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Erin Kathleen Noonan-Wright

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By

ERIN KATHLEEN NOONAN-WRIGHT

B.S. Forestry, University of California, Berkeley, CA 1997
M.S. Environmental Resource Science, University of Nevada, Reno, NV 2002

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Approved by:

Scott Whittenburg,
Graduate School Dean

Dr. Carl Seielstad, Chair
Department of Forest Management

Dr. Brady Allred
Department of Forest Management

Dr. Andrew Larson
Department of Forest Management

Dr. Helen Naughton
Department of Economics

Dr. Laurie Yung
Department of Forest Management

Noonan-Wright, Erin, Ph.D., December 2019, Forestry and Conservation Sciences

Patterns of wildfire risk in the US from systematic operational risk assessments – how risk is characterized by land managers

Chairperson: Carl Seielstad

Since the turn of the 21st century, the complexity and costs of wildfires have increased substantially. There is a need to evaluate entrenched fire management practices that encourage status quo decision making to suppress fires. Data stored in mandated reporting systems collected during wildfires may provide a perspective on fire management decision-making needed to change wildfire governance structures. The Relative Risk Assessment (RRA) resides within a federally mandated workflow process necessary for all longer duration federal wildfires since 2010. Land managers rate hazard, probability and values at risk as high, moderate or low throughout the course of an incident to define wildfire risk as a precursor to strategy. 5,087 published risk assessments were evaluated to provide a snapshot of the how land managers characterize risk from every geographic area (GA) in the United States. Results suggest that most GAs have a tendency to select moderate relative risk; however, two unique regions warranted greater inspection. The Northwest utilizes high risk more than any other geographic area; and the Southwest opts for low risk. Following a mixed method explanatory research design, these GAs became the basis for exploring factors influencing high and low risk by coding qualitative text belonging to the RRA. Investigation of a 20% sample of wildfires from these regions provided finer specificity of the values at risk, hazard, and probability concerns emerging during wildfires. Results suggest that climate plays a pivotal role to lessen the impact of the fire environment in the Southwest and generally increases the severity of the fire environment in the Northwest. When risk is low, land managers exercised greater decision space by using a variety of strategies. High risk constrains decision space and managers opt for suppression strategies. Subsequently, the Southwest is poised to benefit from favorable climate to use more fire and there is mounting evidence that a patchwork of historical wild and prescribed fires are leading to greater decision space for the management of current wildfires by serving as barriers to fire spread. However, suppression strategies were the most common for both GAs suggesting challenges remain for the use of fire to achieve resource objectives.

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Table of Contents

Chapter 1

Introduction

Understanding the factors that drive risk perceptions on wildfires is expected to enable systematic changes of how risk is characterized, thereby allowing for greater decision-space to use wildfire to achieve resource objectives and ultimately, better-alignment of practice and policy. Currently, many ecosystems in the western U.S. are experiencing a fire deficit (Parks *et al.* 2015) or "disturbance deficit" (Vaillant and Reinhardt 2017) and there is critical need to reintroduce fire to vast expanses of land to enhance ecosystem resiliency and reduce uncharacteristic levels of fuel loading. Ongoing and impending changes in climate have increased the urgency of this reintroduction. Considerably reducing the number of directly suppressed wildfires in favor of alternative management strategies such as confine/contain and point/zone protection remains an important goal. Additionally, embedded in every federal land management agency mission statement is an imperative to manage lands for future generations. This directive challenges land managers to consider long-term consequences of current management decisions. There needs to be a systematic process to account for decisions that both achieve and fail to address long term goals of landscape resiliency. One way to address this need is to measure if chosen strategies accomplish both resource and protection objectives on wildfires. Data and methods are needed to enable such measurements.

Characterizing risk is controversial and difficult to articulate when establishing strategies, goals and objectives for emerging incidents which are often chaotic, dangerous, expensive, and prone to controversy. Risk is the expectation of loss or benefit, based on the probability and consequence of uncertain future events (Finney 2005; Ager *et al.* 2010; Calkin *et al.* 2010; Yoe 2011; Miller and Ager 2013; Scott 2013; Thompson *et al.* 2015). While the definition is clear, the implementation of risk-based decisions and the resultant strategy is challenging. Consequently, one might expect differences in risk conception and disparate risk management practices among land managers even for the same incidents (Thompson *et al.* 2016).

Land manager's perceptions of risk that are influenced by a multitude of factors, including assumptions, recent memories, quality, skill and bias associated with professional judgments, perceived affect, and real risk (Tversky and Kahneman 1973; Alhakamil and Slovic 1994; Sjöberg 2000; Kahneman and Klein 2009; Johnson-Laird 2010). These perceptions of risk can lead to excessive risk aversion in fire management decision-making, attributed to mental shortcuts developed during uncertain and conflicting decision environments (Maguire and Albright 2005). In addition, costly and risk-intolerant management strategies were favored by fire managers given social and political constraints simulated in hypothetical scenarios (Calkin *et al.* 2013). However, some studies have demonstrated that risk-accepting behavior is also present during wildfires. For instance, managers with extensive experience were more likely to identify

long-term risk considerations as important and tended to support the use of wildfires in wilderness areas when selecting fire management strategies for hypothetical scenarios (Wilson *et al.* 2011), suggesting that experience and individual risk tolerance play important roles in deciding whether to use wildland fire. Additionally, a commitment to return fire to fire adapted landscapes was the most significant factor influencing fire managers to use wildland fire (Williamson 2007).

Several researchers have attempted to describe perceptions of risk and identify prevailing issues affecting decision-making on wildfires with some success, but the samples are temporally and spatially constrained; for example, two wildfires in 2008 to evaluate external factors affecting decisions (Steelman and McCaffrey 2011) and 28 wildfires in 2008 to evaluate key decisions (Black 2009). Others have exploited surveys completed off-season when stress is low and prevailing issues are less apparent or forgotten to identify factors influencing decision-making on wildfires (Canton-Thompson *et al.* 2008; Calkin *et al.* 2013; Wibbenmeyer *et al.* 2013). Uniquely, the data for this dissertation includes 5,087 systematic evaluations of risk over the course of 8 years collected during wildfires, when the risk was tangible and outcomes were uncertain. These data provide a look at risk perceptions in the US not captured by other studies. Risk directly influences decisions to manage wildfires. Because a wildfire is likely to be one of the most influential disturbance agents on a landscape, it is warranted to consider whether long-term landscape resiliency and health is caused, in part, by management decisions to allow a fire to burn or not. These are critical factors to consider in light of climate change with existing evidence pointing to state changes from forests to grass or shrub lands for some dry forested ecosystems (Davis *et al.* 2019). Time is running out to make informed decisions on wildfires to increase landscape resiliency.

A myriad of information systems provide platforms to tell stories behind the events they are reporting. This dissertation arose from a desire to leverage a mandated decision support system requiring land managers to evaluate risk, objectives, strategies, and costs on wildfires. The Wildland Fire Decision Support System, WFDSS (Calkin *et al.* 2011; Noonan-Wright *et al.* 2011) was mandated for all federal wildfires in 2009 to comply with revised U.S. federal fire policy implementation (USDA/USDI 2009). Within the workflow of WFDSS is a relative risk assessment (RRA), providing a systematic structure to evaluate wildfire risk as a precursor to the development of management strategy. The RRA data are consistent, complete, and provide opportunities for both quantitative and qualitative exploration. They also provided a means of examining risk on an unprecedented number of fires and at variety of scales, from the incident to the unit, region, and nation. The RRA is an empiric risk, reflecting risk perceptions from small groups of land managers that are communicated while a wildfire is burning. This risk is arguably the most influential for strategic decisions made on wildfires. Unless otherwise noted, risk in this study is defined by the risk produced from the relative risk assessment.

Prior to this investigation, the information content of the WFDSS RRA data set and its suitability for studying risk systematically was unknown. Thus, an exploratory approach was taken to better understand the geography of wildfire risk perceptions, and then to identify factors leading to this risk. These considerations led to a related inquiry regarding how land managers connect fire management strategies and risk. Managers in the US are charged with risk-based decision-making which requires them to characterize the risk and to direct resources accordingly. By inference, reducing wildfire risk is expected to cut costs, lessen fire-fighter exposure, and expand the decision space to use fire for resource objectives. However, without understanding the specific factors that produce risk, it is difficult to identify strategies to reduce it. Presumably, when risk is low, managers may have more decision space and therefore more options to use wildfire to achieve a variety of objectives; and when risk is high, that decision space diminishes and land managers suppress fires. Identifying where risk is high and low and what factors are driving that risk, is the first step to mitigating it.

The dissertation is organized in three chapters, each in journal format with some redundancy in the respective introductions. Each chapter tiers from the previous chapter.

Chapter 2 explores the patterns of wildfire risk in the U.S. from the operational Relative Risk Assessments conducted by land managers on 5,087 wildfires from 2010-2017. Thirty-eight percent of these wildfires were considered high risk and 28% had high ratings for values at risk. Large regional variations in risk were evident with the West-Coast regions selecting high risk, and the Southwest and Eastern Regions favoring low risk. Regions with moderate risk profiles utilized unique combinations of risk elements. The Southwest and Southern regions used the highest diversity of options to determine risk and the Great Basin, Northern Rockies, and Northwest used the fewest. Circumstantial evidence suggested that risk was pre-determined on many fires. Considerable low risk was achieved in all regions despite structural application biases against it. By illuminating patterns of risk, this research intends to stimulate examination of the social, cultural, and physiographic factors influencing conceptions of wildfire risk.

In Chapter 3, the factors driving risk assessments were identified from text fields of the RRA justification. Fires in the Northwest and Southwest Geographic Areas (GAs) were used in order to contrast the two most-different risk regions in the US. In short, Northwest land managers utilize high risk to characterize wildfires more than other geographic areas and Southwestern land managers use low risk more than other regions. Annotation from 282 wildfires from the Northwest and Southwest geographic areas were coded and categorized using the risk assessment framework of hazards, values and probability. The effects of climate on seasonal severity, fuel condition, and fire behavior emerged as the most influential factors driving characterizations of risk in both regions. Common factors of low risk fires were low fire behavior, low spread

potential, fires occurring late in the season, numerous barriers, precipitation and high fuel moisture; while dry fuel moisture and large spread potential were synonymous with high risk fires. Precipitation extended the longevity of landscape barriers, especially in the Southwest. The results suggest that a scarcity of values at risk and a mild fire environment identify low risk fires regardless of location, while high risk fires reflect specific local values at risk and geography, under the umbrella of dry climate. The climatic contrasts between the two regions highlights how influential climate change will be on future characterizations of risk.

Chapter 4 uses the same qualitative data as described in Chapter 3 to understand how management strategies are articulated and connected to risk. Overall, strategy was discussed explicitly in ~30% of risk assessments, suggesting that managers are connecting risk and strategy. Suppression strategies dominate this discussion, associated most commonly with high risk fires. Land managers even discuss an intent to suppress when it's untenable due to steep topography and remoteness. 'Other' strategies prevail (e.g., monitoring, confine, point protection) when risk is low or moderate, especially in the Southwest. The Southwest discusses a diversity of 'other' strategies and leverages landscape barriers (e.g., previous wildfires, prescribed fires, fuel treatments) to support different strategies while the Northwest discusses either resource benefit or suppression exclusively and does not overtly link physical barriers to strategy. These results indicate that strategy and risk are often connected, representing an organization that is suppression-oriented and uses 'other' strategies infrequently when risk is low. By inference, an expansion of using fire to achieve resource objectives will require a reduction in risk and/or the increased application of 'other' strategies when risk is high. The ubiquity of landscape barriers in the risk conversation suggests that one way to reduce risk is to increase barriers. With the link made from risk to strategy, it may be possible to start identifying places where we expect more fire to be used to achieve resource objectives based on the geographic analysis of risk in Chapter 1.

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Chapter 2

Spatial Differentiation of Wildfire Risk in the United States from Systematic Operational Risk Assessments – How Risk is Characterized by Land Managers

Abstract

Risk management is a significant component of federal wildland fire management because policy mandates consideration of the use of fire to maintain and restore ecosystems while protecting life and property. In this study, we explore patterns of wildfire risk in the U.S. from the operational Relative Risk Assessments (RRA) conducted by land managers on 5,087 wildfires from 2010-2017. The RRA is the formal risk assessment used to develop strategies on emerging wildfires when concerns and issues related to wildfire management are in real-time. Thirty-eight percent of these wildfires were considered high risk and 28% had high ratings for values at risk. Large regional variations in risk were evident with the West-Coast regions selecting high risk, and the Southwest and Eastern Regions favoring low risk. Regions with moderate risk profiles utilized unique combinations of risk elements. The Southwest and Southern regions used the highest diversity of options to determine risk and the Great Basin, Northern Rockies, and Northwest used the fewest. Relative risk appeared pre-determined on many fires based on the homogenous selection of one rating for all levels of the risk assessment. Considerable low risk was achieved in all regions despite structural application biases against it. By illuminating patterns of risk, this research intends to stimulate examination of the social, cultural, and physiographic factors influencing conceptions of risk

Short abstract

There are regional patterns to risk in the United States, with the West Coast tending to use 'high' risk and the Southwest and the Eastern regions favoring 'low'. Risk profiles of the remaining GAs are 'moderate' with different combination of factors that make them unique.

Introduction

Wildland fire, climate variability, people, and vegetation have interacted over long time periods to create vast fire dependent ecosystems in the United States (Stewart 1951; Vale 2002; Whitlock *et al.* 2010; Marlon *et al.* 2012). Early in the 20th century, policy makers who were focused on the extraction of forest resources to fuel westward migration in the U.S. implemented a fire policy that directed all fire ignitions to be extinguished by 10 a.m. the next morning (Loveridge 1944). By the 1960's, momentum was building to restore fire to some affected ecosystems primarily in the National Park Service lands, followed later in U.S. Forest Service wilderness areas (van Wagtendonk 2007; Smith 2014). Iterations of the U.S. fire policy have evolved to

recognize fire as a 'critical, natural process' with the use of wildland fire as an important component of fire management (Zimmerman and Bunnell 2000). In practice, simultaneously using and extinguishing fire is complicated and consequently, the need to base fire management decisions within a risk framework is critical for success and accountability.

The concept of risk permeates every facet of federal wildland fire policy, guidance, and decision-making. Current fire policy states that federal land managers must consider both short- and long-term consequences (costs, fire-fighter exposure, life, property) and ecological benefits from the use of fire in addition to using specific decision support tools to analyze hazards and risks (USDA/USDI 2009). The related National Cohesive Strategy emphasizes a 'safe and effective wildfire response' as a primary tenet for assessing risk on individual wildfires (USDA/USDI 2011). However, characterizing risk is controversial and difficult to articulate when establishing strategies, goals and objectives for emerging incidents which are often chaotic, dangerous, expensive, and prone to controversy. Risk is the expectation of loss or benefit, based on the probability and consequence of uncertain future events (Finney 2005; Ager *et al.* 2010; Calkin *et al.* 2010; Yoe 2011; Miller and Ager 2013; Scott 2013; Thompson *et al.* 2015). While the definition is clear, the implementation of risk-based decisions and the resultant strategy is challenging. Consequently, one might expect differences in risk conception and disparate risk management practices among land managers even for the same incidents (Thompson *et al.* 2016).

Relative risk assessments such as the RRA in the Wildland Fire Decision Support System (WFDSS) provide estimates of risk based on a conditional risk assessment, given that a fire is already burning and actively spreading on the landscape. Relative risk is based on constrained temporal and spatial scales specific to a single wildfire and incorporates manager perceptions of risk. This type of risk differs from quantitative risk, which avoids risk perception and incorporates all potential fire and weather events that influence whether fires start and where they will spread and potentially impact values at risk (Scott 2013) for a unit, region, or nation. Unless otherwise noted, risk in this study is defined as the risk produced by a relative risk assessment. This is an empiric risk developed while a wildfire is burning, reflecting perceptions of small groups of land managers responsible for the incident, and it is this risk that is arguably the most influential for strategic decisions made on wildfires.

Importantly, risk perceptions inherent in relative risk assessments are influenced by a multitude of factors including assumptions, recent memories, quality, skill and bias associated with professional judgments, perceived affect, and real risk (Tversky and Kahneman 1973; Alhakamil and Slovic 1994; Sjöberg 2000; Kahneman and Klein 2009; Johnson-Laird 2010). These perceptions of risk can lead to excessive risk aversion in fire management decision-making, attributed to mental shortcuts developed during uncertain and conflicting decision environments (Maguire and Albright 2005). In one study, costly and risk-intolerant management strategies

were favored by fire managers given social and political constraints simulated in hypothetical scenarios (Calkin *et al.* 2013). However, other studies have demonstrated that risk-accepting behavior is also present during wildfires. For instance, managers with extensive experience were more likely to identify long-term risk considerations as important and tended to support the use of wildfires in wilderness areas when selecting fire management strategies for hypothetical scenarios (Wilson *et al.* 2011), suggesting that experience and individual risk tolerance play important roles in deciding whether to use wildland fire. Additionally, a commitment to return fire to fire adapted landscapes was the most significant factor influencing fire managers to use wildland fire (Williamson 2007).

The need to embrace the uncertainty of wildland fire is necessary to achieve the long-term missions and goals of natural resource management in the U.S., where fire is viewed as both a benefit and a hazard. Understanding limitations from risk perceptions have manifested in solutions such as those proposed by (Marcot *et al.* 2012), with formal procedures encompassing the four stages of structured decision-making. In addition to facilitating strategic decisions, structured decision making can also be used in an operational wildfire context (Taber 2013). Collectively, enormous resources have been directed at improving risk-informed decision-making, where the risks associated with unwanted fire interacting negatively with values at risk is mitigated with the goal of producing more strategies that increase safety, reduce costs, and ultimately achieve long term management objectives.

Integrating risk management and decision support – WFDSS and the relative risk assessment

In part to promote consistency in risk assessment in the U.S., the Wildland Fire Decision Support System (WFDSS) incorporated a systematic operational risk assessment tool called the Relative Risk Assessment (RRA) for emerging fires on federal lands. The RRA belongs to a collection of data, models, and tools for gaming expected fire behavior, cost, damage, and ecological benefit among other things, in the context of guidance from legally binding land management plans (Calkin *et al.* 2011; Noonan-Wright *et al.* 2011; Pence and Zimmerman 2011; Zimmerman 2011; Zimmerman 2012). Prior to 2009, multiple systems were in use in the U.S. to serve some of the same functions as WFDSS. For example, the Wildland Fire Situation Analysis (WFSA) supported suppression-oriented responses for undesired fires by comparing probable outcomes from two or more different management strategies. In contrast, the Wildland Fire Implementation Plan (WFIP) was used for naturally occurring fires in areas designated for the use of fire for ecological benefit. The hallmark of the WFIP was its guidance for explicit justification of a suppression response in areas where resource benefit fire was allowable. The Long-Term Implementation Plan (LTIP) evolved from the former two systems to guide management of protracted events which posed more uncertainty, required longer outlooks, and more frequent reconsideration of hazards and threats. All of these systems were integrated into a

single web-enabled decision support system (DSS) which was codified by federal policy in 2009 and adopted by every federal wildland fire agency in 2010 (Zimmerman 2012). Development of WFDSS capitalized on the emergence of national-scale cadastral and critical infrastructure data in the U.S., which together with spatial fire models, allowed managers to better quantify threats and hazards to values at risk. This was an important step in advancing risk assessment on wildland fires in the U.S. (Finney 2005).

Since 2010, WFDSS has evolved into a real-time, web-enabled data gathering platform, leveraging multiple geographic information systems (GIS) from other national-level projects, deterministic and probabilistic fire behavior modeling systems, weather analysis tools, and economic assessments of values. WFDSS shares many attributes with wildland fire DSS deployed in other parts of the world (e.g., (Bonazountas *et al.* 2007). In a global review of wildland fire DSS, four common attributes were identified: 1) implementation of a GIS to retrieve weather, values, topography, maps, and satellite fire detection data; 2) mapping of fire danger and fire occurrence; 3) fire spread modeling; and 4) interactive tools to prepare, plan and coordinate fire-fighting resources (Sakellariou *et al.* 2017). Uniquely, WFDSS also integrates spatially-explicit land and resource management plans to ensure that strategies and tactics comply with federal and agency policies across all lands. Adherence to land and resource management plans is legally binding, and allows for natural and cultural resources to be managed in light of tactical fire responses.

Within WFDSS, the Relative Risk Assessment is a semi-quantitative process enabling fire managers to assign relative rankings to risk elements using predetermined categories and terminology (Thompson *et al.* 2016). It is used by federal land management agencies to inform strategies on fires that are expected to persist for relatively long durations and/or cause management challenges. Each RRA includes high, moderate and low ratings for three elements (Values at risk, Hazard, and spread Probability) which are collectively integrated into an overall relative risk rating. Each risk element within the RRA is derived from three sub-elements again with high, moderate, and low ratings (except for the Probability element which has sub-elements having very high and extreme ratings in addition to high, moderate, and low). Most of the RRA elements are derived subjectively through deliberation by small groups of local decision-makers informed by models and data. RRA's are real-time assessments of risk to guide planning and management of incidents. As such, they provide snapshots of how land managers, administrators, and fire specialists with access to state-of-art data, models, and analysis tools assess risk on thousands of wildfires. Over the life of an incident, many RRAs may be produced in response to dynamics of the fire environment. These assessments inform the fire management strategies outlined in the WFDSS decision signed by an agency administrator, and because they document initial, largely-subjective risk specific to an individual fire, they are termed 'relative' risk assessments (Zimmerman 2017).

Records from the RRA database in WFDSS provide a means of identifying patterns of risk perceptions across the U.S. In this study, RRAs were examined from all completed wildfire risk assessments in the U.S. from 2010-2017 to gain insights into the risk profiles shaping fire management decisions. The WFDSS stores one of the most extensive and accessible records of fire management decisions in the world, and of all the data in it, the RRA is perhaps the most complete because it is mandated for all decisions and requires users to evaluate fires on the same criteria. In effect, WFDSS has transferred much of the historical record for wildland fires from cardboard boxes in district offices to a network accessible archive. All fire modeling outputs, risk assessments, economic analyses, environmental data, fire progression data, and associated text-based descriptions and justifications are stored in a retrievable database for each fire. This presents new opportunities to report on trends in decision making, with an eye on improving the safety and effectiveness of response to wildland fire.

Purpose

The purpose of this research is to detect patterns of wildfire risk from the U.S. WFDSS relative risk assessment and to identify areas where risk is distinct. Given the initial investigation of these data, the study is exploratory in nature and intended to facilitate generation of hypotheses to drive future study of human and physiographic factors behind patterns of risk. It focuses exclusively on the Relative Risk Assessment in WFDSS and seeks to answer the following questions:

1. What are the general characteristics of fires in WFDSS?
2. What is the wildfire risk profile for long duration, federal fires in the United States?
3. Are there structural biases within the risk assessment process that produce unequal probabilities of certain outcomes?
4. Are regional differences in risk apparent at the level of Geographic Area (GA)?
5. Is there evidence of risk gaming to gain pre-determined outcomes?
6. Do the factors (sub-elements) leading to a particular risk level vary by GA?
7. Are differences in risk perceptions evident between federal land management agencies?

The RRA is used primarily in federal jurisdictions and by some states (New Mexico, Arizona, and Alaska) and is biased strongly toward emerging incidents that are expected to cause containment problems or burn for long durations. Developing comprehensive decision documents is labor-intensive and managers are understandably reluctant to produce them if they are not mission critical; for instance, managers would likely avoid producing a formal decision for shorter duration fires where containment of the fire was close to being within an initial attack phase. For context, there were 532,455 wildfires in the US from 2010-2017 (NWCG 2018). Of these, 21 percent were fires on federal lands. Among federal fires, 4.5 percent resulted in

publication of a decision in WFDSS. The analysis which follows provides insights into risk on mostly federal lands for emerging fires that were expected to pose management challenges.

