research and development around critical information needs for high-impact decisions. Third, assessment and planning efforts can more strongly incorporate best-available science, including risk assessment and scenario analysis to significantly reduce the uncertainty and in effect buy time for managers making time-pressured response decisions.

Longer-term research is needed to fully evaluate potential alternatives for and consequences of system redesign. This could include system dynamics modeling (e.g., Collins et al. 2013) to play out various policies and identify likely leverage points where change would yield desired results. Fleshing out differences between perception and reality and critiquing assumptions behind any system redesign will be critical (Pennock and Wade 2015), and will in part be reliant on improved information attainable only through improved monitoring and information systems. While concerns that employees might not all react the same way to top-down interventions and demonstrate unpredictable behavior are to be recognized (McDaniel 2007), at the same time it is increasingly clear that a "local always knows best" policy with limited oversight or guidance and possibly counterproductive performance measures has not led to a sustainable trajectory (Olson et al. 2015). It will therefore require a balancing act between top-down accountability and bottom-up innovation to move the system towards its desired horizon (Abrams et al. 2015). This is not to discount critical efforts to help communities become fire adapted and enhance ecological condition as suggested by others (e.g., Carroll and Paveglio 2016; Smith et al. 2015), it is just a call to ensure the full scope of the problem is recognized and framed correctly.

As we stated earlier, it is important to recognize that the fire management system is but a component or subsystem of a much broader meta-system comprised of interrelated social, political, economic, technical, and ecological systems. While we briefly addressed how some external factors can influence fire manager behavior, a broader analysis could for instance explore how socioeconomic interests outside of public land management, such as developers, homeowners, timber producers, and private firefighting companies, have contributed to the structure and behavior of the fire management system we see today. It is possible that the fire exclusion paradigm was deemed more efficient or feasible given the difficulty of comparing largely intangible benefits from provision of ecosystem services to the tangible concerns of those with a direct stake in fire exclusion. Hence the need for future analysis to expand the systems perspective to evaluate intentions and behaviors in light of pressures and interrelationships. Hence also, as we argue here, the need to begin such analyses with a solid understanding of each subsystem. Ideally as systems analysis matures we will be able to leverage new insights on the behavior, structure, and design of systems of systems.

In sum, we believe that insights from systems analysis help provide a unifying perspective to understand and address well-identified issues with wildland fire management. Insights and hypotheses to be tested with future research for instance include: fire manager behavior is a direct and logical result of the structure of the system in which managers operate; systems tend to produce what they are measured against, hence the continued dominance of fire exclusion; and proposed solutions tend to address symptoms rather than root causes, hence a need for more holistic system of systems perspectives and at the subsystem level a sharpened focus on enterprise-level management of risks and opportunities. Research could further evaluate the role of agents and organizational programs, for instance silos and cross-purposes leading to system degradation, or alternatively bottom-up innovation and evolution leading to system resilience (e.g., Abrams et al. 2015). Expanded fire as an alternative paradigm is a much thornier problem than presented here for purposes of comparison, but nevertheless if implemented appropriately and successfully at scale could negate existing feedback loops where suppression begets the need for more suppression, and instead by reducing hazard to both landscapes and responders could lead to a future with more resilient forests, communities, and fire management organizations. Cross-disciplinary collaboration to test, implement, and iteratively improve this management paradigm would mark a high point in SES analysis and design.

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