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Foreword

Towards enhanced risk management: planning, decision making and monitoring of US wildfire response

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Abstract. Wildfire's economic, ecological and social impacts are on the rise, fostering the realisation that business-as-usual fire management in the United States is not sustainable. Current response strategies may be inefficient and contributing to unnecessary responder exposure to hazardous conditions, but significant knowledge gaps constrain clear and comprehensive descriptions of how changes in response strategies and tactics may improve outcomes. As such, we convened a special session at an international wildfire conference to synthesise ongoing research focused on obtaining a better understanding of wildfire response decisions and actions. This special issue provides a collection of research that builds on those discussions. Four papers focus on strategic planning and decision making, three papers on use and effectiveness of suppression resources and two papers on allocation and movement of suppression resources. Here we summarise some of the key findings from these papers in the context of risk-informed decision making. This collection illustrates the value of a risk management framework for improving wildfire response safety and effectiveness, for enhancing fire management decision making and for ushering in a new fire management paradigm.

Additional keywords: fire economics, fire fighters, fire suppression.

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Introduction

Context

Despite significant fire suppression expenditures and exposure of fire responders to an increasingly hazardous fire environment, many aspects of wildfire suppression in the United States (US) and elsewhere remain poorly understood. Key knowledge gaps include how fire managers assimilate various types of information into decision processes, the productive capacity and effectiveness of different suppression resources performing different missions, and the degree to which suppression actions affect fire progression and final fire outcomes (Calkin *et al.* 2013; Holmes and Calkin 2013; Wibbenmeyer *et al.* 2013; Thompson 2014; Duff and Tolhurst 2015; Hand *et al.* 2015; Katuwal *et al.* 2016). In particular, some research suggests that growth of fires escaping initial attack may be insensitive to suppression actions and instead largely determined by weather and landscape conditions (Butry *et al.* 2008; Finney *et al.* 2009). Although the difficulty of developing credible frameworks and corresponding measurement methodologies to evaluate suppression effectiveness should not be understated, it is equally important to acknowledge that the type of comprehensive, systematic monitoring of suppression operations necessary to generate data for evaluative purposes is at present lacking (Mendes 2010; Plucinski and Pastor 2013; Thompson *et al.* 2013). In cases where research efforts have been able to gather sufficient data for analysis, results sometimes reveal patterns that are inconsistent with guidelines for effective resource use or that suggest inefficiencies (Calkin *et al.* 2014; Rodríguez y Silva and González-Cabán 2016; Stonesifer *et al.* 2016). Therefore, in some respects, research on wildfire suppression to date has raised more questions than it has provided answers.

Although there is substantial uncertainty regarding the effectiveness and efficiency of wildfire suppression strategies, there is growing certainty that the business-as-usual approach to fire management in the US is unsustainable (Olson *et al.* 2015). This reflects the increased hazard resulting from fire exclusion in frequent-fire systems, the escalating costs of suppression, expectations of a future where climatic changes drive increased fire activity and an expanding wildland urban interface, among other factors (Haas *et al.* 2013; Calkin *et al.* 2015; Abatzoglou and Williams 2016). Suggested alternative management paradigms deemphasise fire exclusion while promoting expanded application of prescribed fire and managed natural fire (Moritz *et al.* 2014; North *et al.* 2015; Schoennagel *et al.* 2017).

A notable ongoing effort to effectuate change in the US is the National Cohesive Wildland Fire Management Strategy that has articulated a collective vision for the nation to learn to live with wildland fire, has established safe and effective wildfire response as a primary goal, and has promoted risk as an organising concept to determine priorities and guide decisions (Calkin *et al.* 2011; US Department of Interior and US Department of Agriculture 2014).

The transition to a new fire management paradigm will require improved planning and support for decision making that evaluates the inherent tradeoffs among alternative management strategies and better monitoring of fire management decisions, actions and outcomes. These recommendations embody essential elements of risk management, including explicitly considering uncertainty, committing to generating and using best available information, shifting from reactive to proactive responses and facilitating continual improvement through organisational learning (ISO 2009; Yoe 2011; Thompson *et al.* 2016*a*). Risk management involves getting ahead of decisions that individuals or organisations are likely to face in the future, and requires monitoring and feedback to improve future decisions. US Federal fire management has consistently promoted risk management as the basis for sound decision making, and existing risk management protocols call for managers to proactively plan responses to future fires and to minimise unnecessary exposure of fire responders to hazards (Fire Executive Council 2009; National Interagency Fire Center 2017). Yet, operationalisation of risk management is inconsistent and immature, and enhanced comprehension, consistency and capacity are necessary to support broader adoption of risk management principles and practices within the US wildland fire management community (Thompson *et al.* 2016*a*).