There is some significance to using WFDSS data to evaluate wildland fire risk. Although it is the official record for strategic wildfire decision-making on federal lands for longer duration fires, there has been no formal analysis of its contents. WFDSS was created to replace the various paper versions of decision-making on wildland fires (NWCG 2009) with most federal land management agencies actively documenting their decisions in WFDSS by 2010. Additionally, it represents fires from many users and jurisdictions in every geographic area in the United States (Figure 1). Finally, it is the most comprehensive dataset to date that addresses values at risk, hazard, probability and therefore risk in a systematic manner. The relative risk assessment must be completed before a formal decision describing the overall wildfire strategy can be documented in WFDSS.

Methods

Data sources

The data used in this analysis come from the Relative Risk Assessment in WFDSS and from regional fire occurrence data published by the National Interagency Fire Center (NIFC). The NIFC data are used exclusively to contextualize fires reported in WFDSS relative to total fire load. The RRA is composed of categorical data, with users selecting High, Moderate, and Low ratings for nine sub-categories to produce ratings for Hazard, Values, Probability, and ultimately Relative Risk. Users also write qualitative justifications for each specific element (Figure 1). The Values element consists of subcategories that collectively produce a rating for 'Value' or values at risk. For instance, social/economic concerns, natural/cultural/infrastructure values, and proximity and threat of the fire to the values are rated as High, Moderate or Low to derive an overall rating for Value. Hazards are assessed from current and expected fire behavior, fuel condition (relative to the fire regime), and potential fire growth. Finally, the probability of a fire becoming an active event that could adversely affect values is produced from time of season (the temporal context of the current fire in relation to the historical fire season), seasonal severity, and the quantity of physical barriers to fire spread. The ratings of each sub element are combined in a graphical table to assign a rating to each risk element (hazard, values, probability). The final relative risk rating is then derived from the three risk elements in a similar graphical table (Figure 1).

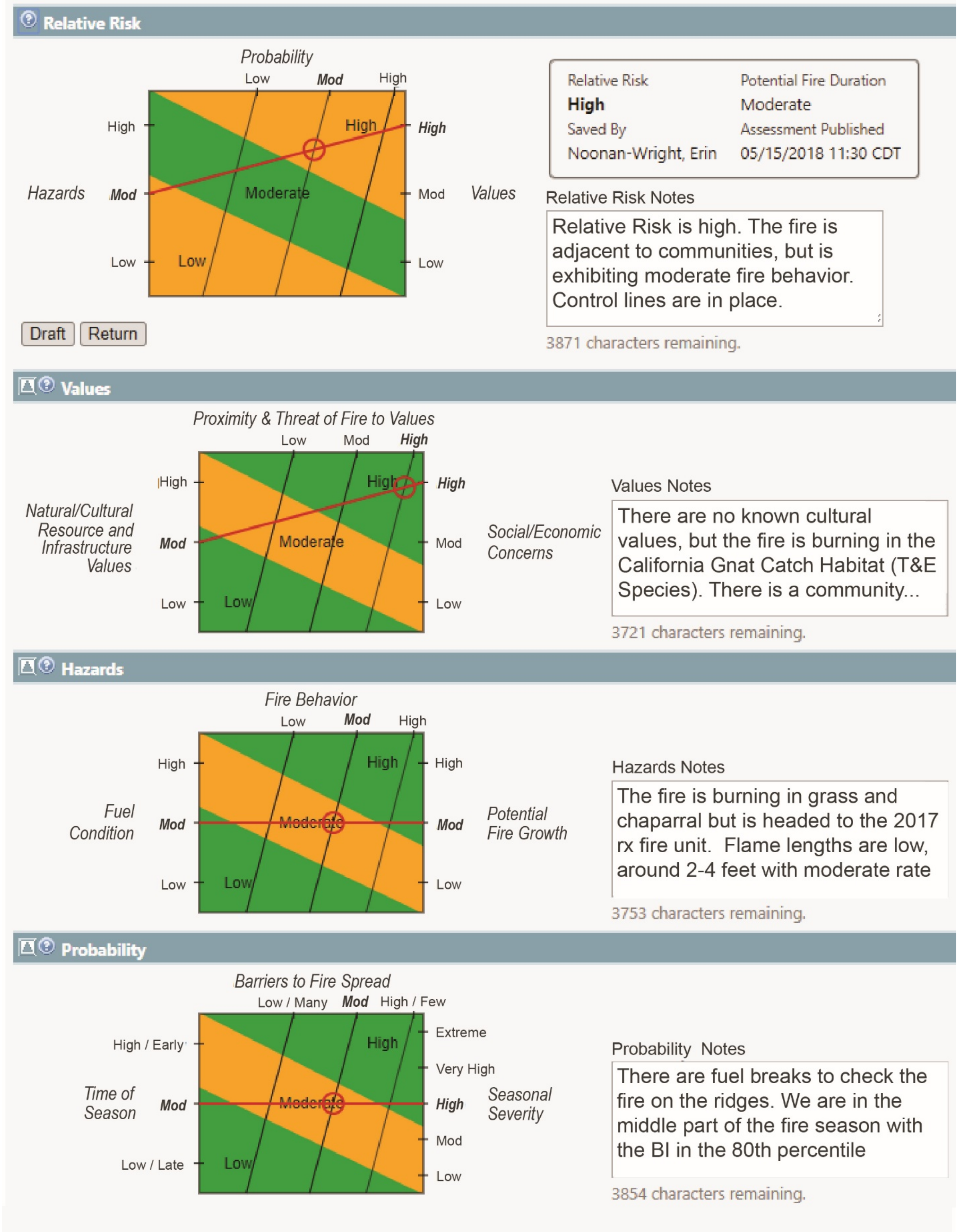

Figure 1. The relative risk assessment in the Wildland Fire Decision Support System (WFDSS).

An example of the relative risk assessment in the Wildland Fire Decision Support System (WFDSS), with three elements (Values, Hazards, and Probability) rated as high, moderate or low, leading to final relative risk rating.

Data collection

WFDSS is a J2EE, java server faces (JSF) web application using a service-oriented architecture (SOA) which integrates a number of other technologies in order to store, create, query, and display geospatial and tabular data through the application server as well as other services (Calkin *et al.* 2011; Noonan-Wright *et al.* 2011). Data stored in the relational data stream management system (RDSMS) were queried though the use of Structured Query Language (SQL) to link data tables and extract information. WFDSS is available to federal and non-federal employees and contractors involved with fire support who complete annual security training per U.S. Forest Service security requirements.

The WFDSS database contains more than 12,000 relative risk ratings from 2010 through 2017. To examine the RRA, all fire records and associated relative risk assessment information in WFDSS were queried, representing a temporal period marked by the first year all federal land management agencies used WFDSS for wildfires to the inception of this project. Duplicates and other anomalies with the data were remedied using CRAN – R (R Core Team 2019) and various packages to compute time (Grolemund and Wickham 2011), create and append data tables (Wickham 2007, 2014, 2016) and expedite processes (Bache and Wickham 2016). More than 134 variables were extracted from the WFDSS database. Thirty-six variables from the RRA were used in this analysis including numeric (mostly discrete variables) and categorical (with a mixture of ordinal and nominal variables). Qualitative notes were also included in the RRA dataset as '_notes' variables (Appendix A) but not used explicitly in this analysis.

Because numerous relative risk assessments can be completed during an incident, the first instance of the most frequently occurring relative risk rating was selected to represent the relative risk for that incident. In the case where incidents had only one high, moderate, and/or low RRA, the first rating was chosen to represent that incident's relative risk. Following this procedure, there were 5,087 unique relative risk assessments in the dataset, from Jan 1, 2010 to Dec 31, 2017.

The resulting RRA dataset is amenable to systematic analysis because it considers the actual risk attributed to each incident by fire managers through a systematic, comparable process. Patterns that emerge from it reflect a complex combination of human factors (perception, culture, risk tolerance) and physiographic factors (terrain, proximity, fuel condition, fire danger). Unless otherwise noted, risk is defined in this research as the outcomes of the WFDSS relative risk assessments made by land managers.

Definition of regions

Risk was assessed at regional scales, referred to as a Geographic Area (GA). GA is a codified institutional level of organization where wildland fire decisions are made in the US (Figure 2). During U.S. fire seasons, large fires are prioritized and fire management resources are allocated by Geographic Area Coordination Centers (GACCs) located in each of the 10 geographic areas. The GACCs also develop criteria to trigger planning level (PL) delineations which communicate the severity of the fire season and the need for more fire resources and logistical support from neighboring GACCs. The dispatch of fire-fighting resources, intelligence, reporting, and multi-agency coordination are also performed at the GACC level. Subsequent analysis also includes summaries at the unit-level (e.g. national forest or national park) and agency-level (e.g. Bureau of Indian Affairs, Bureau of Land Management, etc.).

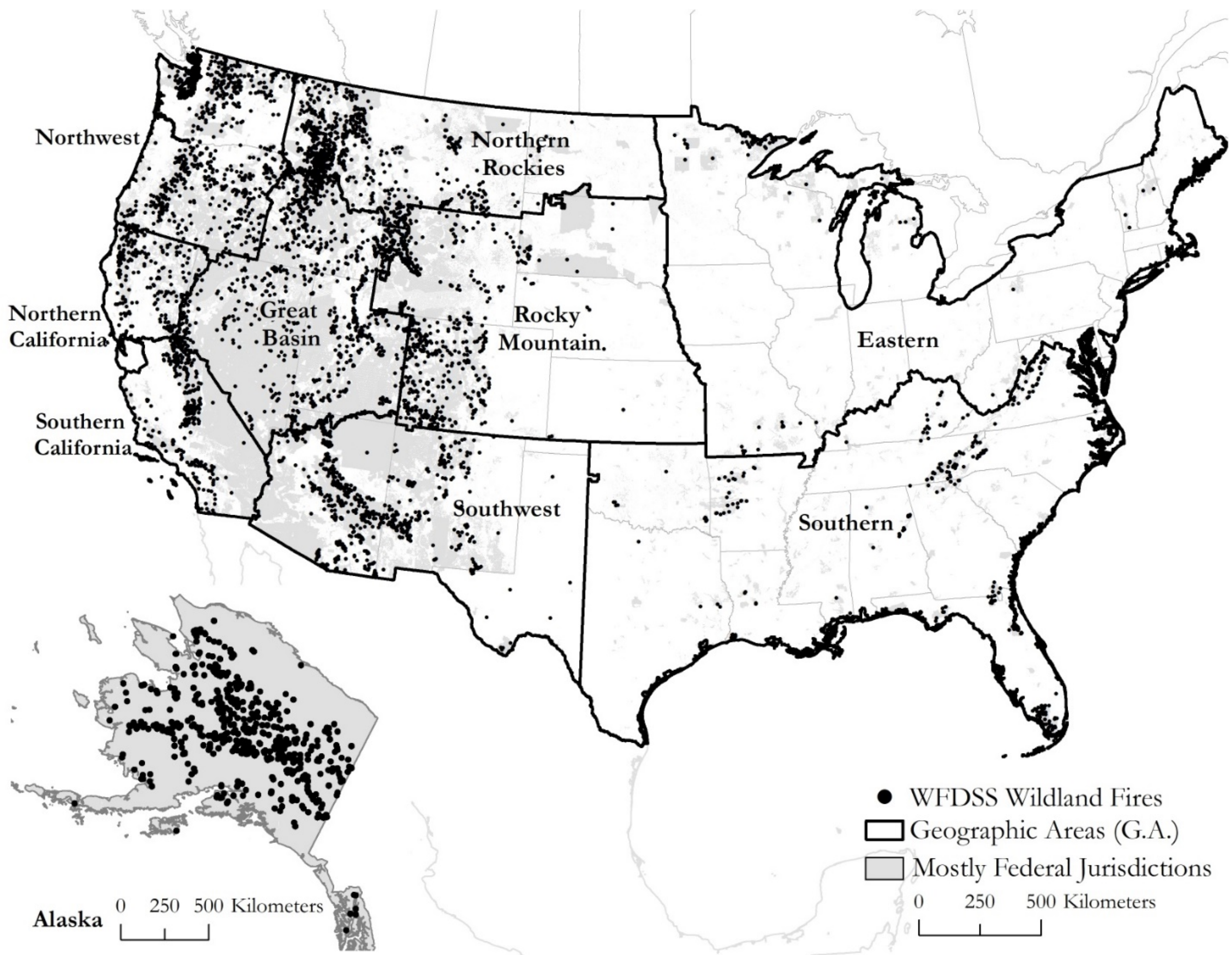

Figure 2. Geographic areas in the U.S. with wildfires from WFDSS

Locations of the 5,087 wildfire incidents (with a published relative risk assessment) within each of the 10 Geographic Areas and in relation to mostly federal lands (includes Alaska Native Corporation Settlement Act and BIA/Tribal lands).

Definition of land management agencies

The primary federal land management agencies that manage wildland fire are composed of the Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS) and the U.S. Forest Service (USFS). Each of these agencies collectively reference mission statements that focus on managing federal lands for future generations, maintaining and enhancing biodiversity (including plants, animals) and values important to the public (water, habitat, economic viability, cultural resources, etc.), coupled with agency specific foci. The BIA mission is to enhance the quality of life, promote economic opportunity, and carry out the responsibility to protect and improve the trust assets of the American Indians, Indian tribes and Alaska Natives (BIA 2019). The BLM manages approximately 1/10 the United States surface area and 30% of the nation's minerals and soils. Mineral, oil, and gas extraction, and livestock grazing are large components of BLM management. Specifically, their mission is to maximize public lands for commercial, recreational and lastly, conservation activities that enhances the quality of life for all citizens through balanced stewardship of American's resources and lands (BLM 2019). The NPS 'preserves *unimpaired* the natural and cultural resources and values of the National Park System for the enjoyment, education and inspiration of this and future generations…' The NPS manages 419 individual units including Yellowstone National Park, covering more than 34,000,000 ha (85 million ac.) in all 50 states with an emphasis on conservation (NPS 2019). With a particular focus on wildlife, the USFWS 'works with others to conserve, protect and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people.' The USFWS manages the National Wildlife Refuge System with more than 560 refuges, small wetlands, and special management areas consisting of approximately 60,700,000 ha. (150 million ac.) (USFWS 2019). Finally, the sole Department of Agriculture agency, the USFS, manages 154 national forests and 20 grasslands in 43 states, with a mission that is focused on sustaining health, diversity and productivity of the nation's forests and grasslands to meet the needs of present and future populations. Included in the USFS is an elite wildland fire fighting organization and a large forestry research enterprise (USFS 2019).

In the U.S. there can be a complicated intermix of different federal, state, county, and local jurisdictions that work collaboratively to manage wildfires, especially in wildland urban interface areas where population density is higher and structure fires and wildfires occur simultaneously. There are circumstances where federal agencies have jurisdiction to provide the strategy and intent of the wildfire, but local, county, and state jurisdictions have the suppression or protection responsibilities. This is most prevalent in the state of Alaska, where the BLM provides suppression capacity for the northern portion of the state, the Alaska Department of Natural Resources, Division of Forestry provides support in the south and the USFS provides support in panhandle, while numerous jurisdictions have the decision making authority to provide the

management strategy, objectives and intent for their specific unit (AWFCG 2010). We use the term multi-jurisdiction to refer to more than one agency or unit at managing wildfire, encompassing aspects of both management direction and protection responsibilities.

Frequency analysis

Computing observed frequencies

The observed frequencies of high, moderate, and low risk (expressed as percentages) were computed from counts of individual ratings for relative risk, the risk elements (values, hazard and probability) and the sub-elements. Counts were produced for the ten geographic areas and for the United States as a whole. Each tally was divided by the total for each respective geographic area to produce frequencies (expressed as percentages).

Computing expected frequencies from chance

The expected frequencies of high, moderate, and low risk (expressed as percentages) were computed from all possible combinations of sub-element ratings (n=32,805) for Relative Risk based on a random selection of risk ratings for each sub-element. Expected frequencies for sub-elements are one in three (33.3%) except for seasonal severity which is one in five (20%). These frequencies are referred to as '% expected' in proceeding analyses and graphs.

Relative frequencies

Observed frequencies (% observed) were compared to expected frequencies for GAs (% expected) and in order to express relative bias-corrected frequencies among regions. GA frequencies were also compared to US frequencies in order to express risk relative to the national picture (% $\text{observed}_{U.S}$). Relative frequencies were used to highlight unique trends between the GAs. Two selection metrics were computed to show the propensity to select specific ratings compared to some norm:

$$selection\ metric_{chance_i} = \frac{\%\ observed_{j,k}}{\%\ expected_{j,k}} - 1$$

Where:

$selection\ metric_{chance_i}$ = unit-less index showing the selection of ratings for each of the *(i)* Geographic Areas and the U.S. normalized by pure chance

$\%\ observed_{j,k}$ = percent observed frequencies for each *(j)* rating (high, moderate or low) by *(k)* relative risk, element, or sub element

$\%\ expected_{j,k}$ = percent relative frequencies from pure chance for each *(j)* rating (high, moderate or low) by *(k)* relative risk, element or sub element.

$$selection\ metric_{U.S._i} = \frac{\%\ observed_{j,k}}{\%\ observed_{U.S._{j,k}}} - 1$$

Where:

$selection\ metric_{U.S._i}$ = unit-less index showing the selection of ratings for each of the *(i)* Geographic Areas compared to the percent observed frequencies for the collective U.S.

$\%\ observed_{j,k\cdot}$ = percent observed frequencies for each *(j)* rating (high, moderate or low) by *(k)* relative risk, element, or sub element

$\%\ observed_{U.S_{j,k\cdot}}$ = percent observed frequencies of the United States for each *(j)* rating (high, moderate or low) by *(k)* relative risk, element or sub element.

In sum, the selection metrics reveal a propensity for the GAs to select specific ratings more or less relative to chance and the U.S. In the interest of simplifying interpretation, one is subtracted from relative frequency such that resulting negative values become the actual percentage difference between observed and expected, for example; -0.20 means that particular rating was chosen 20% less than the expected. For positive values, when 1 is added back to the value, the interpretation is that a region used a particular risk level more than expected; for instance a value of 2.5 indicates a higher usage for that rating of 350% more than expected.

Analysis techniques

Cluster analysis

Cluster analyses were performed on observed frequencies of risk for each GA and the U.S. to explore how geographic areas share or isolate selections of risk and its elements. The observed frequencies of all 27 possible combinations of values, hazard and probability were used as inputs to the relative risk clustering algorithm; for instance, the percent occurrence of HHM (High values, High hazard, Moderate probability). The observed frequencies for each sub-element combination by GA were also used as inputs to the clustering algorithms to predict how GAs cluster based on the elements: values, hazard and probability. For example, to cluster geographic areas for the Values element, observed frequencies for all combinations of high, moderate and low resources, threat, and concern were used. To predict how the GAs clustered based on Hazard, observed frequencies of fuel, fire behavior and potential were used as input; and the Probability element was clustered by observed frequencies of time of season, barriers, and seasonal severity.

We used agglomerative hierarchical cluster analysis on the observed frequency of each element combination with no scaling because the data were already scaled to percentages. Distance was measured as a squared Euclidean distance using Ward's method for a similarity metric, which evaluates an increase in sum of squares as group membership changes. The 'hclust' function in CRAN – R was used to produce the dissimilarity matrices and clustering.

Selection diversity

Some geographic areas opt for specific combinations of Low, Moderate and High ratings more than other combinations. To explore how 'diverse' the selection patterns were by geographic area, we used a non-parametric approach called Proportional Variability - PV (Heath and Borowski 2013). Unlike other measures of variation (coefficient of variation, standard deviation), the PV is not based on a measure of central tendency or average. Instead, it is based on a ratio comparison of all non-negative numbers.

For a given data set of *n* non-negative points ($z_i >= 0$), there are C=n(n-1)/2 unique combinations of situations for (z_i, z_j) which are used to calculate the relative difference D(z_i ,z_j). PV is then defined as:

$$PV = 1/C \sum_{comb} D(z_i, z_j), where$$

$$D(z_i, z_j) = \frac{|z_i - z_j|}{\max(z_i, z_j|)} = 1$$

The larger the PV, the more variability there are in counts between ratings (e.g., some combinations of ratings get used a lot and others with less frequency). If 'diversity' is defined as equal frequency of the selection of multiple combinations of ratings rather than just selecting a few (i.e. a GA always selects High Values, Hazard and Probability), then a lower PV indicates more diversity, because the GA would be using more combinations (a higher diversity) of ratings.

Results

What are the general characteristics of long duration, federal fires?

Between 2010 and 2017, federal land managers conducted 12,526 operational risk assessments on 5,087 fires. Unless otherwise specified, "fires" are defined as wildfires where a relative risk assessment was completed in WFDSS. More than one relative risk assessment was completed on 77.4% of fires (Table 1). The fires were generally long-duration events (average days between start and contained dates was 22.8 days) and 72.1% of them had only one jurisdiction responsible for the wildfire. About 1% of all fires received a published RRA in WFDSS with Alaska using WFDSS for the largest proportion (12.6% of all fires received a RRA), followed by the Great Basin who used WFDSS 5.6% of the time. Both of these geographic areas are dominated by federal lands. The trend is reversed for geographic areas that are more dissected with less federal land (Figure 2). Both the Eastern and Southern geographic areas used WFDSS to publish a RRA on roughly 0.1% of their fires. The Great Basin (977 fires, 19.2%) and Northern Rockies (802 fires, 15.8%) had the largest total number of fires in WFDSS, while Eastern (84 fires, 1.7%) and Northern California (217 fires, 4.3%) had the fewest. Alaska experienced the longest duration fires with an average of 41 days between the start and containment, while the Eastern geographic

area experienced the shortest duration incidents (12.2 days). Both the Northern Rockies and Northwest also experienced long duration fires (36.2 days, 28.4 days, respectively) relative to other regions (Table 1).

Table 1. U.S. federal fire information from the Wildland Fire Decision Support System - WFDSS

Fire data for Geographic Areas and the United States summarized from the Wildland Fire Decision Support System and the National Interagency Fire Center (NIFC) from 2010 - 2017.

	From WFDSS									From NIFC			
	Total (n)				Percent (%)					Total (n)			
Geographic Area	Fires[1]	RRA[2]	Days between Start and Contained Dates	Days between Start and Controlled Dates	Fires[3]	RRA[3]	More than 1 RRA/fire[4]	Single Juris.[5]	WFDSS Incidents/ Total NIFC fires[6]	Fires[7]	Acres[7]	Type 1 IMT[8]	Type 2 IMT[8]
Alaska	542	911	41	44.2	10.7	7.4	60.4	52.0	12.6	4,311	9,516,655	6	27
Eastern	84	222	12.2	31.3	1.7	1.8	83.8	89.3	0.1	83,009	848,657	5	39
Great Basin	977	2003	15.3	20.4	19.2	16.3	69.9	78.0	5.6	17,344	7,307,807	25	143
No. California	217	903	17.1	29.1	4.3	7.3	90.9	65.4	0.7	31,075	2,834,582	30	79
No. Rockies	802	1562	36	43.7	15.8	12.7	68.5	77.4	3.5	23,081	4,589,162	35	122
Northwest	649	1813	28.5	40.4	12.8	14.7	84.8	67.3	2.5	26,130	7,315,057	60	228
Rocky Mtn.	478	1183	15	23.9	9.4	9.6	77.9	69.7	1.8	25,909	3,850,664	23	70
So. California	304	1313	21.6	32	6.0	10.7	91.3	61.2	0.9	34,867	2,161,433	28	79
Southern	304	799	12.7	22.4	6.0	6.5	81.7	76.3	0.1	260,353	10,279,050	33	60
Southwest	730	1615	17.2	24.8	14.4	13.1	74.6	81.6	3.2	22,844	5,050,397	43	79
U.S.	5087	12324	22.8	31	100	100	77.4	72.1	1.0	528,923	53,753,464	288	926

[1]Fires represent wildfires in WFDSS with a completed RRA

[2]RRA represents the total number of completed relative risk assessments.

[3]Percent fires is computed as the total wildfires (with a completed RRA) per GA divided by the 'US', similarly done for the percent RRA.

[4]'More than 1 RRA/fire' is the percent frequency that an individual WFDSS fire had more than one RRA, a measure of the usage of the RRA in WFDSS.

[5]'Single Juris' is the percent of WFDSS fires that involve only one jurisdiction, an indicator of complexity.

[6]‘WFDSS Incidents/Total NIFC fires’ is the difference between WFDSS fires compared to the total record of all wildfires as recorded from NIFC, and indicates a measure of the usage and complexity of wildfires by GA.

[7]Fires and Acres from NIFC reflect all fires, not just federal fires, summarized from the National Interagency Coordination Center yearly statistics and summary data reflecting ‘tactical statistics’ and not necessarily individual agency figures.

[8]Type 1 Incident Management Team (IMT) and Type 2 IMT are also indications of complexity and costs.

All of the GAs published multiple relative risk assessments on at least 60% of their fires, reflecting the dynamic nature of fire management. The West Coast regions of the Northwest, Northern California, and Southern California completed multiple RRAs on over 84% of their fires. The latter three regions also had fewer fires that involved only one jurisdiction (61.2%, 65.4%, 67.3%, respectively) while Eastern and Southwest had the most fires involving only one jurisdiction (89.3%, 81.6% respectively). Nearly half (48%) of WFDSS incidents in Alaska involved more than one jurisdiction, likely due to the unique roles of the BLM, USFS, and State of Alaska providing suppression services on each other's lands, with strategic decision making authority belonging to the jurisdiction that manages the land. Multi-jurisdictional fires can increase the complexity of fire management in the US because different agencies often have competing land management objectives. For example, most federal agencies can employ fire management strategies other than suppression especially in remote locations to achieve objectives related to long term ecosystem health and sustainability. In contrast, most state, county and local agencies are tasked to utilize suppression strategies to protect values at risk from wildfires (values usually within or near the wildland urban interface).

Another indicator of complexity on wildfires is the utilization of Incident Management Teams (IMT). IMTs are generally used to manage longer duration fires that have a high probability of impacting values at risk with a Type 1 IMT being used for the most complicated incidents. Alaska and the Eastern GAs used the fewest number of Type 1 IMTs (n=6, 5, respectively) while the Northwest and Southwest used the most (60, 43, respectively). The Northwest also used the most Type 2 IMTs (n=228), followed by the Great Basin (n=143) and Northern Rockies (n=122), while Alaska and the Eastern GAs used the least (27, 39 respectively). A normalized look at IMT usages reveals that Eastern, Northern California, Northwest, Southern California, and Southern all exceed 3 teams per 10 WFDSS fires (range 3.1 – 5.2).

Wildfire statistics reveal interesting patterns for U.S. agencies as well. The USFS had the most wildfires with a published relative risk assessment in WFDSS from 2010 through 2017 (61.7%), followed by the BLM (27.8%), state-level wildfire agencies including the State of Alaska, which was the primary contributor to this percentage (12.5%) and the NPS (11.6%), BIA (10.9%), and the USFWS (5.7%). Approximately 70% of all relative risk assessments in WFDSS for the time period involved the USFS. The NPS and USFWS recorded the highest proportion of wildfires in WFDSS (18%, 12%, respectively). The USFS and NPS had the highest proportion of single jurisdiction wildfires (75.5%, 67.9%, respectively). Other, county and local, and state agencies had the lowest proportion of single jurisdiction fires, because the WFDSS system is mandated for only federal wildfires and most states and other jurisdictions have different reporting venues (Table 2), excepting the states of New Mexico, Arizona and Alaska which employ WFDSS to document wildfire decisions.

Table 2. Multi-jurisdictional WFDSS and NIFC fires by agency from 2010 – 2017.
A summary of WFDSS and National Interagency Fire Center (NIFC) fire data from 2010 through 2017 by agency.

	From WFDSS								From NIFC	
	Total (n)			Percent (%)					Total (n)	
Agency	Fires[1]	RRA[2]	Days between Start and Contained Dates	Fires[4]	RRA[4]	More than 1 RRA/fire[5]	Single Juris.[6]	WFDSS Incidents/ Total NIFC fires[7]	Fires[8]	Acres[8]
USFS	3138	8382	24.7	61.7	68.0	80.5	75.5	0.06	53,771	12,997,659
NPS	591	1611	32.1	11.6	13.1	81.4	67.9	0.18	3,196	1,066,943
USFWS	289	761	33.7	5.7	6.2	79.0	36.0	0.12	2,459	872,463
BLM	1412	3812	21.1	27.8	30.9	82.2	35.6	0.07	19,838	15,670,523
BIA	554	1561	29.9	10.9	12.7	83.1	31.6	0.02	32,253	3,062,380
ANCSA	126	288	47.9	2.5	2.3	76.0	14.3	--	--	--
Cty & Local	262	822	12.5	5.2	6.7	87.5	2.3	--	--	--
State	634	1894	28.5	12.5	15.4	85.0	13.2	0.00	*420,938*[9]	*21,366,750*[9]
Other	454	1240	16.1	8.9	10.1	83.7	1.3			
DOI	2359	6055	22.6	46.4	49.1	80.1	41.5	0.04	57,746	20,672,309
Federal	4949	12114	23.1	97.3	98.3	77.9	59.4	0.04	111,517	33,669,968
Non-Federal	138	210	14.9	2.7	1.7	55.8	7.7	0.00	420,938	21,366,750
US[3]	5087	12324	--	--	--	--	--	--	532,455	55,036,718

[1]Fires represent wildfires in WFDSS with a completed RRA and may be counted multiple times reflecting multi-jurisdictional fires involving more than one agency/jurisdiction.
[2]Total Relative Risk Assessments (RRA) is the number of RRAs an agency completed and may represent multi-jurisdictional fires.
[3]'US' fires and RRA are the total number of wildfires in WFDSS with a completed Relative Risk Assessment and the total number of completed RRAs in WFDSS, respectively. US fires from NIFC represent total federal and non-federal fires and acres.
[4]Percent fires and percent RRA are computed by agency values divided by the 'US'. The presence of multi-jurisdictional fires results in the total percentage exceeding 100% for these variables.
[5]'More than 1 RRA/fire' is the percent frequency that an individual WFDSS fire had more than one RRA, a measure of the usage of the RRA in WFDSS.
[6]'Single Juris' is the percent of WFDSS fires that involve only one jurisdiction, an indicator of complexity.

[7]'WFDSS Incidents/Total NIFC fires' is the difference between WFDSS fires compared to the total record of all wildfires as recorded from NIFC, an indicator of the usage and complexity of wildfires by agency.
[8]Fires and Acres from NIFC reflect all fires, not just federal fires, summarized from the National Interagency Coordination Center yearly statistics and summary data reflecting 'tactical statistics' and not necessarily individual agency figures.
[9]State and 'other' were combined in the NIFC statistics and represent non-federal fires.

What is the wildfire risk profile for long-duration, federal fires in the United States?

Nationally, a slight majority of fires (n=1915, 38%) received moderate overall relative risk ratings, followed by high (n=1913, 37.6%), and low (n=1239, 24.4%). Land managers chose moderate (52.1%) and high (30.2%) for the probability element. They selected low (37.3%) and moderate (35.9%) for values at risk. Hazard was the most symmetrical element with a selection for moderate (41.6%) and roughly equal proportions of high and low (Figure 3).

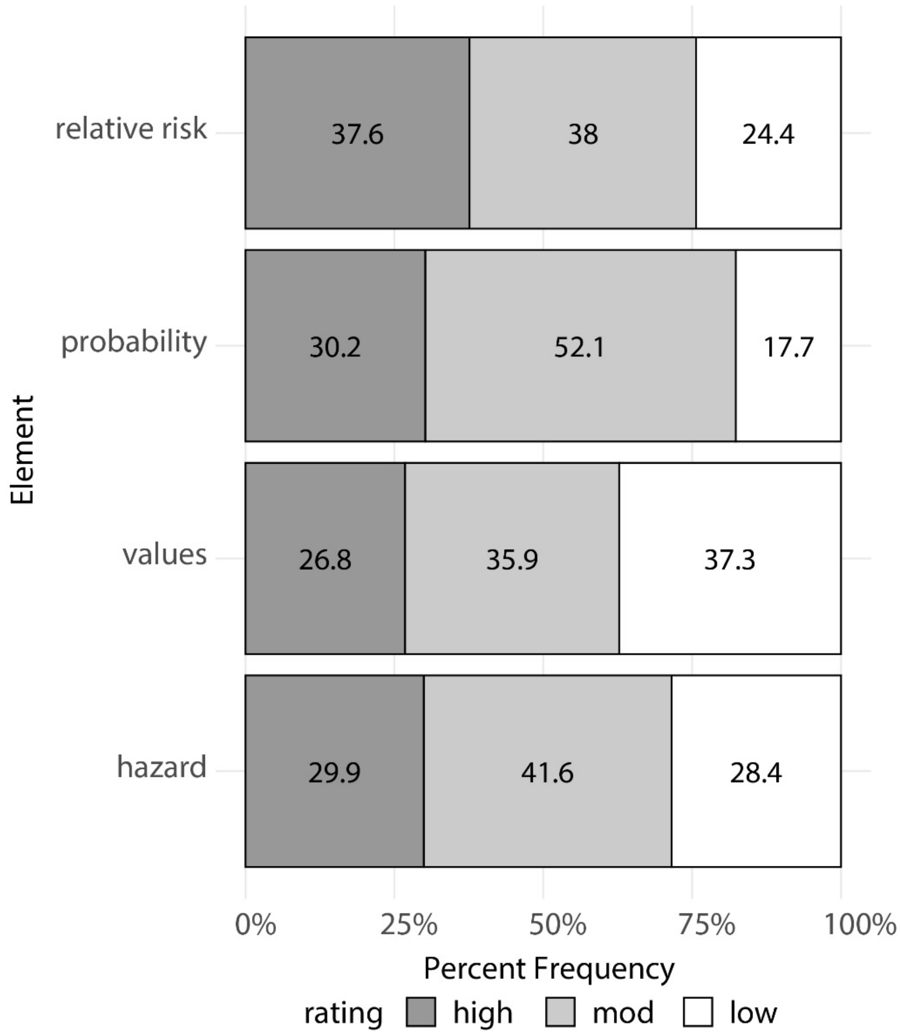

Figure 3. Relative frequencies for the risk assessment and its elements in the U.S.

Sub-element frequencies reveal that greater than 40% of fires were expected to have little impact on values (values- resources) or few socio-economic concerns (values- concern), but 25% of fires were close to values (values- threat) and expected to reach them without mitigation (Figure 4). Observed and expected fire behavior (hazard- fire behavior) was low to moderate on 84% of fires and high on 16%. More than 75% of fires were expected to experience little to moderate fire growth and provide low to moderate resistance to fire control (hazard- potential) with a nearly identical proportion of fires burning in fuels with low to moderate loadings, intact to moderately intact fire regimes, and/or effective to marginally effective fuels treatments (hazard- fuel condition). A majority of fires (58%) were burning in the middle of the fire season (probability- time of season) with 25% late in the season and 17% early. Barriers to fire spread (probability- barriers) were not present on 19% of fires, numerous on 31% with about 80% having at least

some barriers limiting fire spread. Individually, the sub-element frequencies illustrate moderate to low concern roughly 80% of the time (on a per-sub-element basis).

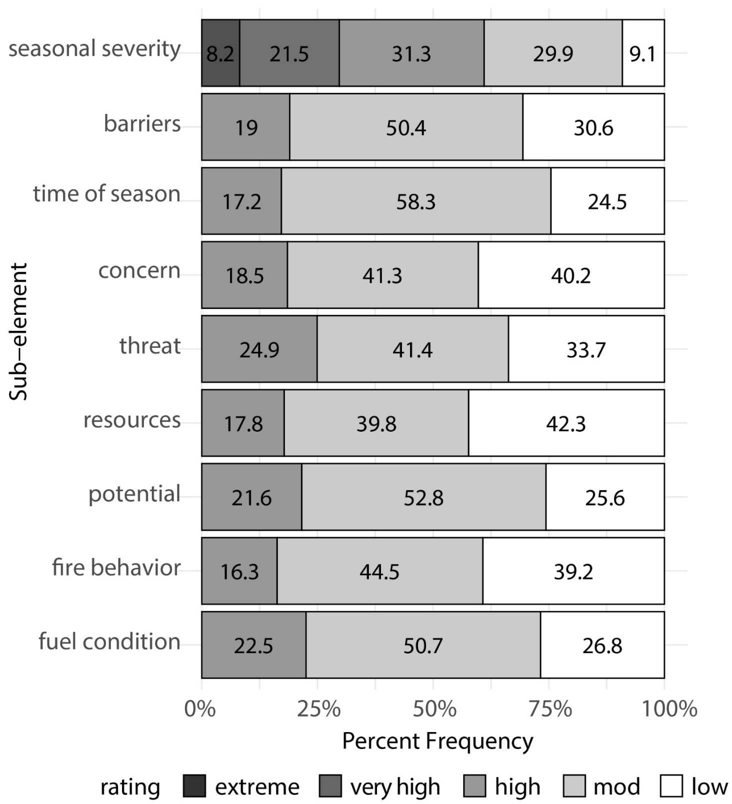

Figure 4. Frequency of sub-elements for the United States

The sub-elements for Probability include Seasonal Severity (ss), Barriers to Fire Spread (bar), and Time of Season (tos); the sub-elements for Values include Social, Economic and Political Concerns (conc), Proximity and Threat of the fire to Values (threat), and Natural, Cultural Resources and Infrastructure Values (res); and those for Hazard include Fire Potential (pot), Fire Behavior (fbeh) and Fuel Condition (fuel). Seasonal Severity has five options for ratings, while the other sub-elements have three (low, moderate, high).

Are structural biases inherent in the relative risk assessment?

Although high, moderate, and low ratings for each of the sub-elements have equal probability of selection (0.33 except seasonal severity with 0.20 probability), the shape and form of the element graphs produce unequal probabilities of high, moderate and low ratings for values, hazard, and probability. High ratings are expected in about 1/3 of the element assessments, moderate ratings in about 1/2, and low ratings in about 1/5 (Table 3). Similarly, the overall relative risk is biased toward high and moderate risk and strongly against low risk, the latter occurring 7 percent of the time from randomly selected sub-elements.

A reconsideration of the risk portfolio of long duration, federal fires in the U.S. in the context of these structural biases reveals a somewhat different profile than the one presented above. Compared to expected (random) outcomes, high and moderate relative risk were generally under-utilized by decision-makers while low relative risk was selected with greater frequencies. In other words, fire managers achieved considerable low relative risk at the expense of high and moderate relative risk in spite of a strong bias against it. This pattern also occurred in two of the risk elements, where low values and low hazard were invoked 2x and 1x more than expected, while high ratings were always under-utilized compared to expected for values, hazard, and probability (Figure 5). Although equal chance applies to the sub-elements, users selected primarily moderate ratings at the expense of high or low. One exception was in the values sub-elements, where a selection for low was observed for concern (conc), threat (threat), and resources (res). One of the hazard sub-elements, fire behavior (fbeh), showed a similar propensity for managers to select low ratings instead of high or moderate.

Table 3. Relative risk by geographic area and the U.S

Observed frequencies by Geographic Area and the U.S. of elements from the relative risk assessment. Expected frequencies (Exp.) is also included to provide a comparison of observed frequencies to pure chance.

Element	Exp. (%)	US (%)	Great Basin (%)	Rocky Mtn. (%)	Southern (%)	Alaska (%)	No. Rockies (%)	No. California (%)	North west (%)	So. California (%)	Eastern (%)	South west (%)
High Relative Risk	47.2	37.6	35.1	35.4	39.1	32.3	37.3	48.4	57.0	46.4	20.2	24.0
Mod Relative Risk	45.8	38.0	39.0	42.7	39.5	45.8	39.9	34.1	27.7	31.9	42.9	37.7
Low Relative Risk	7.0	24.4	25.9	22.0	21.4	22.0	22.8	17.5	15.3	21.7	36.9	38.4
High Values	33.3	26.8	28.5	26.4	26.0	18.6	21.2	36.9	42.2	35.2	10.7	19.2
Mod Values	48.1	35.9	33.9	38.1	37.2	34.9	37.8	35.5	33.0	35.9	45.2	37.3
Low Values	18.5	37.3	37.7	35.6	36.8	46.5	41.0	27.6	24.8	28.9	44.0	43.6
High Hazard	33.3	29.9	27.0	27.2	33.6	26.2	29.2	42.4	46.4	35.5	14.3	18.9
Mod Hazard	48.1	41.6	43.6	46.9	45.4	46.9	40.8	34.1	33.3	37.5	38.1	42.7
Low Hazard	18.5	28.4	29.4	25.9	21.1	26.9	30.0	23.5	20.3	27.0	47.6	38.4
High Probability	35.6	30.2	23.5	25.1	29.9	29.2	36.8	39.6	44.5	34.5	23.8	19.6
Mod Probability	44.4	52.1	57.2	56.7	50.7	60.9	54.1	45.6	45.9	54.3	45.2	41.5
Low Probability	20.0	17.7	19.2	18.2	19.4	10.0	9.1	14.7	9.6	11.2	31.0	38.9

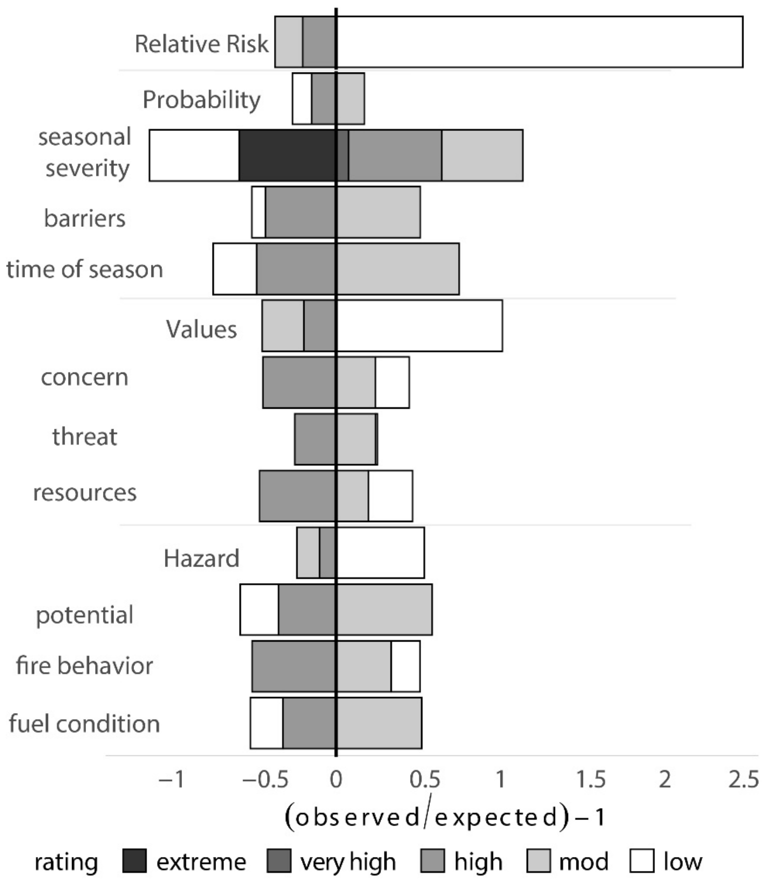

Figure 5. U.S. risk elements difference from chance.

Risk in the U.S. compared to chance for relative risk and all elements and sub-elements. Positive values indicate frequencies greater than chance for the specific element. Negative values indicate frequencies less than chance to a specific rating and element combination.

Are regional differences in risk apparent at the level of Geographic Area (GA)?

The Southwest and Eastern GAs strongly opt for low relative risk; the Northwest, Northern California, and to a lesser extent Southern California GAs select high relative risk, and the other regions fall in between (Figure 6). These patterns are pronounced relative to the risk frequencies of the US as a whole (Figure 7). The Great Basin risk profile is virtually identical to the National (average) profile, followed closely by the Southern, Northern Rockies, and Rocky Mountain GAs. All of the regions select low relative risk more than chance (7%, Table 3). The Northwest and No. California stand out as the only regions using high relative risk more than chance (Table 3).

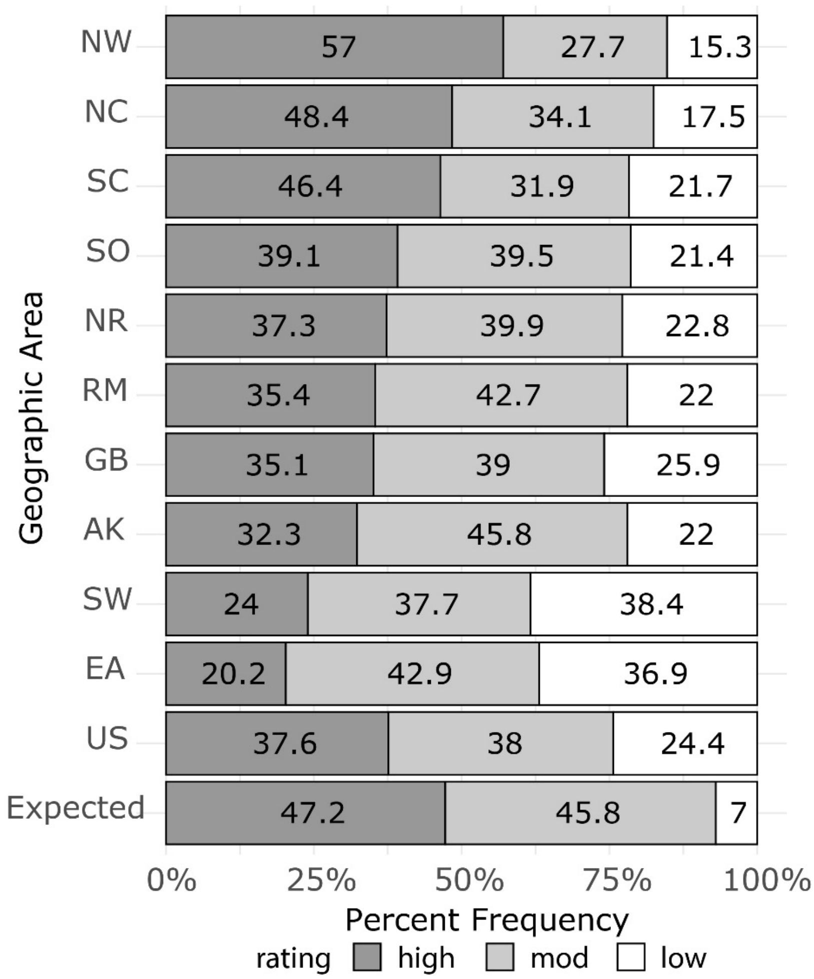

Figure 6. Relative risk by geographic area.

The percent frequencies of high, moderate and low relative risk by geographic area. Geographic Areas include the Northwest (NW), Northern California (NC), Southern California (SC), Southern (SO), Northern Rockies (NR), Rocky Mountain (RM), Great Basin (GB), Alaska (AK), Southwest (SW), Eastern (EA), the United States (US), and Expected Frequencies.