Purpose and organisation

This special issue presents new research on wildfire response in the US and frames it from the lens of risk management. We expand upon a special session convened at the International Association for Wildland Fire 5th International Fire Behaviour and Fuels Conference held in April 2016 in Portland, Oregon, USA. In that special session, presentations centred on the primary topics of monitoring, modelling, and accountability of fire management policies and practices, and sought to synthesise ongoing research focused on wildfire response decisions and actions (Thompson *et al.* 2016*b*). Papers in this special issue build on those discussions, and are organised around three key themes: strategic planning and decision-making; use and effectiveness of suppression resources; and allocation and movement of suppression resources. These concepts and their relationships to making risk-informed decisions through monitoring and accountability are core tenets of risk management.

Strategic planning and decision making

Embracing risk management means investing time and resources in upstream assessment and planning in an attempt to reduce the uncertainties and time-pressures of the incident decision environment (O'Connor *et al.* 2016; Thompson *et al.* 2016*c*). The first set of articles describes and demonstrates these concepts. The resulting risk-informed decision processes can ideally develop a suite of response options that are likely to be successful, select an appropriate set of suppression resources that limit unnecessary exposure, and efficiently achieve social, ecological and economic objectives.

In the first paper of this special issue, Ingalsbee (2017) argues that we may be on a cusp of a paradigm shift towards what he terms ecological fire management. Despite evidence that the aggressive suppression era is alive and well, the author identifies that what once was a predominantly academic consensus around the need for a more ecologically based approach to wildfire management is increasingly recognised in policy and public discourse. Application of emerging knowledge and adoption of risk management principles to establish clear objectives and promote efficient suppression resource use will be necessary to move towards a more ecologically based fire management era.

Thompson *et al.* (2017) review the decision environment surrounding fire managers as they deliberate, develop and implement management strategies of rare, often high-impact events. The authors discuss key uncertainties, outline existing decision support approaches and identify opportunities to fill knowledge gaps. They discuss the importance of context, and include examples of how historical fire regimes, values-at-risk and variation in fire policy are important to response decisions. A discussion follows on evaluating the consequences of fire, including considerations of both direct and indirect effects. The authors consider near and long-term consequences, and relate these to strategic decisions from the single event to cumulative impacts over time. Importantly, they contrast the effects of fire on highly valued resources and assets with the effects of aggressive fire suppression and a perpetuation of the existing fire deficit. These perspectives provide a picture of the complexity of fire management, and lead to a discussion on decision support approaches using examples from Spain and the US. The authors emphasise that the limited ability to credibly model avoided damages associated with alternative suppression approaches means that significant investments are needed in monitoring and analysis. They conclude their review by examining future research needs, including a call for expanded use of economic theory and perspectives and further adoption of comprehensive risk analyses to improve fire management decision making.

Jolly and Freeborn (2017) draw linkages between fire danger indices, fire behaviour and responder risk in an effort to increase the safety of fire responders. The authors use a probabilistic model to link spatially explicit fire danger indices (energy release component and burning index) with reported observations of fire behaviour during historical large fires in portions of the western US. They translate these estimates into a risk metric by weighting the predicted fire behaviour's potential effect on responder exposure to varying levels of fire behaviour. Managers can spatially derive this fire behaviour risk rating across broad geographic areas, including forecasts several days into the future. First responders can use the fire behaviour risk rating to improve situational awareness in support of tactical decisions that reduce responder exposure to the flaming front. In addition, fire managers can use this information during large fire management to support both strategic and tactical response. This can have the added benefit of increasing response efficiency by allocating resources to alternative tasks when the fire behaviour risk rating reaches a threshold where direct engagement carries too much exposure and is likely to be ineffective.

O'Connor *et al.* (2017) applies a geospatial dataset of large fire perimeters to begin to evaluate factors that contribute to successful containment lines. The authors combined spatial information including access, topographic features and fuels to quantify factors most likely to be observed at the location of the final fire perimeter. Using an example from southern Idaho and northern Nevada, the authors determined that distance to an existing natural or man-made fire barrier, travel cost, suppression difficulty index and distance to a valley were the top four variables for predicting the presence of a fire perimeter. They then created perimeter probability surfaces across the region of interest, spatially displaying where the probability of success of controlling a fire would be greatest (or lowest). In advance of or following an ignition, fire managers can use these spatial datasets to develop a response strategy for fires escaping initial attack or those managed to meet resource benefits. In addition, the control probability surfaces will help fire managers to reduce unnecessary exposure for fire responders, coordinate pre-fire planning with stakeholders and develop a network of control line locations that could aid alignment of fire management decisions with land management objectives.