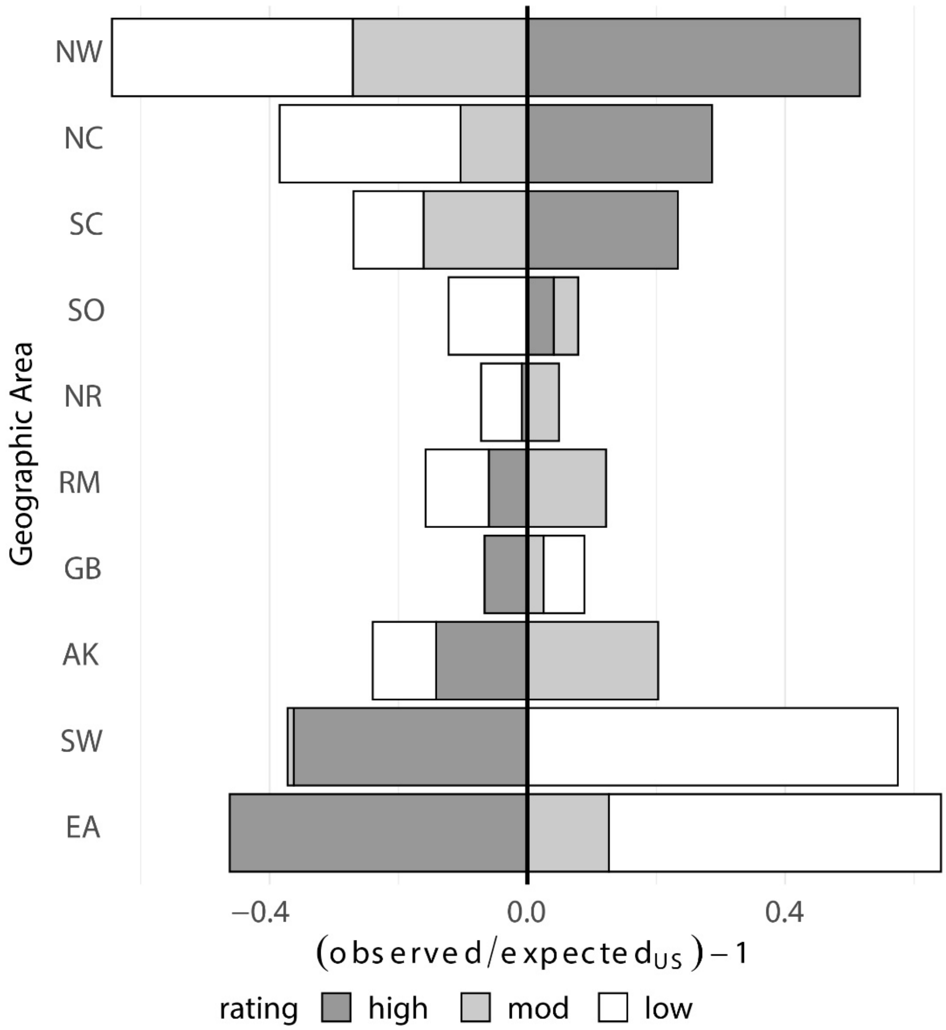

Figure 7. Geographic area relative risk difference from the U.S.

Geographic area relative risk ratings compared to the U.S. using the selection metric equation. Positive values show higher usage for specific ratings while negative values show less frequent usage. Geographic areas include the Northwest (NW), Northern California (NC), Southern California (SC), Southern (SO), Northern Rockies (NR), Rocky Mountain (RM), Great Basin (GB), Alaska (AK), Southwest (SW) and Eastern (EA) ranked from highest to lowest usage of high relative risk.

A dendrogram produced by hierarchical clustering of the main risk elements (values, hazard, probability) produced four general risk groups consistent with the patterns described above (Figure 8). Geographic Areas on the West Coast make up a high risk group; Southwest and Eastern form a low risk group; Rocky Mountain, Great Basin, and Southern are a National Average group; and Alaska and Northern Rockies make up a National Average subgroup that tends to perceive somewhat lower values and higher probabilities than the National Average group.

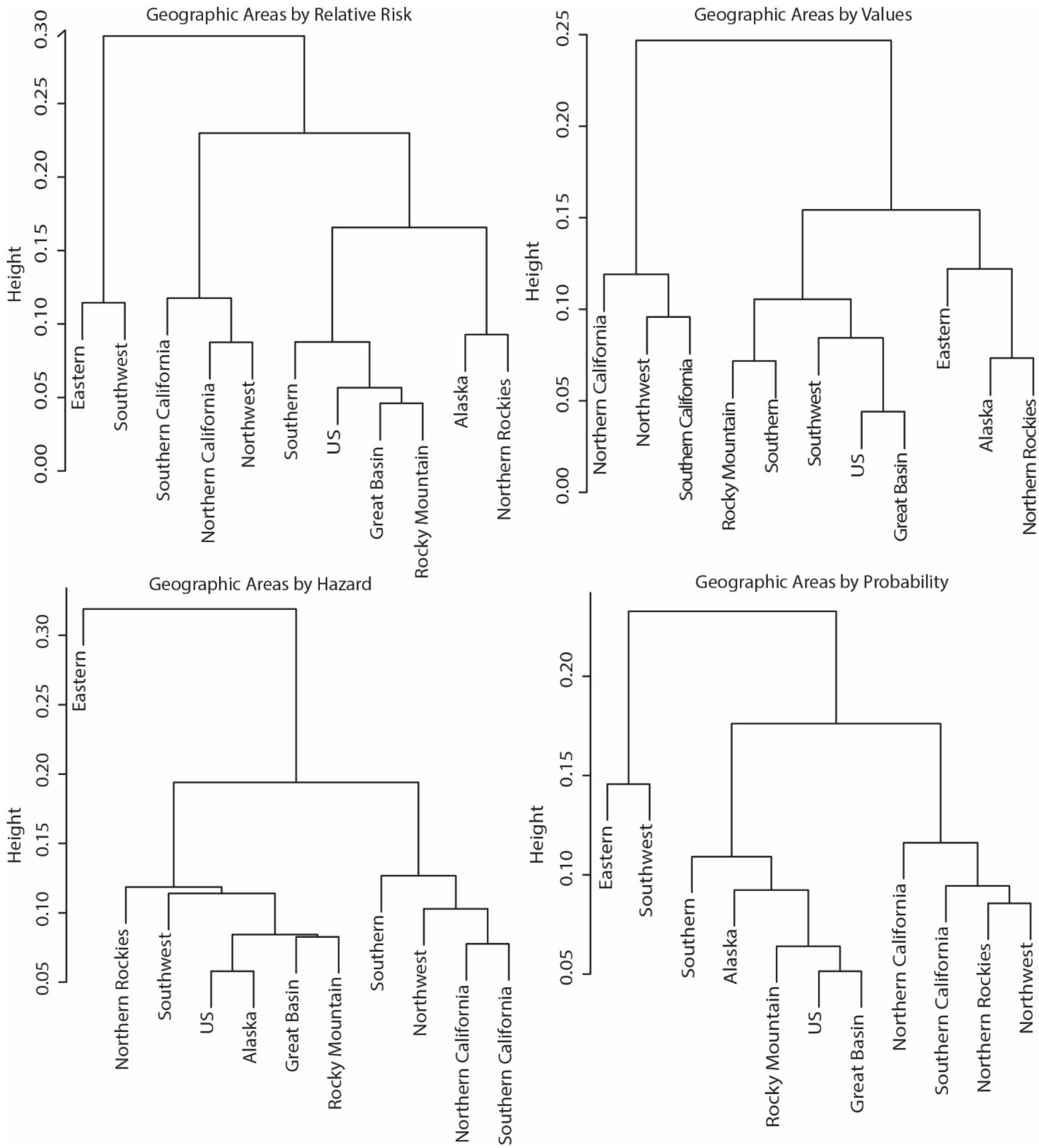

Figure 8. Hierarchical Clustering of the Risk Elements for each GA and the U.S.

Dendrograms of relative risk from (frequencies by geographic area for values, hazard, and probability), Values (frequencies of resources, threat, and concerns), Hazard (from frequencies of fuel condition, fire behavior and potential) and Probability (frequencies of seasonal severity, barriers and time of season).

Clustering individually on the risk elements reveals other differences. For values (resources, threat, concern), the Northern Rockies, Alaska and Eastern form a low value cluster. Northern California, the Northwest, and Southern California clustered separately as high value. The rest of the GAs, including the US as a whole, clustered in the middle (Figure 8). For hazard (fuels, fire behavior, fire potential), Southern joined the high-risk group of Northern and Southern California and the Northwest. The remaining GAs clustered together in unique patterns: Rocky Mountain and Great Basin; U.S. and Alaska; Northern Rockies and Southwest. Eastern, which had the smallest sample size, clustered independently. Probability (time of season, barriers, seasonal severity) produced the familiar low-risk group of Eastern and Southwest, a moderate probability group (Rocky Mountain, Great Basin, Southern, Alaska, and the US), and the Northern Rockies joined the high-risk group of the Northwest, Northern and Southern California.

When combinations of Value, Hazard and Probability were explored within a dissimilarity matrix (Table 4), some common attributes emerged within the groups. The high risk group (Northwest, Northern California, and Southern California) generally used high relative risk derived from a combination of high values, hazard and probability more than the other groups. They also select low ratings at a lower frequency compared to other GAs. Southern California was the most different in this group, using a greater frequency of low ratings and low relative risk and employing a greater diversity of options to arrive at high risk compared to the Northwest and Northern California. The low-risk group (Southwest and Eastern) used low relative risk ratings and used many combinations of elements to achieve low risk. They also used high ratings with less frequency.

Table 4. Usage of risk elements by geographic areas and the U.S.
Relative frequencies (expressed as proportions) of the unique combinations of hazard, value, probability combinations that produce a high, low and moderate rating for relative risk. Ratings include High (H), Moderate (M), and Low (L) for relative risk, values (val), hazard (haz) and probability (prob) elements. 'Values, Hazard, Prob.' refers to the 27 unique combinations of those elements and ratings to derive a relative risk rating. Expected (Exp.) frequencies or those derived from chance were computed for each unique combination. Values with darker shades of red indicate higher usage.

Relative Risk	Values, Hazard, Prob.	val	haz	prob	Exp. (%)	US (%)	Great Basin (%)	Rocky Mtn. (%)	Southern (%)	Alaska (%)	No. Rockies (%)	No. California (%)	North west (%)	So. California (%)	Eastern (%)	South west (%)
H	HHH	H	H	H	4.0	12.9	11.7	11.5	11.2	7.7	13.2	18.4	22.7	18.1	4.8	8.2
H	MHH	M	H	H	5.7	5.7	3.4	4.4	6.9	6.3	7.4	8.8	10.6	4.9	2.4	2.1
H	HHL	H	H	L	2.2	0.4	0.3	0.2	1.0	0.0	0.1	1.4	0.5	0.3	0.0	0.5
H	HHM	H	H	M	4.9	4.4	5.7	5.4	4.6	2.4	1.7	6.0	6.8	6.6	0.0	3.3
H	MHM	M	H	M	7.1	3.3	2.8	2.5	5.6	3.7	4.0	2.8	3.1	4.3	2.4	2.3
H	HLH	H	L	H	2.2	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.2	0.0	0.0	0.1
H	HMH	H	M	H	5.7	2.4	2.3	1.7	3.6	2.8	2.1	4.6	3.4	3.0	0.0	1.4
H	MMH	M	M	H	8.2	4.0	2.5	4.2	2.3	6.3	6.4	3.7	3.2	3.3	6.0	3.0
H	HMM	H	M	M	7.1	4.5	6.6	5.4	3.9	3.0	2.2	2.8	6.6	5.9	4.8	3.0
L	HLL	H	L	L	1.2	0.4	0.2	0.2	0.7	0.4	0.1	0.9	0.6	0.3	1.2	0.7
L	LLL	L	L	L	0.7	8.3	9.9	9.0	6.3	5.4	5.0	7.8	4.9	3.6	15.5	16.4
L	MLL	M	L	L	1.8	2.8	2.6	2.9	3.0	1.1	1.2	1.4	1.1	2.6	7.1	7.1
L	LLM	L	L	M	1.5	10.1	9.7	7.7	7.6	13.5	15.5	7.4	7.2	13.8	8.3	7.1
L	LML	L	M	L	1.8	2.8	3.5	2.1	3.9	1.7	1.0	0.0	1.4	1.3	4.8	7.0
M	LHH	L	H	H	2.2	1.5	1.2	0.8	1.6	2.8	1.4	3.2	1.5	0.3	3.6	1.0
M	LHL	L	H	L	1.2	0.1	0.0	0.2	0.3	0.2	0.0	0.5	0.0	0.0	1.2	0.1
M	MHL	M	H	L	3.2	0.4	0.6	0.6	0.3	0.2	0.1	0.5	0.0	0.3	0.0	0.7
M	LHM	L	H	M	2.7	1.4	1.3	1.5	2.0	3.0	1.2	0.9	1.2	0.7	0.0	0.7
M	LLH	L	L	H	1.2	0.9	0.5	0.4	1.0	0.4	2.0	0.0	0.6	1.0	2.4	1.1
M	MLH	M	L	H	3.2	0.6	0.3	0.2	0.7	0.4	0.6	0.9	0.3	2.0	2.4	0.7
M	HLM	H	L	M	2.7	1.1	1.1	0.8	0.3	1.8	1.2	1.4	1.4	0.3	0.0	1.0
M	MLM	M	L	M	4.0	4.2	5.0	4.6	1.6	3.9	4.2	3.7	4.0	3.3	10.7	4.1
M	LMH	L	M	H	3.2	2.2	1.7	1.9	2.6	2.4	3.6	0.0	2.0	2.0	2.4	2.1
M	HML	H	M	L	3.2	0.6	0.6	1.0	0.7	0.4	0.2	1.4	0.2	0.7	0.0	1.0
M	MML	M	M	L	4.6	2.0	1.5	1.9	3.3	0.7	1.2	0.9	0.9	2.0	1.2	5.3
M	LMM	L	M	M	4.0	10.0	9.7	11.9	11.5	17.3	11.3	7.8	5.9	6.3	6.0	8.1
M	MMM	M	M	M	10.3	13.1	15.3	16.7	13.5	12.4	12.6	12.9	9.7	13.2	13.1	11.9

The Moderate group(s) are the rest of the geographic areas that chose moderate ratings with some isolated high or low selections depending on the main elements. The group containing the Northern Rockies and Alaska selected low values with higher frequencies. When moderate risk was selected, it was derived mostly from combinations of moderate probability and hazard along with moderate or low values. High probability was a strong driver for the group's high relative risk fires. Even for its low risk fires, probability was more frequently rated as moderate when other main elements were low. Alaska used a higher diversity of combinations to achieve a moderate relative rating, selecting for low values compared to the Northern Rockies. The second moderate group is composed of the Great Basin, Rocky Mountain and Southern GAs. They selected moderate risk with a coincident usage of moderate ratings for all the main elements. Second to this selection was moderate risk from low values, and moderate hazard and probability. High values were a driving factor for high risk fires. The Southern GA is the most different in this group and uniquely chose high hazard and selected a higher diversity of options for all of its risk categories.

Another way to look at differences between the GAs is by examining the diversity of ratings for values, hazard, and probability leading to a particular relative risk. The non-parametric Proportional Variability metric was used to characterize diversity of risk by region, where maximal diversity is defined as equal frequency of selection of all possible element combinations (e.g., PV = 0) and minimal diversity indicates the use of the same element combination for every decision (PV = 1). The Southwest and Southern regions were the most diverse and the Great Basin, Northern Rockies, and Northwest the least diverse (Table 5). All of the regions exercised the lowest diversity of risk ratings for low risk fires except the Eastern GA, and four regions used the highest diversity of choices for high risk fires (NW, NC, AK, SO). The Southwest used the highest diversity for moderate ratings, followed by the Great Basin, Southern California, Rocky Mountain, and Northern Rockies.

Table 5. Diversity of relative risk usage by geographic area.

The Proportional Variability (PV) for all combinations of elements leading to a relative risk frequency; followed by PV for High, Moderate, and Low Relative Risk fires. Lower values indicate a wider range of elements and ratings to derive a relative risk rating.

Geographic Area	PV All (%)	PV High (%)	PV Mod (%)	PV Low (%)
Southwest	64.4	59.7	57.2	67.7
Southern	65.3	61.8	64.7	66.9
No. California	68.8	62.6	67.6	78.9
Eastern	68.9	65.6	71.7	62.2
Alaska	69.2	63.7	69.2	78.2
So. California	69.3	65.5	63.6	82.5
Rocky Mtn.	69.4	67.5	65.9	71.8
Great Basin	70.1	67.0	62.8	79.2
No. Rockies	70.3	68.7	67.2	86.8
Northwest	71.7	69.4	72.2	76.7

Is there evidence of risk gaming to gain pre-determined outcomes?

There is evidence that risk is pre-determined on many fires as indicated by a manager selections to arrive at a specific relative risk through the pathways of LLL, MMM, and HHH (Value, Hazard, & Probability). Managers can select options to obtain a risk assessment rating, which they can adjust before they formally complete the assessment. LLL, which has a 0.7 percent chance of selection was obtained on 8.3 percent of risk assessments nationally, while HHH which has a 4.0 percent chance of selection was obtained on 12.9 percent of assessments (Table 4). MMM was also used heavily (13.1%), but only modestly more than expected due to chance (10.3%). Overall, more than half of the possible combinations of value, hazard, and probability were rarely or never invoked.

National choices for risk are perhaps more revealing in some of the lesser used combinations. For example, LLM (Low Value, Low Hazard, and Moderate Probability) was selected over other combinations that produced low relative risk, suggesting a tolerance for elevated probability if value and hazard were low. Similarly, LMM (Low Value, Moderate Hazard and Probability) was used frequently to produce moderate relative risk, indicating general comfort with moderate hazard and probability as long as values were low. Finally, MHH was used slightly more for high relative risk fires, revealing that moderate values along with high hazard and probability occurred more commonly than expected. The combinations that included mixes of low and high ratings (e.g., HHL, HLH, LHH, HLL) were used sparingly.

Do the factors (risk sub-elements) leading to a particular risk level vary by GA?

The evaluation of the sub-elements presents an opportunity to evaluate the frequency of ratings without bias due to the structure of the RRA. Generally, moderate to low ratings were selected by all GAs for all sub-elements (Figure 9). Overall, natural-cultural-infrastructure values, socio-economic concerns, threat to values, and fire behavior trend low in comparison to the other sub-elements. Some specific regional differences are also evident when the GAs are compared to the US as a whole. For example, fuel condition poses an elevated risk in Northern California, Southern California, the Northwest and Southern relative to the other GAs and fire is more proximate to values in the two California regions and the Northwest. Barriers limiting fire spread are less prevalent in the Northwest and Northern Rockies and more prevalent in the Southwest and Eastern. Seasonal severity is more often extreme and very high in Southern California, Northern California, Northern Rockies, Northwest, and arguably for the Eastern Region that selects extreme seasonal severity more than any other GA. Time of season is often late in the Southwest, which is rarely the case for Alaska, and can occur throughout fire season in Southern and Eastern. Potential for fire spread is comparatively low in Eastern, Southwest, and to a lesser extent Rocky Mountain and high in Northwest, Northern California, and Alaska. Social-economic concerns are low in the Southwest and Alaska and high in Southern California and the Northwest, while resource and infrastructure values are low in Alaska, Northern Rockies, and Eastern and relatively high in Northern California and Northwest. Southern California has fewer natural resource/infrastructure concerns and more social-economic concerns relative to Northern California.

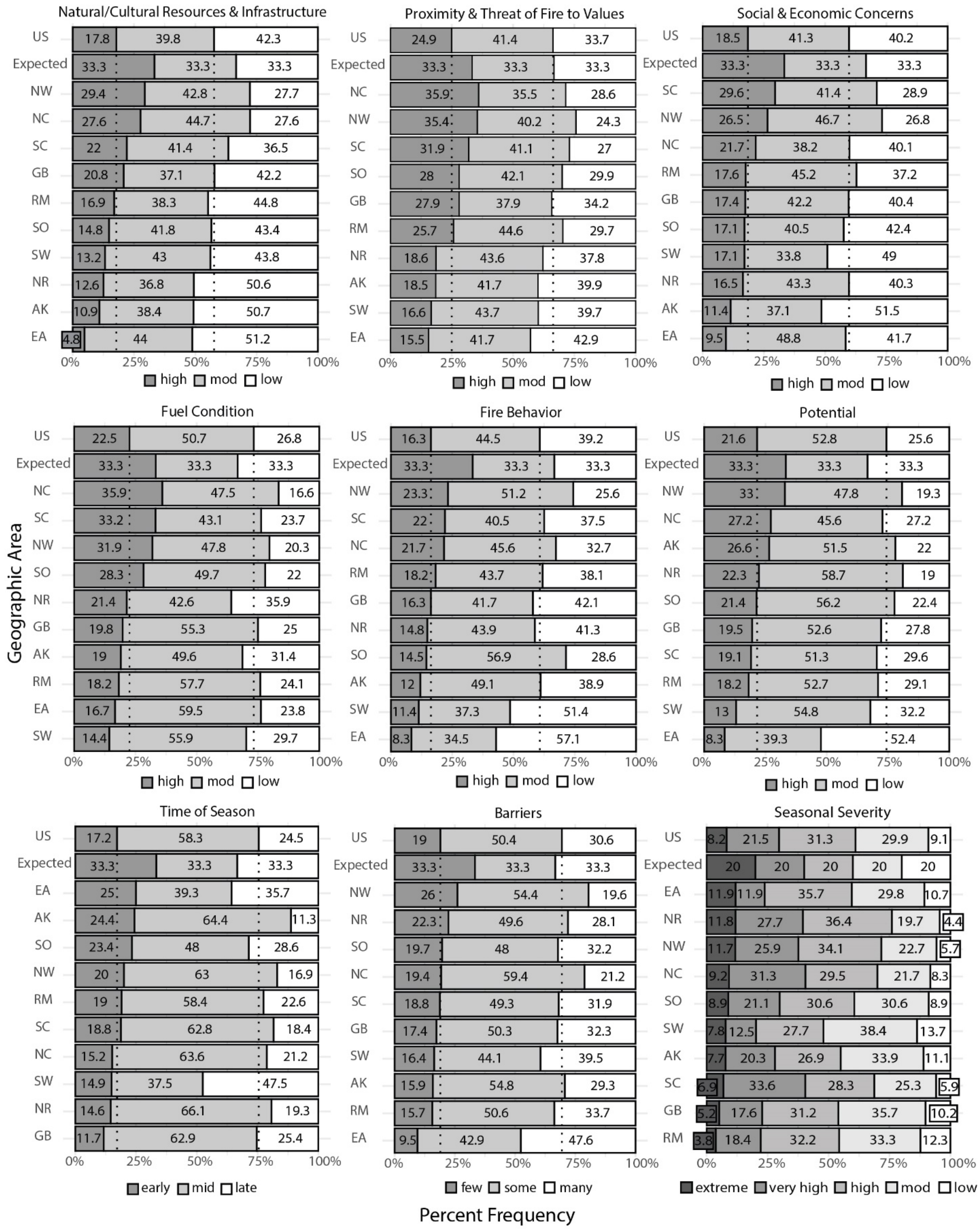

Figure 9. Frequencies of sub-elements by geographic area.

Frequencies of high, moderate and low ratings for sub-elements by geographic area, the U.S. and expected. Geographic Areas include the Northwest (NW), Northern California (NC), Southern California (SC), Southern (SO), Northern Rockies (NR), Rocky Mountain (RM), Great Basin (GB), Alaska (AK), Southwest (SW), Eastern (EA), the United States (US) and expected. Dotted lines extend from the threshold of high, moderate and low ratings from the U.S. and show how the GA frequencies compare to the US. Value sub-elements, followed by hazard and probability sub-elements are shown sequentially.

Are differences in risk evident among land management agencies?

The National Park Service (NPS) uses high relative risk with the lowest frequency compared to other agencies, selecting moderate and low relative risk with greater frequencies (Figure 10). The U.S. Forest Service (USFS) also uses moderate and low relative risk relative to other agencies. County and local, state and 'other' jurisdictions invoke high relative risk and strongly limit low relative risk. Of the federal agencies, the Bureau of Indian Affairs (BIA) and the Bureau of Land Management (BLM) use high relative risk with the U.S. Fish and Wildlife Service (USFWS) selecting high and moderate in similar proportions. All agencies use low relative risk more than by random chance except the 'other', county and local and state agencies. With the exception of the USFS and NPS, all agencies select low relative risk with lower frequencies (< 24.4%) when compared to the national average for the U.S. Ninety-eight of the 138 non-federal fires occurred in Alaska reflecting the multi-jurisdictional role of the State of Alaska and in some instances, the Alaska Native Claims Settlement Act (ANCSA) involvement in managing federal wildfires. The remoteness of many of these fires in Alaska likely contributed to the frequency of moderate and low relative risk for these non-federal land management agencies.

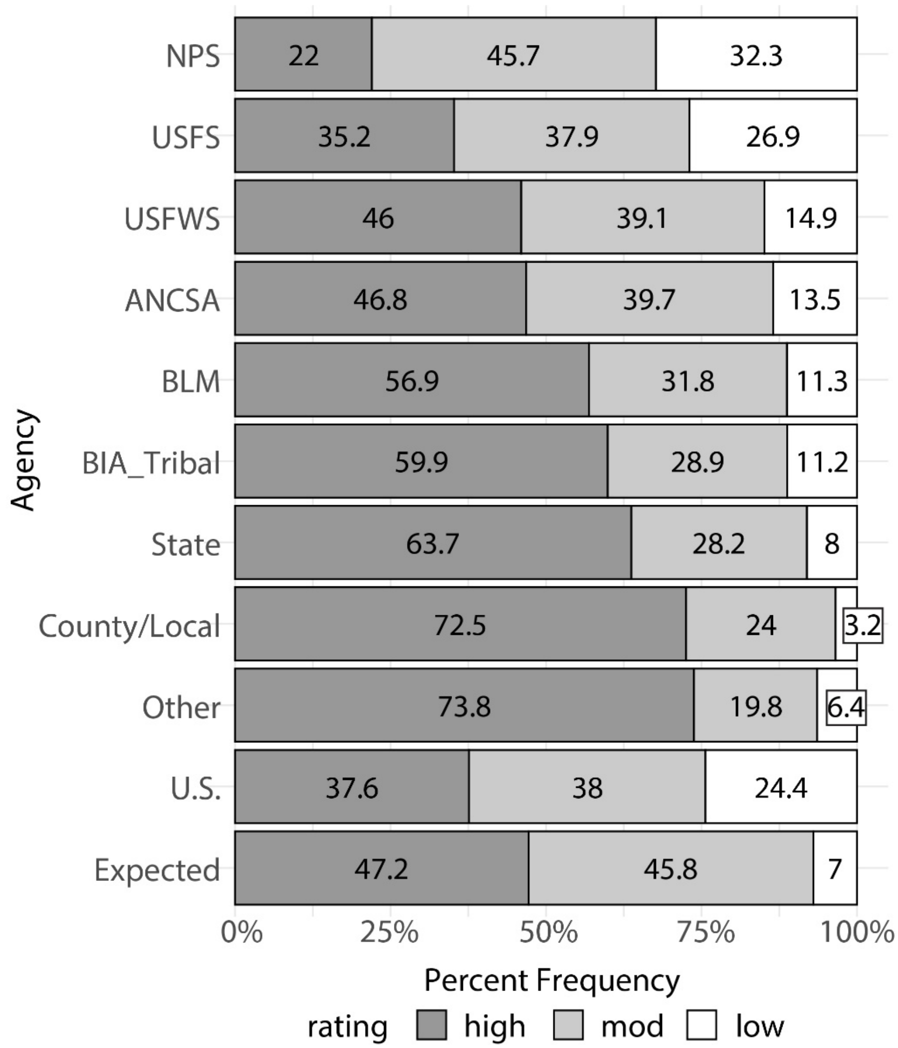

Figure 10. Relative Risk by agency including summaries for Department of Interior (DOI), Federal (DOI, USFS), Non-federal (ANCSA, Other, State, County & Local), the U.S., and expected due to chance.

Discussion

The concept of risk pervades fire decision-making in the U.S. because federal policy mandates consideration of the use of fire to maintain and restore ecosystems while simultaneously protecting values at risk including life and property. Many remote fires that are extinguished to protect life and property are a missed opportunity to restore ecosystems and decrease fuels, and conversely, fires that are used to meet land management objectives can be a potential threat to life and property. While life and private property are salient to all wildfire objectives, a patchwork of priorities for fire management exist, in part, because the missions of the various federal agencies differentially emphasize protection objectives of values at risk versus ecosystem values. Almost by default then, wildland fire management is set up to be complex in the U.S., because when federal policy is applied on a specific wildfire, tension often arises from the

juxtaposition of protection objectives for values at risk with objectives recognizing the natural resources expected to benefit from fire. Fundamentally, the reason the assessment of risk factors so heavily into wildland fire decision-making is because land managers are charged with protecting life and property first, do not wish to expose fire fighters to unnecessary danger, and do not want to spend vast sums of money eliminating fire from landscapes that need fire to remain healthy.

Despite the complexity inherent in balancing these factors, fire managers used the formal WFDSS risk assessment process on only 5,087 of 528,923 total fires (~1 percent) between 2010 and 2017. By inference, 99% of wildfires in the period were either not federal (417,406 fires), not long duration, were extinguished or went out on their own before a formal assessment was necessary. The fires examined in this study were long duration, lasting 20-30 days on average and over 30% were shared between more than one jurisdiction, suggesting a degree of administrative complexity. WFDSS fires were also dominated by one agency, the US Forest Service (~60%), indicating a fairly strong influence of this agency on the data.

Notwithstanding the generally complicated nature of wildfires represented in WFDSS, most of the United States selected low and moderate ratings for relative risk even though the risk assessment is strongly biased against the selection of low relative risk. Given the amount of bias in the RRA against low risk, with significantly fewer combinations of sub-elements to produce a low relative risk rating, the U.S. still finds low risk two to three times more than expected. These findings indicate that a majority of federal wildfires that are complex enough to merit a formal risk assessment are not rated as high risk. The reasons they are not perceived to be high risk may be due to a lack of values at risk in the areas where these fires occur (value ratings are consistently rated lower than other elements in all GAs), or federal land managers may be able to mitigate the adverse effects of fire from important values at risk while concurrently allowing fire to burn for resource benefits. It is accepted theory that many of the ecosystems in the U.S. both evolved from wildland fire and continue to benefit from it (Agee 1993) and federal policy strongly acknowledges its role in the environment. The selection of low and moderate ratings suggests that some land managers may have a higher risk tolerance.

Although we do not have evidence that risk level translates directly into particular fire management strategies, we suspect that strategic approaches are more limited on higher risk fires. Therefore, a risk assessment that pre-disposes high risk outcomes may inadvertently be limiting strategic responses on many fires and maintaining a status quo suppression bias (Wilson *et al.* 2011; Calkin *et al.* 2015; North *et al.* 2015). Currently, structural biases inherent in the relative risk assessment lend themselves to obtaining high, then moderate and rarely, low characterization of risk. Arguably, it may be better to err on the side of caution and infer higher risk to minimize the chance of under-characterizing risk (Type I error), as was preferred when the prescribed natural fire program was emerging in the U.S. in the 1970s. However, it may be

time for policy makers to revisit the structure of the relative risk assessment to ensure that land management objectives are being best served. If a long-term goal of federal fire management is to restore ecosystems then a risk assessment process that provides equal chances of high, moderate, and low risk might support the use of more fire on the millions of acres of federal land that are experiencing a fire deficit (Parks *et al.* 2015). In addition, wildfire limits the subsequent occurrence of future large wildfires (>20ha) and lessens the likelihood of future fire spread events at least for 6-18 years (Parks 2015; Parks *et al.* 2016), suggesting that extinguishing a natural ignition may have unintended, future negative consequences for adjacent values at risk.

Revisiting the structure of the RRA may also be warranted because only a few combinations of elements are used regularly to derive risk. Approximately 30% of the element combinations were invoked less than 1% of the time. Further, due to the diagonal risk, regions within the RRA graphs, the elements on the right-hand side of each graph produce a different effect on risk than the elements on the top and left (e.g., Values (RRA), Social/Economic Concerns (Values), Potential Fire Growth (Hazard), and Seasonal Severity (Probability)). For example, if low values are selected, it is never possible to obtain high relative risk, but if low probability or hazard are selected, the chance of getting high relative risk is 1 in 9. Similarly, a selection of high values gives a 1 in 9 chance of a low relative risk rating while a selection of high probability or hazard removes any chance of a low relative risk rating. There is no such differential effect at moderate risk ratings. The same patterns hold for Social/Economic Concerns (Values), Potential Fire Growth (Hazard), and Seasonal Severity (Probability).

Regional Differences in Risk

There is a regional geography to wildfire risk in the U.S. and although our research focused exclusively on national and regional scales, it is insightful to look within regions. We used the location quotient (LQ) to identify spatial concentrations of high relative risk by unit across the western U.S. (Figure 11). Unit refers to the geographic management within agencies, for example, individual national forests, national parks, reservation, and wildlife refuges. The location quotient measures the extent to which different units depart from some norm (Shaw and Wheeler 1985); in this case, the concentration of high risk compared to the national occurrence of high risk, with values >1.0 indicating concentrations of high risk and therefore, the selection of high risk more than the national average.

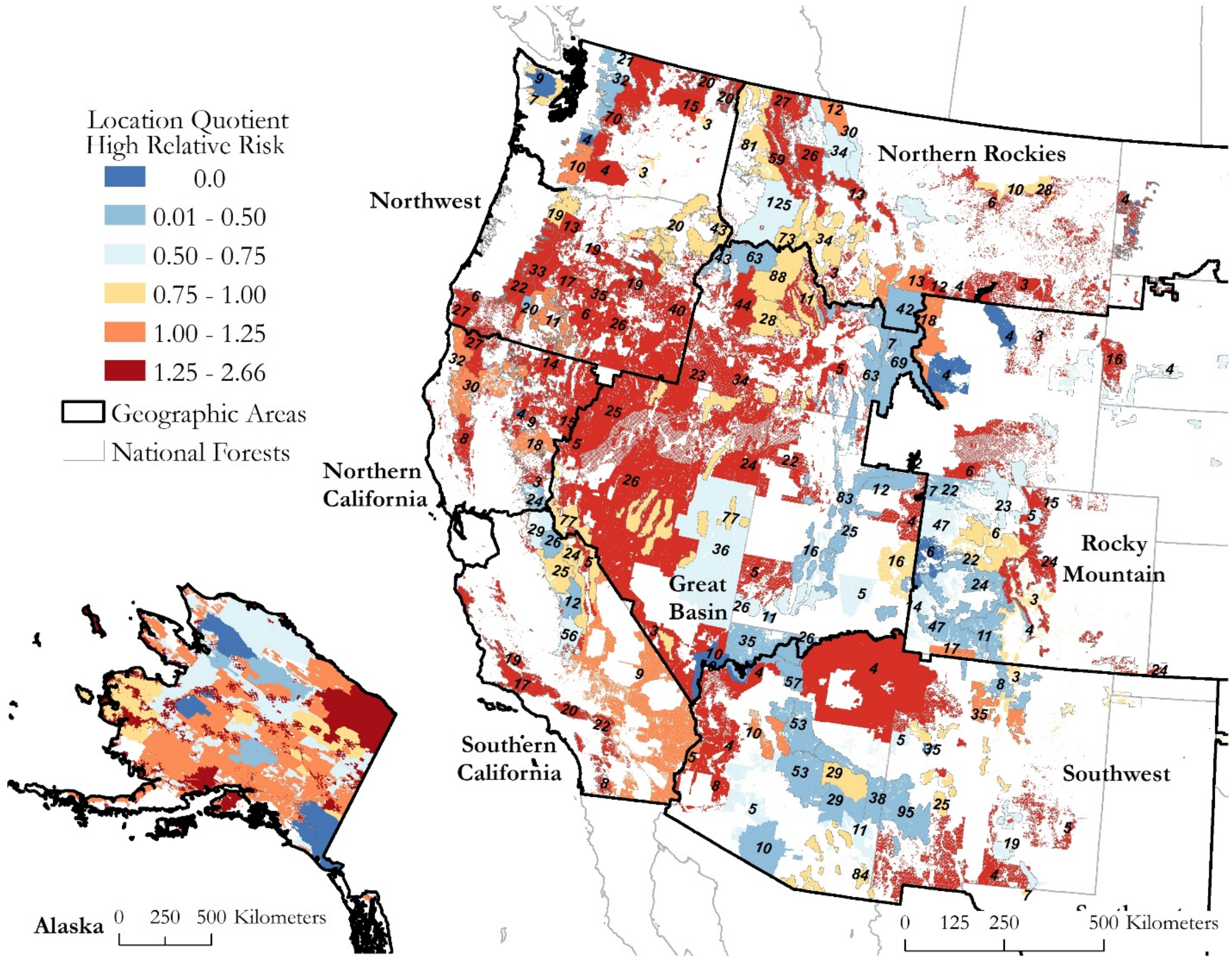

Figure 11. Concentrations of high relative risk by jurisdiction in the western U.S. Concentrations of high relative risk from the location quotient (LQ) for federal jurisdictions with at least 3 WFDSS fires in the western U.S. Number of fires in each jurisdiction are labeled. LQ>1 would indicate a higher usage of high relative risk and is reflected in darker shades of orange and red. LQ<1 would indicate lower usage of high relative risk and is indicated by shades of yellow and blue.

The LQ of high risk reveals several interesting patterns. For example, the Great Basin and the southeastern portion of the Northwest GA are high risk across the GA boundary, probably reflecting the dominance of rangeland vegetation, flashy fuels and fast-moving fire, the prevalence of grazing, occurrence of a threatened species (sage grouse), expansion of invasive annual grasses in the area, and primarily BLM administration. These locations are dissected with range allotments for cattle grazing or private lands interspersed amongst federal lands especially along historic railroad corridors where land was provided to corporations and states through land grants to encourage development and westward migration in the middle of the 19th century (The Pacific Railroad Act 1862). Ecological and social challenges related to federal land use juxtaposed with the preservation of highly flammable sage grouse rangeland habitat, a near-

threatened indicator species of the sagebrush rangelands endemic to the Great Basin, may also be a factor (Wisdom and Chambers 2009; Shinneman *et al.* 2018).

Bureau of Indian Affairs (BIA) lands are also associated with high relative risk. We speculate this may be due to a desire to protect important values at risk from unwanted fire. Many reservations are located in windy areas dominated by flashy fuel types. Property is widely dispersed within reservations and there is a reliance on timber assets to support their local economy. Among all agencies, jurisdictions associated with drier forest types appear to use high relative risk more than the national average, especially in the Eastern Cascade mountain range in Washington and the Southern Cascades (Northwest GA, Northern California GA). These trends are different for the dry forests in the Southwest that use high relative risk less than the national average and are managed primarily by the USFS. Concentrations of high risk also occur in national forests adjacent to communities, as demonstrated in the Rocky Mountain and Northern Rockies GAs, with considerably lower use of high risk in back-country areas and wilderness.

The missions of different land management agencies may also be contributing to observed patterns in risk. The National Park Service mission emphasizes conservation which likely contributes to greater risk tolerance. For instance, Crater Lake National Park located in the southern portion of the Northwest GA and Lassen National Park in the northeast portion of the No. California GA are islands of lower risk in relation to the national forests that surround it (LQ<0.50). Similar patterns emerge in the central Sierra Nevada mountain range in California (collectively within the Northern and Southern California GAs). These units use high relative risk with lower frequencies than the coastal mountain ranges, especially the NPS jurisdictions of Sequoia-Kings Canyon and Yosemite National Parks. Sequoia and Yosemite are some of the original locations where prescribed natural fire was introduced in the late (van Wagtendonk 1995). Physiographic characteristics amenable to low risk (high-elevation, rocky terrain, moist forest types, etc.) for some NPS units may also be a contributing factor to the less frequent use of high relative risk. Similarly, USFS lands with a strong wilderness presence tend to use high risk less frequently. The 1964 Wilderness Act designated wilderness as lands for protection and preservation in their natural condition, similar to the conservation emphasis of the NPS mission (The Wilderness Act 1964). The traditional use of wildland fire to maintain natural conditions in wilderness areas may be contributing to the lower characterizations of risk as seen in the central and southern Sierra Nevada in the northeast portion of the Southern California GA, and in the Selway-Bitterroot and Frank Church wilderness (Great Basin GA) and the Bob Marshall, Great Bear, and Scapegoat wilderness areas in the Northern Rockies (Dale 2006; Collins and Stephens 2007; Collins *et al.* 2009; Miller *et al.* 2012; Larson *et al.* 2013; Parks *et al.* 2013; Hunter *et al.* 2014; Boisrame *et al.* 2017). Combined with the remoteness of these areas, a legacy of using fire to maintain ecological integrity may be contributing to a familiarity with wildland fire and its risks and leading to greater risk tolerance.

Some of the observed regional differences may be attributed to differences in agency representation coupled with low values. We suspect this contributes to Alaska's diversity as far as the infrequent usage of high risk. National Park Service lands in the less inhabited northwestern portion like the Noatak Preserve and Gates of the Arctic National Park use high relative risk infrequently compared to the State of Alaska lands in the Southern portion of the GA. A similar phenomenon likely also occurs in the Southern California GA which finds a high diversity of risk among its fires relative to Northern California and the Northwest. In this GA, high risk is concentrated in the heavily inhabited mountain ranges to the south and the absence of high risk is found in the central Sierra Nevada Mountains to the north. In short, the scale of a geographic area is not entirely adequate for explaining patterns of risk when perusing patterns of risk at the unit level.

In sum, the regional variations in risk identified in this research are likely caused by a complex mix of biophysical factors (distributions of fire regimes), infrastructure and community development patterns, agency missions, and regional fire culture. Causal explanations for patterns are obscured by the variability of these factors within GAs. Although it is probable that the fire environments of the Northwest and Northern California tend to produce more higher risk fires than the Southwest due to higher density of values, proximity of fire to values, less certainty in future weather, longer duration events, higher fuel loads, and more continuous fuels, it is also likely that cultural differences among fire managers contribute to these differences. Risk avoidance is not new to the Northwest nor is risk tolerance unfamiliar in the Southwest. In a previous study of USFS decision- makers (Cortner *et al.* 1990), patterns of risk tolerance were reported by geographic area that matched patterns found in our study. The Southwest and Great Basin GAs were higher risk-takers and lower spenders while California and the Pacific Northwest were more risk averse, consistently selecting low risk/high expense options for a range of hypothetical planning scenarios. Decision-makers from the Northern Rockies chose more middle of the road options. Risk avoidance was influenced most strongly by safety, values and resources at risk, public opinion, and the reliability of information (Cortner *et al.* 1990). The commonality in patterns between (Cortner *et al.* 1990) and ours is suggestive that some of the regional differences in risk perception identified almost 30 years ago may still persist. It's most plausible that a combination of cultural differences within a geographic area coupled with biophysical risk is interacting to determine how risk is characterized by land managers.

Risk Groups

As detailed elsewhere in this paper, there are three general risk groups in the US. The West Coast states of Washington, Oregon, and California are in a distinct high risk group. Although the Pacific Northwest is joined by Northern and Southern California in opting for high risk, a finer look at the sub-elements reveals that Southern California is more diverse at the unit-level scale due to the inclusion of the central Sierra Mountains. The Moderate group is unique in

many respects. While Alaska generally uses Moderate ratings for all sub- and main elements, it consistently uses low ratings for Values, similar to the Northern Rockies. The Great Basin, Rocky Mountain and Southern GA's share similar usage of low values when compared to chance, but the similarities become less evident when compared to the U.S. as a whole. Finally, the Eastern and Southwest GAs are comparable in use of both probability and relative risk and opt for low to moderate ratings for all sub- and main elements.

Despite the general emphasis of this discussion on high risk, many fires in the study are characterized by low risk. The ratings of the sub-elements which are a direct result of land manager selections provide some explanation. The Southwest selects Low for Fire Behavior (Hazard sub-element), Resources, Threat, and Concern (Values sub-elements), and Time of Season (Probability sub-element) more than chance. This translates into Low ratings for all of the main elements, especially Values, and consequently, 38% of its fires are low relative risk when adjusted for bias. Southwest also selects High ratings with much lower frequency than chance for all sub-elements except seasonal severity.

In comparison, the Northwest uses high risk more than any other geographic area and it uses High Values, High Hazard and High Probability together more than any other geographic area, suggesting that high risk may often be known before the formal risk process is completed. Northwest also uses High ratings for Fuel Condition, Potential (Hazard sub-elements) and Seasonal Severity (Probability sub-element) more than chance; however, the GA overwhelmingly use Moderate ratings for the other sub-elements. The usage of High risk becomes apparent when compared to the U.S. More than 60% of its fires are high relative risk when adjusted for bias and >30% of its fires involved multiple agencies. The Northwest is the only GA to have at least 2 fires with all federal agencies involved (Renner and Okanogan Fires, 2015). Despite the discussion above regarding risk aversion tendencies in the Northwest, there is little doubt that the GA and its neighbors in California are at the epicenter of biophysical risk, with large populations living adjacent to highly flammable landscapes (Ager *et al.* 2013; Ager *et al.* 2019).

Conclusion

By illuminating patterns of risk by geographic area, agency and unit, we seek to encourage thoughtful discussion regarding how risk is characterized across the U.S., whether the RRA is working as intended, and where additional investments in tools and training might be targeted. This is the first formal summary of risk data housed in the Wildland Fire Decision Support System (WFDSS). While numerous DSS exist globally, the ability to summarize patterns of risk over a reasonably long period of time is unique to WFDSS. Risk patterns can provide insight into the factors that are influencing local decision-making and may provide opportunities to direct resources and research to where it is needed most. Some locations may benefit from increased

support for working with communities to better prepare for fire (e.g. locations where social concerns are rated high and resources and infrastructure are rated high). Other locations may benefit from closer examination of landscape barriers and how they spatially connect to create contingency lines (e.g. locations where barriers are rated as numerous or low). The spatial manifestation of risk may also help policy makers better allocate resources to address local-level fire management concerns.

We strove to summarize risk spatially by evaluating components of a systematic operational risk assessment process mandated for all federal wildfires that burn beyond initial attack. Because the relative risk assessment becomes part of the situational assessment for these more complex federal fires, it also serves as a component of the permanent record related to specific fires in WFDSS, reviewed and signed by a decision-making authority. For these reasons, we believe the relative risk assessment represents a unique and useful data set for characterizing federal risk from wildfires occurring across all geographic areas over long time spans, not hypothetically before incidents occur or after they are out. It is our belief that risk characterizations should reflect land managers' summaries of risk while wildfire is burning, when concerns and issues related to wildfire management are tangible and in real-time.