Use and effectiveness of suppression resources

Once a fire management strategy has been selected, efficient use of wildfire responders and equipment is critical for reducing their unnecessary exposure to hazards while meeting wildfire response needs. There are varieties of suppression resources that support different tactical actions, at different costs, while exposing personnel to a range of hazards. The factors that influence allocation and movement decisions locally, regionally and nationally, particularly during periods of resource scarcity, are not well understood. Additionally, quantifying resource use and abundance during management of large fire events is critical information for assessing whether or not current use of suppression resources is efficient.

Stonesifer *et al.* (2017) conducted an expert opinion survey querying US Forest Service employees with direct or indirect responsibility for ordering fire management resources. The survey was designed to obtain insights about the relative importance, scarcity and substitutability of commonly deployed resources. In particular, the authors hoped to distinguish resources of high value, high scarcity, and few substitutes from resources of low value, commonly available, and many substitutes. The largest number of respondents identified Type I handcrews (highly experienced, typically 20-person ground crews) as the most important resource for direct and indirect attack. The importance of these crews is because of their capabilities coming from high levels of training and experience. Lead planes and advanced timber fallers were viewed as not substitutable and providing often-necessary services. Survey results identified fire engines as important for direct attack and bulldozers for indirect attack, but they did not view these resources as scarce. Other specialised resources like very large airtankers, helicopter rappelers, and smokejumpers had the highest proportion of responses with no opinion, suggesting either niche roles or relatively low utility compared to other resources. The breadth of expert opinions reported by the authors provides a foundation for understanding the relative effectiveness of the many resources commonly employed to manage wildfires and suggests priorities for future investments by the fire management community.

Katuwal *et al.* (2017) applied economic theory and perspectives to describe resource use during large fire management, using an integrated geospatial and tabular database of fire growth and resource use on large fires. The authors investigated incident-level fireline production capacity relative to length of fire perimeter and evaluated absolute and relative abundance of resources during the active growth and control phase (determined by the date the fire ceased growing) of large fires. They follow by assessing the relationship between the actual and self-reported percent containment of large fires. Total suppression resource fireline production capacity (based on established production rates) exceeded, often by an order of magnitude or more, the amount necessary to build fireline around the final fire perimeter. Additionally, fire managers retained an average of 21% of total incident resource productive capacity on these fires after they stopped growing, and similar resource packages (relative abundance of ground and aerial resources) were observed in the active growth and control phases. The authors also observed self-reported percentage of perimeter contained averaged only 70% at the time the fire stopped growing. Collectively, these results suggests that managers commit substantial levels of resources to ensure that non-spreading fires do not escape the existing perimeter and that there is a delay between fire growth cessation and when managers are comfortable reporting containment. Thus, opportunities may exist to improve management efficiency by balancing the likelihood and consequences of less intensive resource use on non-spreading fires against the opportunity cost of that resource use on emerging incidents.

Hand *et al.* (2017) investigated resource use on wildfires in response to multiple driving factors, including variation among individual incident management teams (IMTs). Using a utility-theoretic model, the authors focus on the relative importance of incident and landscape characteristics and the IMTs responsible for managing wildfires. Their results suggest the primary drivers of resource use include managers' expectations of future fire growth, housing value in proximity to the fire and the uncontained fire area. Somewhat surprisingly, fuel type, the current fuel moisture and weather conditions, and ignition on private lands were not statistically associated with resource production capacity. One of the most significant findings was the influence of IMT on total resource use. The authors observed that managers approach resource use similarly within or outside their region of typical operation, but that all teams use more resources in California relative to other geographic areas. Some teams consistently use more resources, and accounting for the IMT managing the fire explained 14–17% of additional variation in resource orders. In fact, dozens of crews and hundreds of personnel per day separated the highest- and lowest-ranked IMT after accounting for other factors influencing resource orders. The authors attribute this to differences in personal risk perceptions, experiences, preferences and other unobserved characteristics. Increasing awareness of the differences among IMTs and sharing of knowledge across IMTs could help reduce unnecessary responder exposure and improve overall incident and organisational efficiency.

Allocation and movement of suppression resources

Ensuring that the correct amount and types of suppression resources are assigned to large fires is a critical challenge of the fire management community. If the delivery of those resources to events throughout a fire season is inefficient (e.g. nearest available resources are not assigned) the result is likely additional financial cost, more time spent driving and delayed suppression response. Most federal fire suppression resources in the US are available to travel nationally. Many factors influence the allocation of these resources, including existing policies, budgets, interagency agreements and uncertainty around future demand. A broader understanding of how various factors influence the efficiency of resource allocation and movement could help reduce unnecessary exposure to driving hazards while better meeting fire management objectives. The papers on resource movement focus on the use of fire engines and handcrews. There is, of course, a broader variety of resources that provide different services with varying experience levels; factors that will influence allocation and movement decisions locally, regionally and nationally, which could be the subject of future research. The research efforts highlighted here demonstrate that significant opportunities exist to improve the efficiency of resource allocation of engines and handcrews.