A tendency when examining patterns of risk assessments from operational assessments is to wonder what the real risk is. This tendency implies the existence of objective risk (e.g., quantitative maps) that managers might not know or don't use. We argue that the RRA is real risk because this is risk that is driving strategic responses on wildfires. However, we suspect that disparities exist between risk from the RRAs and the various quantitative risk assessments used for land management planning and this is the subject of future research. Although risk has been assessed systematically at a national scale for planning purposes in the U.S. (Calkin *et al.* 2010; Scott 2013; Ager *et al.* 2019), this Quantitative Risk Assessment (QRA) applies at spatial and temporal scales that may be incompatible with the RRA. For example, QRA applies fuel condition and fire behavior modeling assumptions at broad scales that may not adequately address the finer-scale temporal or spatial fuels, weather, and fire behavior during an incident, and risk factors such as fire behavior may be moderate for most of a fire's duration but extreme on a few days, making it difficult to describe fire behavior by choosing a single rating of low, moderate or high. QRA may also miss the breadth of values at risk for a specific fire as discerned by a land manager in favor of spatially consistent cadastral records and values layers. The RRA data represent individual fires where levels of risk ebb and flow based on a myriad of circumstances and environmental conditions on multiple time scales and summarized with multiple relative risk assessments. We chose to characterize fires with the relative risk rating that occurred most often, recognizing we are not capturing all of the vagaries of a wildfire. Therefore, risk assessments are likely representing conditions reflecting the beginning to middle temporal scale of a wildfire's duration. Identifying the appropriate scale to match quantitative and

operational risk presents a challenge for future work, but to bridge quantitative and operational risk will help individual decision makers make more informed decisions. Ultimately, this equates to responding to wildfire ignitions using the best available information and tools that allow fire to be part of ecosystems while protecting life and property.

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Appendix: WFDSS data

Variable	Type	Description
WFDSS_RR_ID	numeric	Unique Identifier for each relative risk assessment and fire
WFDSS_ID	numeric	Unique Identifier for each wildfire (in WFDSS)
RR_ID	numeric	Unique Identifier for each relative risk assessment (in WFDSS)
LATITUDE	numeric	Latitudinal location of the fire start (DD)
LONGITUDE	numeric	Longitudinal location of the fire start (DD)
start_month_day_year	numeric	Fires Start Month, Day, and Year
contained_month_day_year	numeric	Fire Contained Month, Day, Year
controlled_month_day_year	numeric	Fire Controlled Month, Day, Year
start_contained_d	numeric	Difference in days between the contain date and start date of the fire
start_controlled_d	numeric	Difference in days between the control date and start date of the fire
rr_create_month_day_year	date	Month Day Year when the Rel Risk was created
rr_publish_month_day_year2	date	Month Day Year when the Rel Risk was published
Fire_Name	text	Wildland fire name
FOREST_NAME	text	Unit Name (e.g. Lolo National Forest)

Jurisdiction	text	Unit Name based on Jurisdictional Agencies GIS data layer, 5 digit ID starting with the STATE and the 3 digit identifier for the jurisdiction
UNIQUE_FIRE_ID	text	YYYY-State Abbreviation-Home Unit Identifier - 6 digit unique fire code (as given from other reporting systems)
STATE_ABBREV	text	State Abbreviation of fire start location
resp_unit_poi	text	The location of the responsible unit for the fire start
potential_fire_duration_name	text	Estimated Fire Duration from the day the Rel Risk was created (type = low, mod, high)
hazf_departure_fuel_conditiondesc	text	Fuel Condition Sub Element Ratings (High, Mod, Low): Hazard Element
hazf_fire_behavior_desc	text	Fire Behavior Sub Element Ratings (High, Mod, Low): Hazard Element
hazf_potential_fire_size_growth_desc	text	Potential Fire Size Sub Element Ratings (High, Mod, Low): Hazard Element
hazf_notes	text	Qualitative Notes Describing Hazard ratings
hazf_rr_desc	text	Hazard Ratings Used in RRA, (High, Mod, Low): Hazard Element
probf_time_of_season_desc	text	Time of Season Sub Element Ratings (High, Mod, Low): Probability Element
probf_barriers_to_fire_spread_desc	text	Barriers to fire spread sub element ratings (High, Mod, Low): Probability Element
probf_seasonal_severity_desc	text	Seasonal severity sub element ratings (Extreme, Very High, High, Mod, Low): Probability Element
probf_notes	text	Qualitative notes describing probability ratings
probf_rr_desc	text	Probability ratings used in RRA, (High, Mod, Low): Hazard Element
valf_natural_cultural_resource_infrastructure_desc	text	Natural/Cultural & Infrastructure Values (High, Mod, Low): Value Element
valf_threat_to_values_desc	text	Threat to Values (High, Mod, Low): Value Element
valf_soc_econ_pol_conc_desc	text	Social/Economic/Political Values (High, Mod, Low): Value Element
valf_notes	text	Qualitative notes describing value ratings
valf_rr_desc	text	Value ratings used in RRA, (High, Mod, Low): Hazard Element
rrf_notes	text	Qualitative Notes describing the relative risk rating
rrf_rr_desc	text	Rating used for the relative risk (High, Mod, Low)

Chapter 3

Factors influencing risk during wildfires: contrasting the Southwest and Northwest US

Abstract

Managers in the US are charged with risk-based decision-making which requires them to know the risk and to direct resources accordingly. By inference, mitigating wildfire risk is expected to cut costs, lessen fire-fighter exposure, and expand the decision space to use fire for resource objectives. However, without understanding the specific factors that produce risk, it is difficult to identify strategies to reduce it. Risk characterized by land managers during wildfires was evaluated from 2010-2017 to identify factors driving risk in the US. Annotation from 282 wildfires from the Northwest and Southwest geographic areas were coded and categorized using the risk assessment framework of hazards, values and probability. The effects of climate on seasonal severity, fuel condition, and fire behavior emerged as the most influential factors driving characterizations of risk in both regions. Common factors on low risk fires were low fire behavior, low spread potential, fires late in the season, numerous barriers, precipitation and high fuel moisture; while dry fuel moisture and large potential were synonymous with high risk fires. Precipitation extended the longevity of landscape barriers, especially in the Southwest. The results suggest that a scarcity of values at risk and a mild fire environment produce low risk fires regardless of location, while high risk fires reflect specific local values and geography, under the umbrella of dry climate. The climatic contrasts between the two regions highlights how influential climate change will be on future characterizations of wildfire risk.

Keywords: fire management, relative risk assessment, WFDSS, climate

Introduction

Federal land management agencies have sought to adopt risk management for almost every facet of wildland fire management. Risk assessment frameworks are commonly applied for a variety of spatial and temporal scales to plan and prepare for wildland fires pre-season (Calkin *et al.* 2010) (Scott 2013); to assess risks associated with fire-fighting tactics and operations (NWCG 2010), and strategically in the Wildland Fire Decision Support System (WFDSS)(Zimmerman 2011) (WFMRDA 2019), with the relative risk assessment (RRA) representing a synthesis of operational and strategic wildfire risk. However, risk is controversial, with unclear concepts and terminology manifesting in multiple assessments based on specific contexts within wildland fire management processes (Thompson *et al.* 2016). In the research presented here, risk is the result of hazard, spread probability and values at risk ratings from the relative risk assessment in

WFDSS (Taber 2013). The RRA represents a continuum of risk identified from an operational and strategic perspective during a wildfire. It is a component of the WFDSS fire decision, whereby objectives, strategy, costs and rationale are communicated and vetted by an administrator with responsibility for the wildfire (USDA/USDI 2019), and it is a tool to help decision-makers consider all facets of wildfire risk that could impact their ability to manage wildfire. In addition, it can be used to assess the initial risk of emerging incidents that lack a formal decision and provide documentation of the probability, hazard and values influencing the characterization of risk (Taber 2013).

Arguably, there is no single definition of risk. Instead, 'risk' is a conceptual understanding based on the probability and consequence of uncertain future events (Yoe 2011). The biophysical characterization of risk composed of wildfire hazard, the likelihood of a wildfire event (probability), and a measure of how values at risk will be changed by wildfire, provides an objective measure of "risk" (Scott 2013). However, this quantitative risk may not explicitly reflect land manager's perceptions of risk that are influenced by a multitude of factors. Assumptions, recent memories, quality, skill and bias associated with professional judgments, perceived affect, and real risk are factors influencing risk perceptions (Tversky and Kahneman 1973; Alhakamil and Slovic 1994; Sjöberg 2000; Kahneman and Klein 2009; Johnson-Laird 2010). Unless otherwise noted, risk is defined by the risk produced from the relative risk assessment. The relative risk assessment likely reflects perceptions of risk from land managers guided, in part, by the objective, biophysical risk, which collectively composes the 'real' risk that impacts decisions made on wildfires.

Historically, the assessment provided a systematic process to rapidly assess risk in order to decide whether to use wildland fire as an alternative to suppression (USDI/USDA 2005), stemming from a desire to formalize protocols related to wildland fire use that emerged after the 1988 Yellowstone wildfires. In 2009, the RRA evolved to inform initial assessments of risk to guide any fire management strategy including full suppression, reflecting revisions in terminology and policy that merged all previous types of fire into two: prescribed and wildfire (USDA/USDI 2009). The RRA arguably carries less weight for small fires, intended to be extinguished during initial attack due to a pre-determined suppression management objective; and has greater value as the preliminary risk assessment for longer duration incidents (Zimmerman 2017).

The relative risk framework evaluates risk based on three common tenets of risk: values at risk, hazard and spread probability and provides a visual estimate of high, moderate or low risk relative to a specific wildfire (Figure 1). Users have the option to describe their selected ratings through qualitative text inputs, providing a clearer understanding of why some fires are characterized as low, moderate or high risk. The values element is composed of ecological ratings concerning natural resources, cultural values and infrastructure, social and economic

concerns, and the proximity and threat of the fire to the values at risk. Hazard represents the conditions of the fire and is composed of ratings related to fire behavior, fuel condition, and the potential growth of the fire. The probability element also has three sub-elements, including seasonal severity ranging from low to extreme; quantity of barriers ranging from numerous (low) to few (high) and time of season of the first start in relation to the normal fire season ranging from late (low) to early (high) (WFMRDA 2019). The RRA provides an estimate of risk based on a conditional risk assessment, given that a fire is already burning and actively spreading on the landscape. It differs from quantitative risk assessment which includes the likelihood a fire will occur and it's likely spread under thousands of hypothetical weather scenarios (Scott 2013).

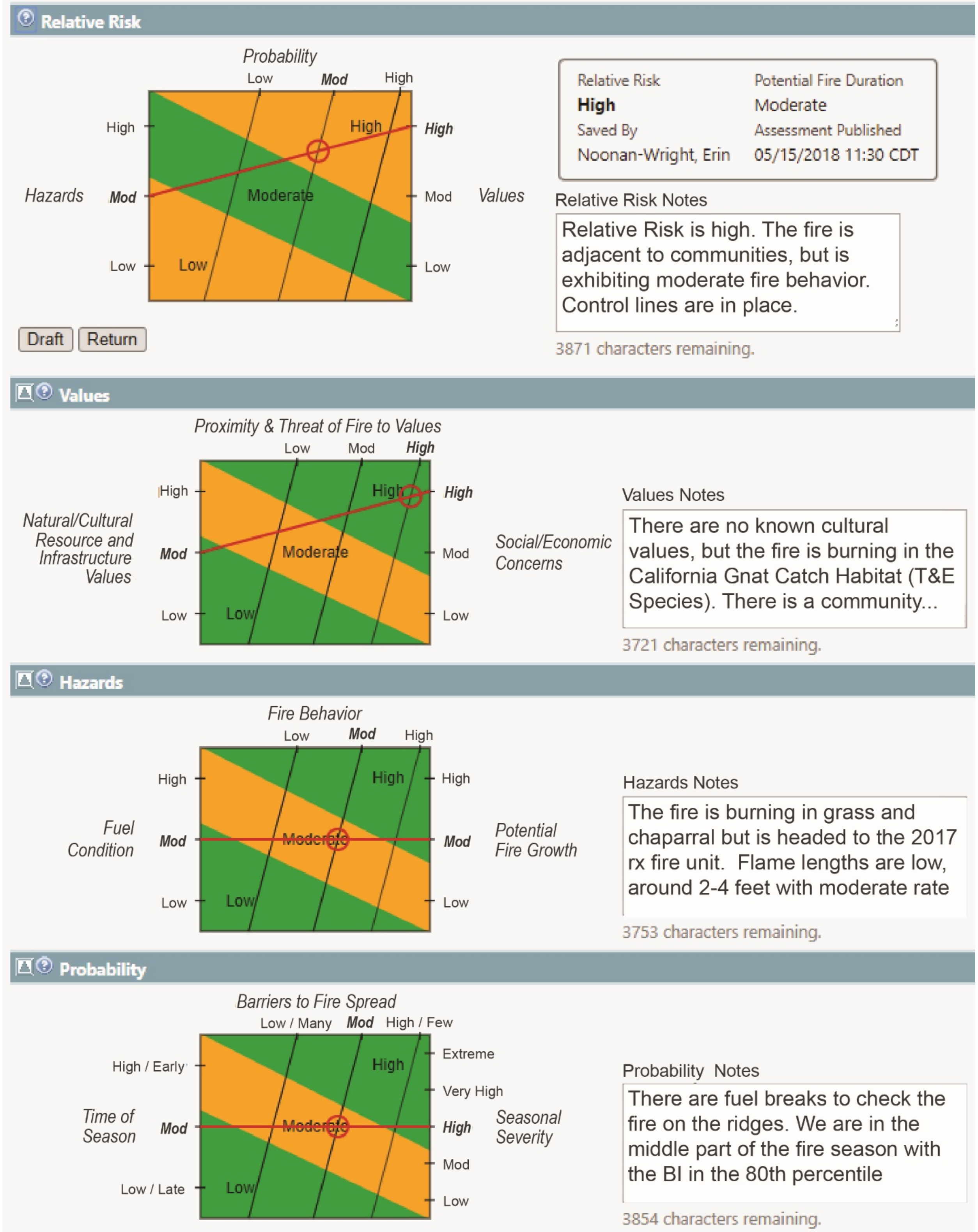

Figure 1. An example of the relative risk assessment in WFDSS and qualitative text to support semi-empirical ratings for relative risk, values, hazards and probability.

Purpose

The evaluation of data collected during real-time wildfires provides a novel and detailed portrayal of issues influencing wildfire risk and decision making. Although this research does not attempt to discriminate between objective, biophysical risk and risk perception, it is worth noting that the risk articulated by land managers on active wildfires matters because this is risk that directly influences how fires are actually managed.

Qualitative data were analyzed from the two most wildfire risk divergent GAs, the Northwest and Southwest. These 'extreme' GAs were examined instead of sampling from all regions because the majority of other GAs use primarily moderate relative risk ratings, making more difficult the task of discerning patterns affecting high and low risk. While this approach provides the advantage of insight into factors related to risk at the two ends of the risk continuum it comes at the cost of overlooking the factors representing the average condition. Specifically, the research addresses four general questions aligning with the elements of the WFDSS RRA;

1. What are the main themes and factors of high and low risk fires and are there geographic dependencies?
2. What are the common and local VALUES at risk discussed by land managers on wildfires?
3. How do land managers characterize HAZARD conditions amenable to fire spread?
4. What PROBABILITY factors are discussed that influence the likelihood of active fire?

Background

An empirical evaluation of the relative risk ratings revealed distinct regional patterns of risk (Chapter 2). Land managers in the Northwest more often selected high or moderate relative risk ratings to characterize wildfires; while the Southwest opted for low/moderate (Figure 2). This disparity in risk assessments provided the basis to investigate qualitative RRA text records associated with these regions to better understand what managers were thinking about when they determined risk.

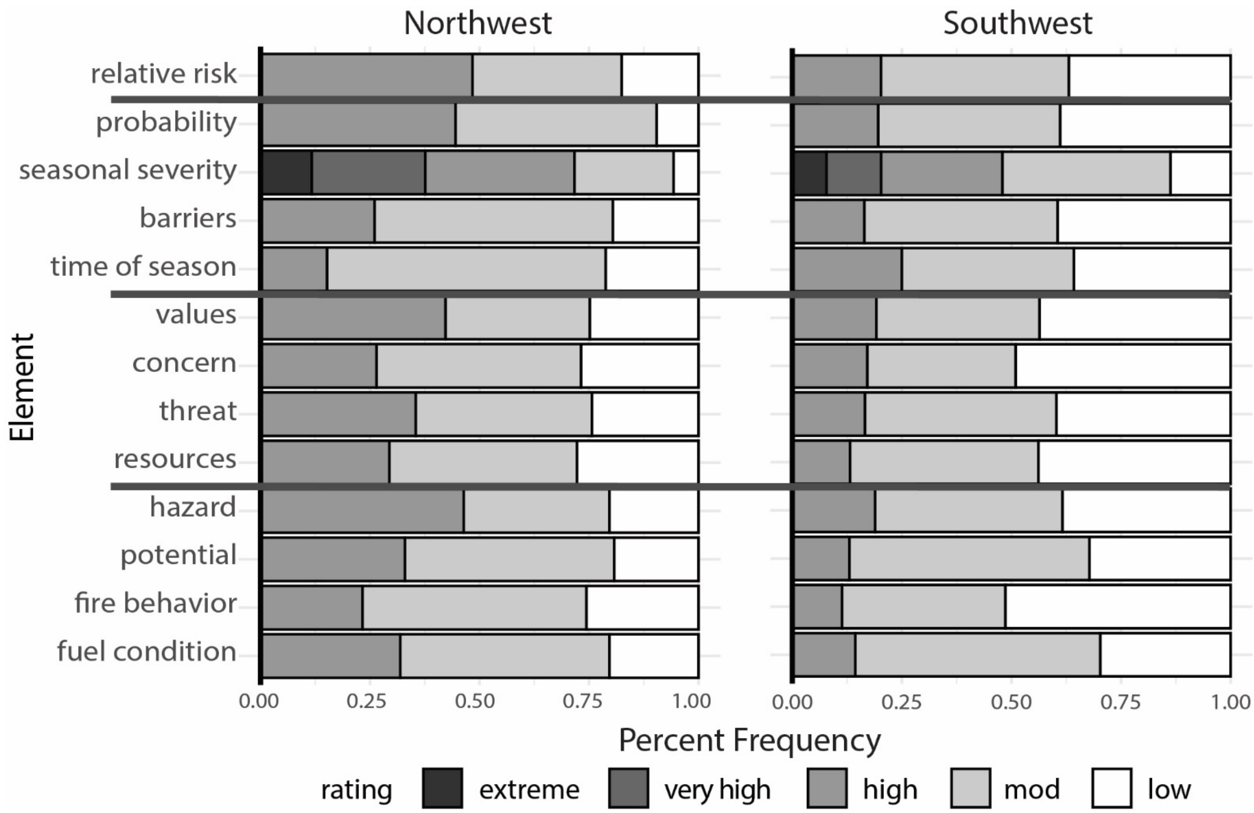

Figure 2. Relative risk elements and themes for the Northwest (n=639) and Southwest GAs (n=730) derived from a summary of semi-empirical ratings associated with the Relative Risk Assessment (Chapter 2). Percent frequency is shown for each risk level, element combination.

Methods

This analysis capitalizes on a dataset that is mandated for specific federal wildfires that either required action beyond the initial attack of the fire or had objectives that resulted in a longer duration event, i.e. fires with resource objectives. These types of federal wildfires necessitate formal decisions (USDA/USDI 2009) and the RRA is part of the decision workflow (Taber 2013) (Figure 1). This research followed a mixed method explanatory design by using frequency summaries of the risk ratings (quantitative data) to inform the sample design of the relative risk notes (qualitative data) (Creswell and Plano Clark 2007; Ivankova *et al.* 2016). Mining qualitative text provides a "deeper" understanding regarding some phenomena such as risk perceptions related to wildfire (Creswell 2003; Creswell and Plano Clark 2007) by generating greater specificity through text coding, and by providing a holistic understanding of the factors influencing risk assessments on specific fires.

Data Collection

A stratified random sample representing 20% of the fires from the Northwest and Southwest geographic areas were selected to develop codes from the RRA qualitative notes. The fires were

stratified by high, moderate and low relative risk and agency to ensure the sample was representative of the geographic area (Figure 3). Ultimately, 133 sample fires were coded for the Northwest; and 149 sample wildfires were coded for the Southwest. Land management agencies included the Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), National Park Service (NPS), Fish and Wildlife Service (FWS), United States Forest Service (USFS), State, County & Local, and Other (Department of Defense, Bureau of Reclamation, Department of Energy (DOE), etc.). Land management agencies have different missions which may reflect in the characterization of risk. Overall, the frequencies of high, moderate, and low relative risk ratings between the population and sample differed by < 1%. Agency differences were < 4%. The sample (and population) reflect dominance of U.S Forest Service wildfires (Table 1).

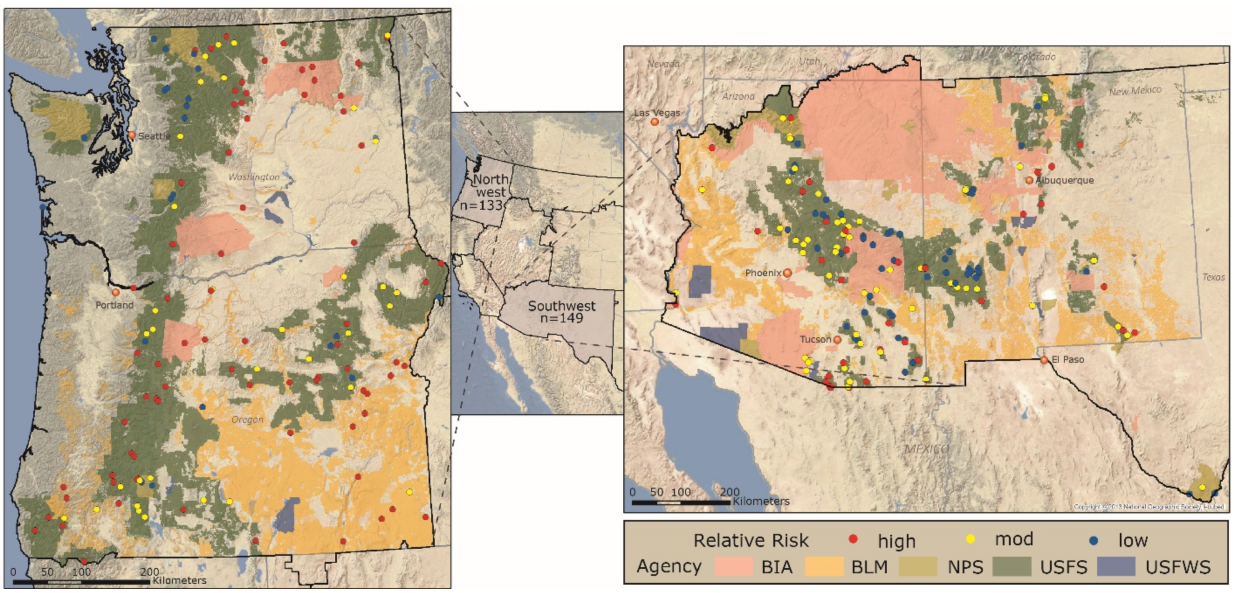

Figure 3. Relative risk rating for each of the sampled wildfires for the Northwest geographic area (n = 133) and the Southwest geographic area (n = 149) with the primary federal land management agencies in the background.

Table 1. Jurisdictional composition of the sample fires reflecting the multijurisdictional nature of fire management, with many agencies sharing responsibility for one wildfire, regardless of the ownership of the point of fire origin.

	Agency							
Geographic Area	USFS (%)	BLM (%)	BIA (%)	County (%)	NPS (%)	Other (%)	State (%)	FWS (%)
Northwest	62	31	8	7	12	15	11	8
Southwest	69	16	16	3	15	5	8	1

Coding

Each wildfire documented in the risk assessment could have from 1 to 4 entries reflecting hazard, values, probability, and relative risk (Figure 1). The entries are typically 1-3 sentences per element. Approximately 11% of users write no text to explain any rating and a handful of users write paragraphs for each element. The analysis was informed by grounded theory methodology (Glaser and Strauss 1967) and used codes to develop broad, conceptual ideas reflecting the magnitude (e.g. low versus high temperature) and causation (e.g. the monsoon causes precipitation) of common themes discussed during a wildfire risk assessment . The first author was the primary coder, who had an extensive background in fire management and attempted to capture the major themes discussed by land managers when characterizing risk on wildfires. A code can be a word or short phrase that symbolically represents an important meaning from language based data (Saldana 2009). As each wildfire was evaluated, simultaneous codes were developed that were later categorized into broader classifications using the general framework of the relative risk assessment. This was an iterative process, requiring re-evaluation of the codes and their potential applicability to explain levels of risk. For instance, lumping and splitting of codes occurred, i.e. the 'elevation' code was eventually split to into 'high' and 'low' elevation, as it became apparent land managers were noting high elevation fires and docile fire behavior that could be amendable to low risk. NVIVO v11 coding software (QSR 2017) was used to organize and categorize the codes and to map coding structures.

A random sample of fifteen wildfires were also coded by three individuals with extensive operational and fire management backgrounds to verify the comprehensiveness of the coding scheme and accuracy of the main coder. They collectively achieved a mean Kappa of 0.67 (moderate agreement). Kappa scores were also measured for individual codes. Lower kappa scores were often the result of a check coder missing an opportunity to denote a code that had been discussed in the qualitative text or the codes themselves were too broadly defined, leading to a different interpretation from the main coder. In some cases, these discrepancies necessitated further lumping of codes. Additional queries were run in NVIVO to minimize the main coder error associated with missing key concepts and to verify that each code was only represented once per wildfire record. A total of 93 separate codes were developed from themes that tiered from hazard, values, probability and fire management. The seven codes relevant to fire management themes were omitted, leaving the 87 codes directly applicable to the RRA values at risk, hazards and probability to be used for further analysis (Figure 4, Appendix A). Codes were counted once per wildfire, even if certain concepts were discussed numerous times to facilitate computing frequencies on a per fire basis. Subsequently, the results of the quantitative analysis below are, in part, artifacts of decisions made regarding the number of codes and the lumping and splitting of themes into one or more codes.

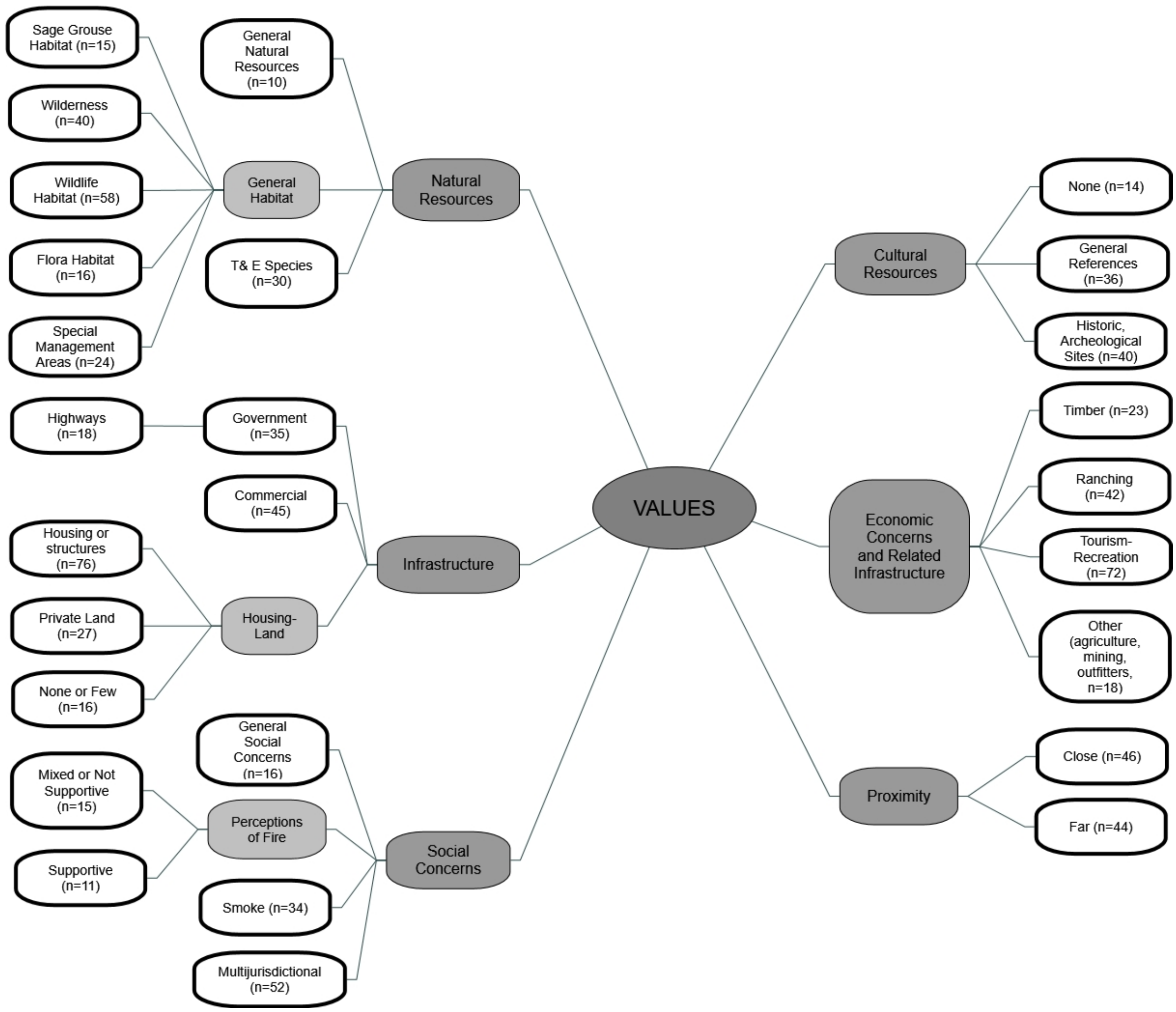

Figure 4. An example of the coding structure that follows the framework of the relative risk assessment for the Values element. The Values element is composed of themes such as **natural**, **cultural resources** and **infrastructure** values, **proximity** and threat of fire to values, and **social** and **economic concerns**. White shapes represent codes with the frequency that code occurred on wildfires (n), while gray shapes represents themes and related sub-themes (infrastructure – housing, land; social concerns – perceptions of fire; and natural resources – general habitat) used to organize the codes and communicate findings. Coding structures for hazard and probability are shown in Appendix A.

Data Analysis

Data analysis was a mixture of different techniques to investigate how values at risk, hazard and probability affect summaries of relative risk and how that risk was geographically unique or similar. First, the presence of each code was summed and divided by the total number of sample

fires per geographic area (n=133, Northwest; n=149, Southwest) to compute percent frequencies by relative risk rating level (high, moderate, and low). Some percentages exceed 100% because multiple codes occurred for one wildfire; for example, users may note that both housing and private land occurred as values at risk, which were normalized individually by the total number of sample fires, not the total sum of codes. Percent frequencies of codes were also summed by major themes and elements to provide broader perspectives on patterns, e.g. the infrastructure theme collectively summarizes commercial, government and housing-land infrastructure (Figure 4). Second, aggregate summaries were generated for specific individual codes to identify collinearity between associated codes. In these instances, percent frequencies were computed as the total number of times the collinear codes were present divided by the total number of times the individual code in question was present. Third, Pearson's Chi-square tests were performed on a 3 by 2 level matrix (3 levels of relative risk by 2 levels representing presence or absence for each code). Some codes occurred for all levels of risk. P-values less than 0.05 suggest that the composition of the codes had unequal proportions of high, moderate or low relative risk ratings, e.g., some ratings were used more or less than expected. Fourth, random forest machine learning was used to identify the most relevant variables to classify high, moderate and low relative risk from the original 93 codes (Table 2). Some codes that were not referenced in the qualitative notes were eliminated; for instance, positive social perspectives regarding fire, monsoon, and low resistance to control were not included in the Northwest variables; and sage grouse habitat was eliminated from the Southwest variables. Ten iterations of random forest were run for each geographic area due to the instability of the modeled output following (Dillon *et al.* 2011). A model selection approach implementing an improvement ratio metric (Murphy *et al.* 2010) reduced the dataset to 46 variables for the Southwest and 47 variables for the Northwest. A Classification and Regression Tree (CART) model was performed using the variables selected from the random forest iterations to provide a tangible pathway to identify the main factors important to risk in the two regions. An additional CART model was run using aggregated variables (26 themes) to provide another measure of the factors relevant to different levels of relative risk by GA (Appendix C). For example, all variables related to topography were grouped in a single topography theme. All analyses were performed using R software (R Core Team 2019) and various packages: Random Forest analysis (Liaw and Werner 2002), Classification trees (Therneau and Atkinson 2019), Model Improvement Ratio (Evans and Murphy 2018), and plotting (Wickham 2016).

Study Area

Northwest

The Pacific Northwest encompasses a diverse range of topography, flora and fauna. The geographic area is divided into 7 Bailey ecoregions and is dominated by temperate deserts, marine regime mountains and temperate steppe regime mountains composing roughly 80% of the

area (Bailey 1980). Wildfire has historically shaped landscape level disturbance across the region, resulting in highly diverse and productive forests along the Cascade Range (Agee 1993). Broadly, the geographic area can be classified into 2 main climatic regions: a moist zone west of the crest of the Cascades influenced by typical Mediterranean climate (cool, wet winters coupled with hot, dry summers). East of the Cascades, climate patterns resemble more continental patterns characterized by colder winters with precipitation occurring as primarily snow coupled with very hot and dry summers. Classifications of forests are best described as moist or dry, rather than spatially explicit descriptions like east or west (of the Cascades) (Franklin and Johnson 2012; Wimberly and Liu 2014). The area also contains the Columbia Basin, representative of Great Basin rangeland vegetation composed of sagebrush ecosystems and annual and perennial grasslands (Figure 3).

Southwest

The Southwest is composed of tropical/subtropical deserts typified by extreme aridity, high air and soil temperatures with strong deviations of night and day-time temperatures. Annual precipitation is less than 200mm with predominant sparse vegetation types such as the Sonoran Desert. Locations with slightly more precipitation have savanna and steppe grasslands and forests at the high elevation mountainous regions. Less than 20% of the area is allocated to tropical/subtropical regime mountains (where many fires occur), temperate steppe or steppe mountains (Bailey 1980). Most of the forest and grasslands in the Southwest are fire-adapted (Swetnam 1985), with larger fires occurring during regional droughts, but also associated with wet antecedent years whereby finer live fuels, when cured, contribute to heavier fuel loads during fire season (Swetnam and Betancourt 1998). Inter-decadal climate variability, land-use patterns of grazing, and wildfire have all shaped the diversity of vegetation in the Southwest (Covington 2000; Abella *et al.* 2007). A hallmark of Southwestern climate is the North American monsoon which provides quasi-predictable moisture near the beginning of July (Sheppard *et al.* 2002).

Results

Themes and factors related to wildfire risk

Managers in the Southwest generally discuss a greater diversity and quantity of risk related concepts, especially for hazard and probability themes (Figure 5). Both GAs similarly discuss themes related to spread potential, landscape barriers, fuel condition, and seasonal severity. Northwest land managers also discuss natural resources with high frequencies.

Cumulative percent frequencies often exceeded 100%, because land managers discussed multiple aspects related to hazards, values at risk and probability to communicate risk, resulting in multiple codes used simultaneously for each wildfire. For instance, it was not uncommon for land managers to discuss multiple kinds of fuel types ("the fire spread through grass and shrub

fuels"), resulting in multiple codes to summarize fuel type (i.e., one code for "grass; and one code for "shrub"). Each code is individually normalized by the total number of wildfires in each GA to provide an objective basis of comparison amongst GAs that is consistent throughout the analysis. Subsequently, the summation of percent frequencies by themes involving multiple codes can exceed 100%., A comparison of codes summarized by theme and by region identified broad concepts related to risk that were unique to each GA. However, the results show that these summaries were more similar than different.

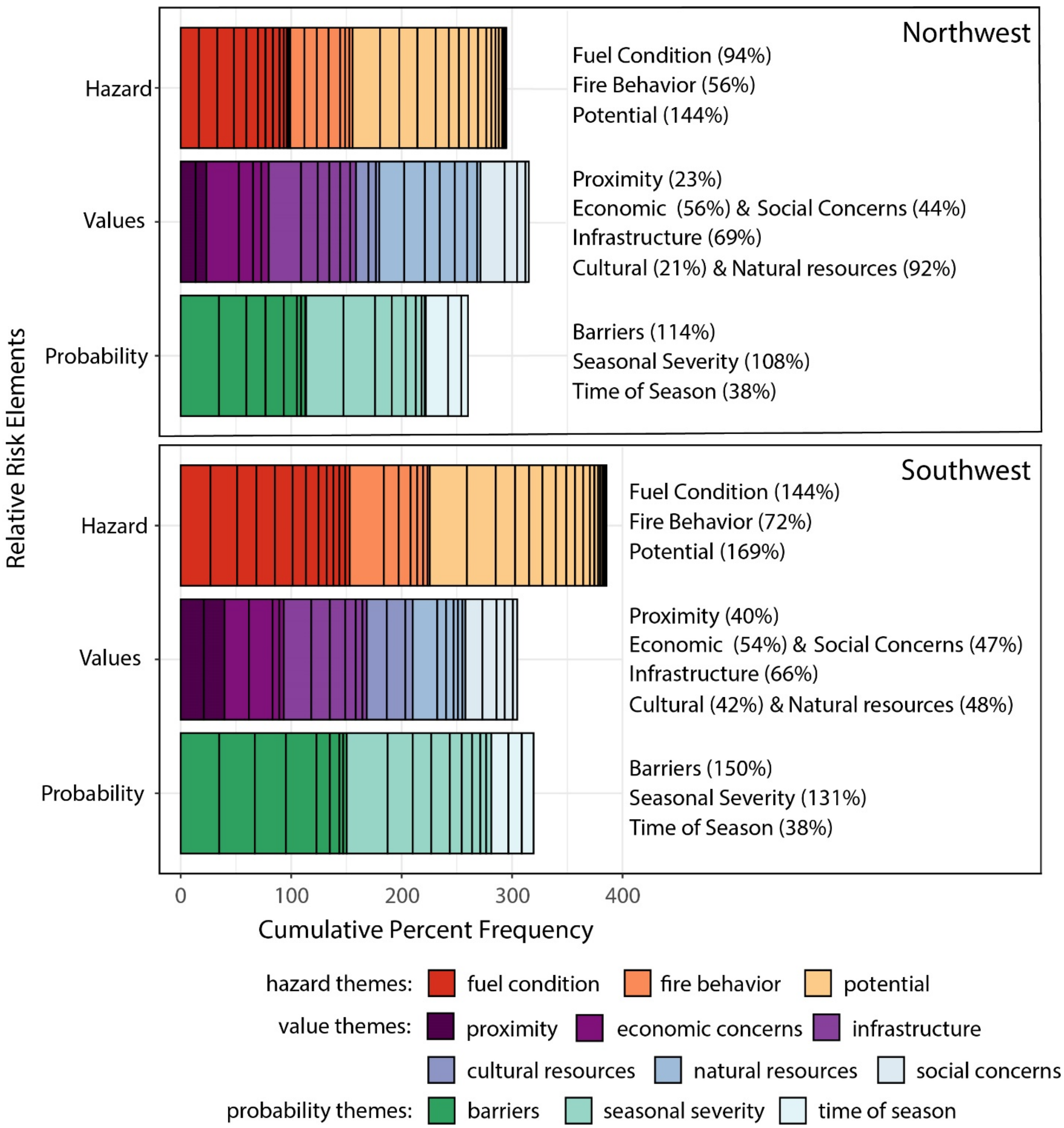

Figure 5. A high-level summary of the cumulative percent frequency of individual codes summarized by themes and elements by geographic area.

Table 2. Influential codes and associated statistics for high and low risk fires,

Element	Sub-code	Code Descriptor	Northwest							Southwest						
			Frequency (%)				Chi-sq.	RF MIR, rank	CART, Var. Imp., rank	Frequency (%)				Chi-sq.	RF MIR, rank	CART, Var. Imp., rank
			H	M	L	T	p-value			H	M	L	T	p-value		
Hazard	fire behavior	extreme fire behavior	3%	0%	1%	4%	0.406			4%	1%	1%	5%	0.003		
Hazard	fire behavior	low fire behavior	2%	5%	5%	11%	0.001	5		1%	9%	21%	31%	0.000	1	1
Hazard	fire behavior	moderate fire behavior	8%	2%	0%	11%	0.146		5	4%	3%	3%	11%	0.419		
Hazard	fire behavior	passive fire behavior	7%	4%	2%	13%	0.900			4%	5%	4%	13%	0.705		
Hazard	fire behavior	spotting fire behavior	8%	3%	0%	11%	0.208			2%	2%	0%	4%	0.116		
Hazard	fire behavior	surface fire behavior	4%	1%	0%	5%	0.380			1%	5%	0%	6%	0.023		
Hazard	fuel condition	average fuel loads	3%	3%	0%	6%	0.175			1%	4%	0%	5%	0.046		
Hazard	fuel condition	forested fuel types	6%	5%	5%	17%	0.044	13		5%	5%	7%	17%	0.512		
Hazard	fuel condition	grass fuel types	14%	2%	0%	17%	0.009	12	2	8%	10%	9%	27%	0.561		
Hazard	fuel condition	high fuel loads	11%	3%	2%	15%	0.475			9%	4%	3%	16%	0.000	6	
Hazard	fuel condition	highly departed vegetation	7%	0%	0%	7%	0.030	11		3%	3%	1%	7%	0.353		
Hazard	fuel condition	low fuel loads	2%	3%	2%	7%	0.078			0%	7%	11%	17%	0.002	12	
Hazard	fuel condition	shrub fuel types	3%	0%	0%	3%	0.223			7%	9%	8%	24%	0.580		
Hazard	fuel condition	vegetation within range	4%	2%	5%	11%	0.018			4%	3%	5%	12%	0.310		
Hazard	potential	high elevation	2%	3%	4%	8%	0.007	15		0%	1%	1%	2%	0.485		
Hazard	potential	high temperature	7%	2%	0%	9%	0.241		4	5%	3%	1%	9%	0.038		
Hazard	potential	large potential	15%	2%	0%	17%	0.002	6		7%	1%	0%	7%	0.000	2	
Hazard	potential	low relative humidity	7%	2%	0%	9%	0.241			7%	4%	1%	12%	0.000	13	8
Hazard	potential	moderate potential	6%	2%	0%	8%	0.243			3%	9%	5%	17%	0.183		
Hazard	potential	precipitation present	4%	3%	5%	12%	0.006	9		2%	12%	19%	34%	0.000	7	3
Hazard	potential	red flag conditions	3%	1%	0%	4%	0.506			6%	0%	0%	6%	0.000	4	
Hazard	potential	small potential	4%	5%	8%	17%	0.000	3		3%	9%	14%	26%	0.018	10	
Hazard	potential	steep topgraphy	16%	3%	6%	25%	0.085			5%	5%	2%	13%	0.057		
Hazard	potential	windy	14%	3%	1%	17%	0.074			7%	4%	1%	12%	0.002		
Probability	barriers	few barriers	11%	3%	2%	17%	0.555			7%	5%	1%	12%	0.001	15	
Probability	barriers	fire scars as barriers	7%	3%	2%	12%	0.968			6%	9%	13%	28%	0.386		
Probability	barriers	natural barriers	15%	9%	11%	35%	0.005	10		8%	12%	15%	35%	0.674		
Probability	barriers	numerous barriers	4%	5%	9%	17%	0.000	1	1	2%	10%	16%	28%	0.001		7
Probability	barriers	prescribed fire barriers	0%	1%	0%	1%	0.231			0%	2%	7%	9%	0.006		
Probability	barriers	unnatural barriers	17%	6%	2%	25%	0.135			5%	13%	14%	32%	0.302		
Probability	seasonal severity	average fire danger	5%	5%	4%	13%	0.111			1%	6%	9%	17%	0.050		
Probability	seasonal severity	drought	11%	4%	1%	15%	0.287			3%	5%	1%	9%	0.162		
Probability	seasonal severity	dry fuel moisture	26%	5%	3%	34%	0.004	4		6%	3%	1%	11%	0.004	11	
Probability	seasonal severity	high (wet) fuel moisture	2%	0%	3%	5%	0.008		10	1%	7%	9%	17%	0.020		4
Probability	seasonal severity	high fire danger	19%	5%	5%	29%	0.438			13%	6%	4%	23%	0.000	3	2
Probability	seasonal severity	high seasonal severity	5%	4%	1%	9%	0.365			3%	2%	0%	5%	0.016		
Probability	seasonal severity	monsoon	0%	0%	0%	0%	N/A			3%	12%	21%	37%	0.000	9	6
Probability	time of season	early time of season	8%	3%	1%	12%	0.464			5%	4%	2%	11%	0.103		
Probability	time of season	late time of season	2%	2%	3%	6%	0.025			2%	3%	10%	15%	0.012		
Probability	time of season	middle time of season	15%	5%	1%	20%	0.080			5%	7%	1%	12%	0.011	14	12

Element	Sub-code	Code Descriptor	Northwest							Southwest						
			Frequency (%)				Chi-sq.	RF MIR, rank	CART, Var. Imp., rank	Frequency (%)				Chi-sq.	RF MIR, rank	CART, Var. Imp., rank
			H	M	L	T	p-value			H	M	L	T	p-value		
Values	cultural resources	cultural resources	5%	2%	0%	7%	0.317			6%	5%	7%	18%	0.280		
Values	cultural resources	cultural sites	8%	3%	1%	11%	0.541			2%	7%	8%	17%	0.255		
Values	economic concerns	economic concerns, ranching	7%	1%	0%	8%	0.094			7%	5%	9%	21%	0.209		
Values	economic concerns	economic concerns, timber harvest	11%	2%	0%	13%	0.057			2%	1%	1%	4%	0.284		
Values	economic concerns	economic concerns, tourism, recreation, trails	16%	6%	8%	29%	0.176			7%	7%	8%	22%	0.334		
Values	infrastructure	commercial infrastructure	11%	4%	0%	15%	0.079		3	5%	5%	6%	17%	0.579		10
Values	infrastructure	government infrastructure	8%	2%	1%	11%	0.488			1%	9%	4%	14%	0.043	8	
Values	infrastructure	housing, structures	26%	3%	1%	29%	0.000	2	8	9%	7%	8%	25%	0.078		
Values	infrastructure	private land	8%	1%	2%	10%	0.258			0%	3%	6%	9%	0.035		
Values	mitigation	mitigation ineffective	2%	0%	0%	2%	0.328			4%	0%	1%	5%	0.000		9
Values	natural resources	sage grouse habitat	11%	1%	0%	11%	0.012			0%	0%	0%	0%	N/A		
Values	natural resources	special management areas	11%	2%	0%	14%	0.040		7	1%	3%	1%	4%	0.334		
Values	natural resources	threatened and endangered species	8%	3%	2%	14%	0.938			3%	3%	1%	8%	0.200		
Values	natural resources	wilderness	14%	4%	5%	23%	0.315			1%	3%	2%	7%	0.731		
Values	natural resources	wildlife habitat	12%	5%	2%	19%	0.737			9%	5%	8%	22%	0.044		
Values	proximity	values are close to fire	11%	2%	1%	14%	0.062			7%	5%	7%	19%	0.249		
Values	proximity	values are far from fire	5%	3%	2%	10%	0.648			2%	9%	9%	21%	0.106		
Values	social concerns	general social concerns	5%	3%	0%	8%	0.262		9	1%	2%	1%	4%	0.557		
Values	social concerns	multijurisdictional	16%	5%	2%	22%	0.151			8%	5%	3%	15%	0.002		
Values	social concerns	smoke	5%	2%	5%	11%	0.004			4%	5%	4%	13%	0.699		

Factors most influential to classification of risk were identified using Random Forest (RF) and CART analyses (Figures 6-7) and by tabulating a combination of Chi-square p-values < 0.05 and decreasing frequencies (Tables 3-6). In addition, a summary of the most influential codes is included in Table 2, where the frequency of codes by H (high), M (moderate), L (low) relative risk, and T (total) relative risk ratings are expressed as percentages including Chi-square p-values, and rankings from RF and CART. Codes excluded from RF and CART due to Chi-square p-value > 0.05 or very low frequencies are given in Appendix B.