Wei *et al.* (2017) used simulation and optimisation modelling to capture daily engine and handcrew assignments across several dispatch zones during a fire season. The authors used historical assignments and forecasts of fire activity to design and test their model, and simulation and optimisation procedures to allocate resources to meet next-day response demands within each dispatch zone. The authors then examine how assignment length, the accuracy of demand predictions, minimum staffing requirements, and the compounding effects of resource shortages affect assignments and resource sharing. They observed that (1) resource shortages for initial attack or prior day demand increased costs for future days, and (2) relaxing minimum staffing restrictions generally decreased the use of out-of-state resources and transport costs because it allowed for more resource sharing between nearby dispatch zones. These results highlight the tradeoffs inherent in decisions where there is substantial uncertainty in predictions of resource demands within and outside individual zones. Because sharing resources between zones can increase transportation costs, greater investment in predictive models could reduce uncertainty and improve resource dispatch. In particular, a greater focus on improving fire weather predictions and their relationship to resource needs could have significant benefits to increasing efficiency.

Belval *et al.* (2017) used a probabilistic model to examine the effects of fire activity, fire seasonality, and resource scarcity on interregional engine assignments. By leveraging several existing databases tracking resource use and fire activity, the authors accounted for the number of ignitions and large fires in both the source and response geographic coordination areas, variation in fire season across regions, and resource scarcity as estimated by the national preparedness level. Expectedly, an increased number of large fires within a region resulted in more interregional exchange, with shared resources often dispatched from adjacent regions. These relationships changed as adjacent regions entered into fire season or had a concurrent fire season. Under those conditions, their model revealed more interesting and less intuitive patterns. For example, an increase in new ignitions in the south-west region resulted in a transfer of resources from regions with a different timing of fire season. However, the shared engines typically transferred from the Northern Rockies and not the Pacific Northwest despite both regions being off fire season. The authors suggest these trends may result from varying networks and relationships that drive broader resource sharing decisions, and these informal rules and heuristics may be inefficient. As research continues to understand how and why resource movements occur, improved models should support a more effective fire management response across the system as a whole.

Conclusion

As articulated in the introduction and in the piece by Ingalsbee (2017), there is increasing consensus on the need for fundamental change in US wildfire management. Maintaining social-ecological resilience to the rapidly changing fire environment will require adaptation of policies (Stephens *et al.* 2016), social perspectives and expectations (Moritz *et al.* 2014; Schoennagel *et al.* 2017), ecosystems (Stephens *et al.* 2013; North *et al.* 2015), and the behaviour of the fire management system itself (Thompson *et al.* 2015). This special issue focuses on the latter, based on the premise that how fires are managed is a key determinant of the resiliency of the broader social-ecological system. We highlighted the importance of risk management and its attendant emphasis on assessment, planning, decision support, monitoring and feedback.

Several key points emerge from the papers in this issue. First, risk management provides a sound framework for enhancing the quality of fire management decisions, especially through improved strategic planning. Second, large knowledge gaps exist regarding suppression effectiveness and persist because of a lack of high-quality data on management objectives, decisions, actions and outcomes. This is evident in the variation in expert opinions of the importance of various suppression resources and significant uncertainty in the spatial and temporal allocation of suppression resources on incidents, to incidents and by incident management teams. Thus, increased investment in data collection, monitoring and assessment are needed. Third, even with the current level of knowledge, there are substantial opportunities to improve large fire response by minimising unnecessary responder exposure to hazards and inefficient use of resources. For example, maintaining excessive resources after a fire has stopped growing may limit their availability for incidents of higher priority, resulting in increased costs and transfer of risk to responders and highly valued resources and assets on those incidents. The broad differences between levels of resource use by IMTs suggest human factors significantly influence our approach to fire management, with consequences for responder exposure, costs and programmatic efficiency. Fourth, better fire weather predictions can enhance decision making through improved situational awareness for initial and extended response, and predictions of resource demands across geographic areas. This directly contributes to national safety goals by reducing responder exposure to extreme fire behaviour and unnecessary travel; both significant contributors to responder injuries and fatalities.

We recognise that these key points, and the subjects compiled in this special issue, are not comprehensive; however, they do support our assertion that infusing risk management throughout the fire management system is the foundational step for filling knowledge gaps and realising change. Researchers from a range of disciplines, employing a range of techniques, and working closely with fire management practitioners, natural resource managers and communities at risk, can together expand upon this effort and forge society's new relationship with wildfire.

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