Barriers and fire behavior played critical roles to produce risk level for both GAs. The absence of numerous barriers was the most important variable in the Northwest (Figure 6). High risk occurred when land managers failed to note that barriers were numerous. Risk was also high when numerous barriers with grass fuel types were present, although this occurred on only three fires. Numerous barriers in the presence of non-grass fuel types and commercial infrastructure (electrical, communication transmission lines) produced moderate risk. Low risk in the Northwest was a product of numerous barriers, non-grass fuel types, and a lack of commercial infrastructure. Overall classification accuracy between observed and predicted observations was 68%, with a tendency to misclassify moderate and low risk as high risk.

Risk levels were further evaluated to supplement the findings from the CART models. Codes that occurred infrequently but clearly with specific risk levels were examined and provided a different portrait of risk (Tables 3-6). High risk fires in the Northwest generally had more references to values at risk than just commercial infrastructure (from the CART model),

including housing, special management areas and sage grouse (Table 3). References to fuel conditions such as grass and highly departed vegetation were also important. Dry fuel moisture and housing were the most important factors influencing high risk and occurred for approximately 25% of high-risk fires (Table 2). Low risk fires were described by small potential, precipitation, high elevation, forested fuel types and vegetation within historical ranges. Natural and numerous barriers ranked as the first and second most important variables (Table 4), reinforcing the CART results that identified numerous barriers as the most influential variable related to moderate or low risk fires in the Northwest.

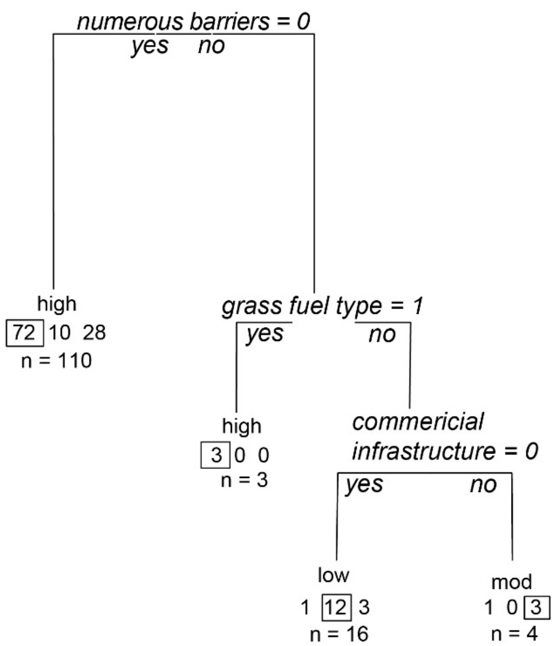

Figure 6. Northwest CART model classifying high, moderate and low relative risk.

Table 3. Codes and associated themes that were important for high risk fires in the Northwest. Codes were included if they had a p-value < 0.05 and were ranked by frequency from highest to lowest. An asterisk denotes P < 0.005. Underlined codes were common to both GAs.

Northwest High Risk

Codes	Themes	Rank
dry fuel moisture*	seasonal severity	1
housing*	infrastructure	2
large potential*	potential	3
grass fuel type	fuel condition	4
special management areas	natural resources	5
sage grouse	natural resources	6
highly departed vegetation	fuel condition	7

Table 4. Codes and associated themes that were important for low risk fires in the Northwest. Codes were included if they had a p-value < 0.05 and are ranked by frequency from highest to lowest. An asterisk denotes P < 0.005. Underlined codes were common to both GAs.

Northwest Low Risk

Codes	Themes	Rank
natural barriers*	barriers	1
numerous barriers*	barriers	2
small potential*	potential	3
forested fuels	fuel condition	4
precipitation	potential	4
smoke*	social concerns	4
low fire behavior*	fire behavior	5
veg within range	fuel condition	5
high elevation	potential	6
high fuel moisture	seasonal severity	7
late time of season	time of season	7

In the Southwest, the presence of low fire behavior was the most important predictor of relative risk for both the random forest and CART analysis (Figure 7). The CART was fairly simplistic

and included two variables: low fire behavior and high fire danger. High risk is predicted when fire behavior is not low and fire danger is high. Moderate risk is predicted in the absence of low fire behavior and high fire danger. Low fire behavior predicts low risk. Classification accuracy was 59.7% with a tendency to misclassify to moderate risk.

High risk fires in the Southwest generally included a discussion of factors influencing high fire spread potential, e.g., low relative humidity, large potential, windy, red flag conditions, high temperature; and by seasonal severity, e.g., high fire danger, dry fuel moisture, high seasonal severity (Table 5). There were other important factors related to fuel condition (high fuel loads), natural resources (wildlife habitat) and social concerns (multijurisdictional fires). High fire danger ranked first and was included in the CART model. Low risk fires were described by seasonal severity themes such as the monsoon, high fuel moisture, and average fire danger. Themes related to potential and barriers were also common: precipitation, small spread potential, numerous landscape barriers and prescribed fire barriers. Low fire behavior ranked second (Table 6), but was the most influential variable in the CART model.

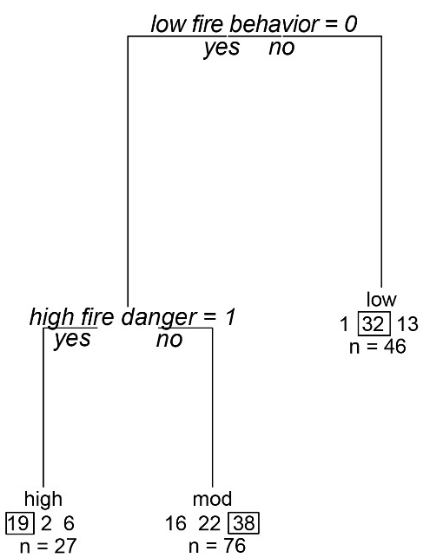

Figure 7. Southwest CART model classifying high, moderate and low relative risk.

Table 5. Codes and associated themes that were important for high risk fires in the Southwest. Codes were included if they had a p-value < 0.05 and were ranked by frequency. An asterisk denotes P < 0.005. Underlined codes were common to both GAs.

Southwest High Risk		
Codes	Themes	Rank
high fire danger*	seasonal severity	1
high fuel loads*	fuel condition	2
wildlife habitat	natural resources	3
multijurisdictional*	social concerns	4
low relative humidity*	potential	5
few barriers*	barriers	6
large potential*	potential	6
windy*	potential	6
red flag conditions*	potential	7
dry fuel moisture*	seasonal severity	7
high temperature	potential	8
middle time of season	time of season	8
extreme fire behavior*	fire behavior	9
mitigation ineffective*	mitigation	9
high seasonal severity	seasonal severity	10

Table 6. Codes and associated themes that were important for low risk fires in the Southwest. Codes were included if they had a p-value < 0.05 and were ranked by frequency. An asterisk denotes P < 0.005. Underlined codes were common to both GAs.

Southwest Low Risk

Codes	Themes	Rank
monsoon*	seasonal severity	1
low fire behavior*	fire behavior	2
precipitation*	potential	3
numerous barriers*	barriers	4
low fuel loads*	fuel condition	5
small potential	potential	5
late time of season	time of season	6
high fuel moisture	seasonal severity	7
average fire danger	seasonal severity	7
prescribed fire barriers	barriers	8
private land	infrastructure	9

Common and local VALUES at risk discussed by land managers on wildfires

In general, when land managers from the Northwest discussed 'values at risk', they did so in the context of high risk fires. Southwestern land managers discussed values in the context of low risk fires. By evaluating total frequencies (Table 2) and contrasting geographic areas through assessment of the most commonly occurring codes (Figure 8), values at risk were examined in more detail than provided above.

For example, in the Northwest, natural resources, specifically wilderness (23%), wildlife habitat (19%), threatened and endangered species (14%) and special management areas (14%, Table 2) occurred with the highest frequencies. Many of these codes were associated with high risk fires (Figure 8). Infrastructure, especially housing and structures, was overwhelming discussed for high risk fires (26%, Table 2) and was ranked as the second more important variable in the random forest analysis. Economic concerns related to recreation/tourism were prevalent for all levels of risk, but were frequently discussed for high risk fires in the Northwest (16%). Timber was mentioned for primarily high risk fires (11%), but was not significant. Social concerns regarding multijurisdictional fires were also not significant, but occurred for 22% of fires, mostly with high risk. Proximity of the wildfire 'close' to values at risk was discussed for 14% of fires, largely for high risk fires in the Northwest.

Infrastructure more than any other value at risk theme was discussed by land managers in the Southwest, overwhelming related to housing and structures that occurred for all levels of risk (25%, Table 2). Government infrastructure occurred more than expected for moderate risk fires and private land was mentioned for low risk fires. Natural resource concerns were discussed at about half the frequency of the Northwest and were specific to wildlife habitat, occurring for all levels of risk (22%) but more than expected for high risk fires (Table 2). Cultural resources were discussed twice as much in the Southwest as the Northwest for all levels of risk, mostly referencing general cultural resource sites and concerns. Economic concerns related to recreation and tourism and ranching were prevalent for all levels of risk. Multijurisdictional fires tended to be high risk fires. Proximity was discussed almost twice as much in the Southwest, and wildfires were characterized as 'far' (at least 1 mile away) from values and more often associated with low and moderate risk fires.

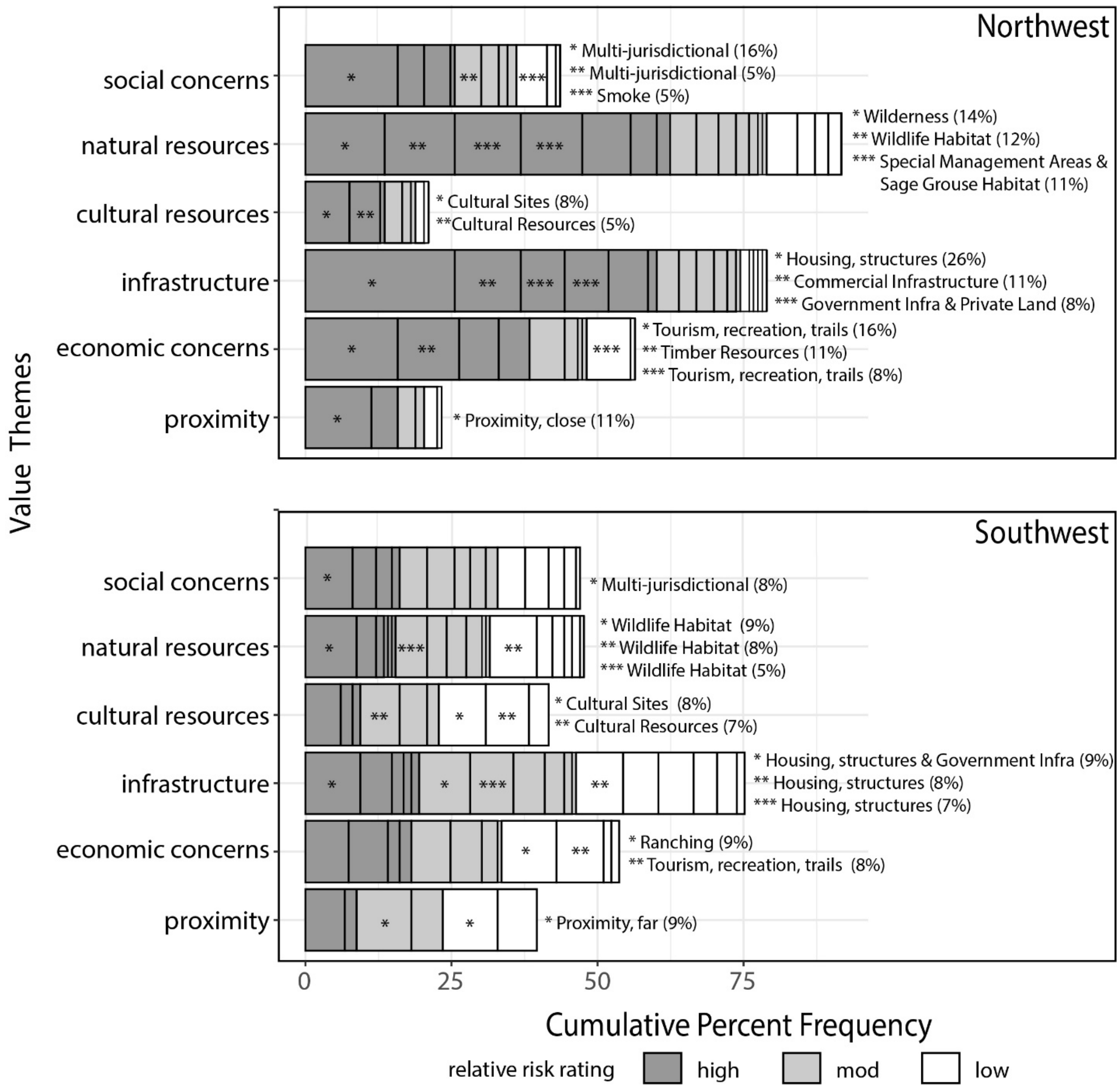

Figure. 8. Cumulative percent frequency of codes summarized with 'Value' themes by high, moderate and low relative risk ratings for the Northwest and Southwest GAs. The most common codes and their percent frequency are listed in the figure and available in table 2.

HAZARD conditions amendable to fire spread

"Hazard" describes the conditions under which a fire will spread, including the anticipated spatial extent and severity of the fire. Land managers from both GAs discussed fire "potential" more than the other hazard sub-themes (Figure 9) and many related codes were significant, suggesting that potential, topography and weather are impactful attributes associated with either high or low risk fires. Steep topography (16%) and windy conditions (14%) were additionally

used to describe potential for high risk fires in the Northwest. High fuel loads, likely associated with “highly departed vegetation” were also more common for high risk fires in the Northwest.

As noted previously, discussion of hazard in the Southwest was dominated by precipitation (34%) and low fire behavior (31%), both significant variables on low risk fires and ranked highly in the CART model (Table 2). A finer inspection of hazard themes especially for fuel condition shows that grass and shrub fuel types were discussed with some frequency (greater than 20%) for all levels for risk. Fuel loading was also important. High fuel loads were noted more for high risk fires; low fuel loads were noted for low risk fires, and average fuel loads occurred more than expected on moderate risk fires ($p<0.05$).

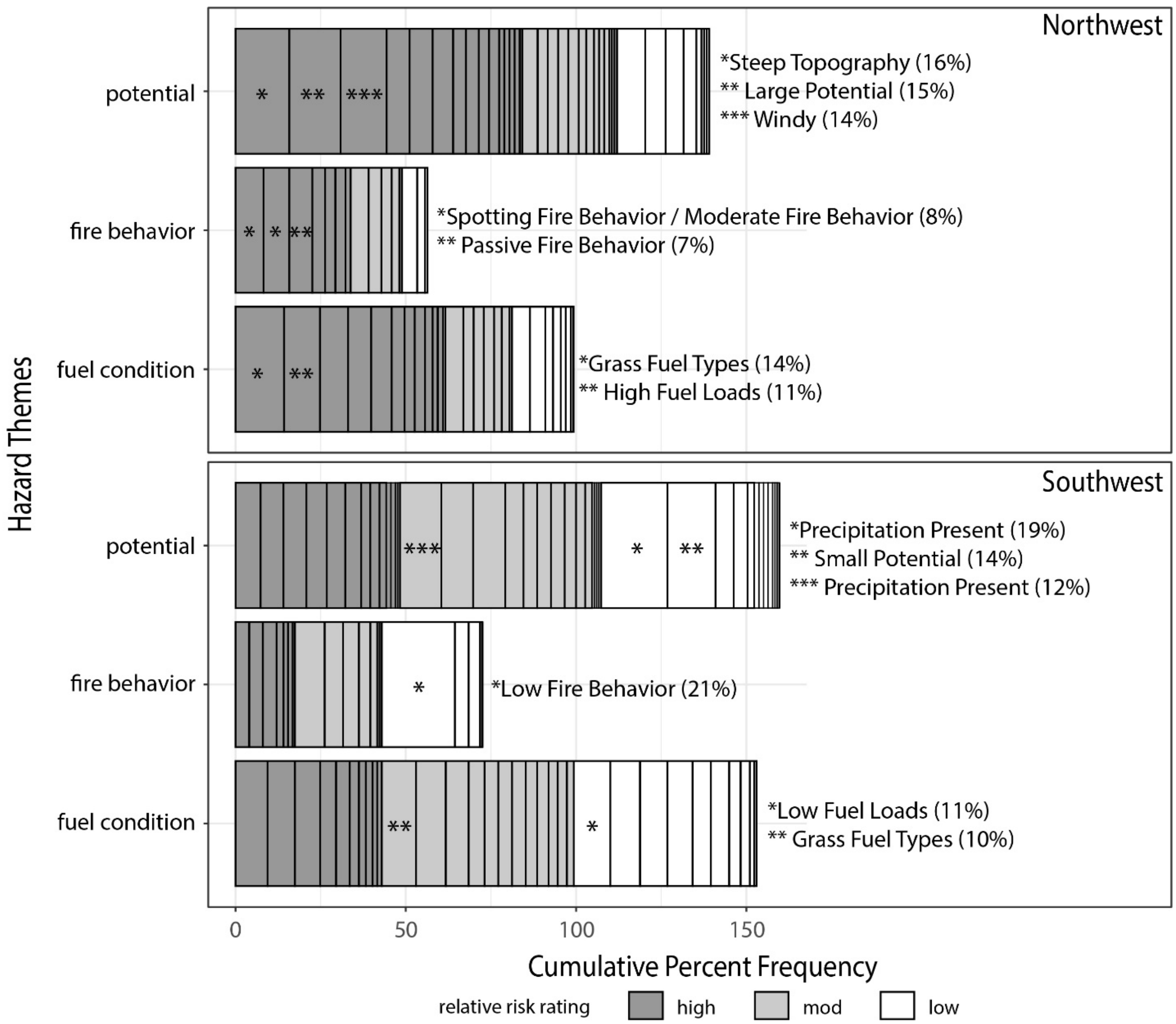

Figure 9. Cumulative percent frequency of codes summarized with ‘Hazard’ themes by high, moderate and low relative risk ratings for the Northwest and Southwest GAs.

Passive and moderate fire behavior was discussed commonly by both GAs, in connection with all levels of risk in the Southwest, and with moderate and high risk in the Northwest (Figure 10). The Northwest also discussed spotting for high and moderate risk fires. While used sparingly, extreme fire behavior was a significant factor in the Southwest for high risk fires and surface fire (vs crown fire) was significant for moderate risk fires. Low fire behavior also dominated the fire behavior discussion in the Southwest (31%), was used significantly more than expected for low risk fires, and was also discussed by the Northwest for all levels of risk.

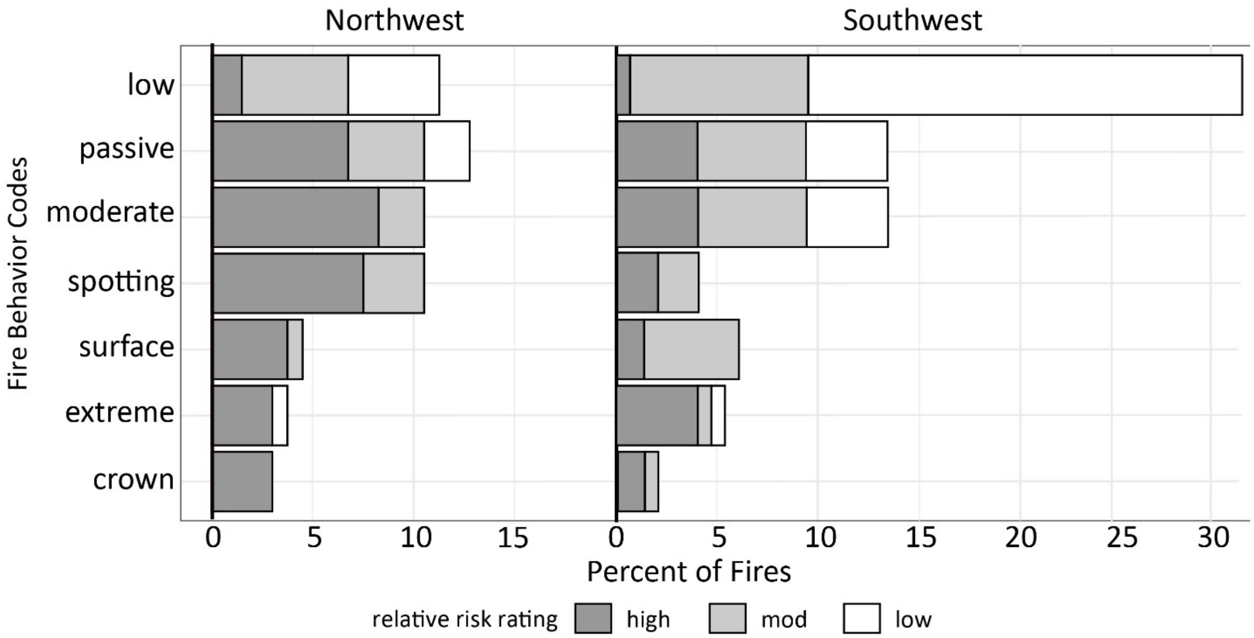

Figure 10. The frequency of fire behavior codes by relative risk ratings for the Northwest and Southwest geographic areas.

PROBABILITY factors influencing the likelihood of active fire

Land managers assess the likelihood of a fire becoming more active and potentially impacting values at risk when discussing themes and codes related to probability. An inspection of probability related codes identified barriers and seasonal severity factors as the most commonly discussed in both GAs. The Northwest commonly described the conditions of a challenging fire environment for high risk fires (Figure 11), although high fire danger and drought were discussed frequently for all levels of risk. Time of season was not discussed with high frequency relative to the other probability themes, but there were some interesting trends. The Northwest referenced middle time of season (15%) and early season fires (8%) more for high risk fires. Additionally, the type and number of landscape barriers was important at all levels of risk. References to "few" barriers preferentially occurred on high risk fires supporting the CART findings that identified numerous barriers (the alternative to few barriers) as the most important factor in classifying risk in the Northwest.

Probability themes and codes related to seasonal severity were largely associated with low and moderate risk fires in the Southwest. The southwest monsoon contributes to low (21%) and moderate risk (12%); and high fire danger was present not only for high risk fires (13%), but for all risk levels (23%) , indicating a dominant dry climate impacted by sporadic (but somewhat predictable) monsoonal rains that trigger low to moderate risk. Fires that began late in the fire season occurred more than expected for low risk fires. Similar to the Northwest, natural, unnatural and numerous landscape barriers were common descriptors of barriers, but prescribed fire barriers occurred more than expected for low risk fires even though they were discussed less frequently. Low fuel moisture was significant for high risk fires and high fuel moisture was significant for low risk fires in both GAs (Table 2).

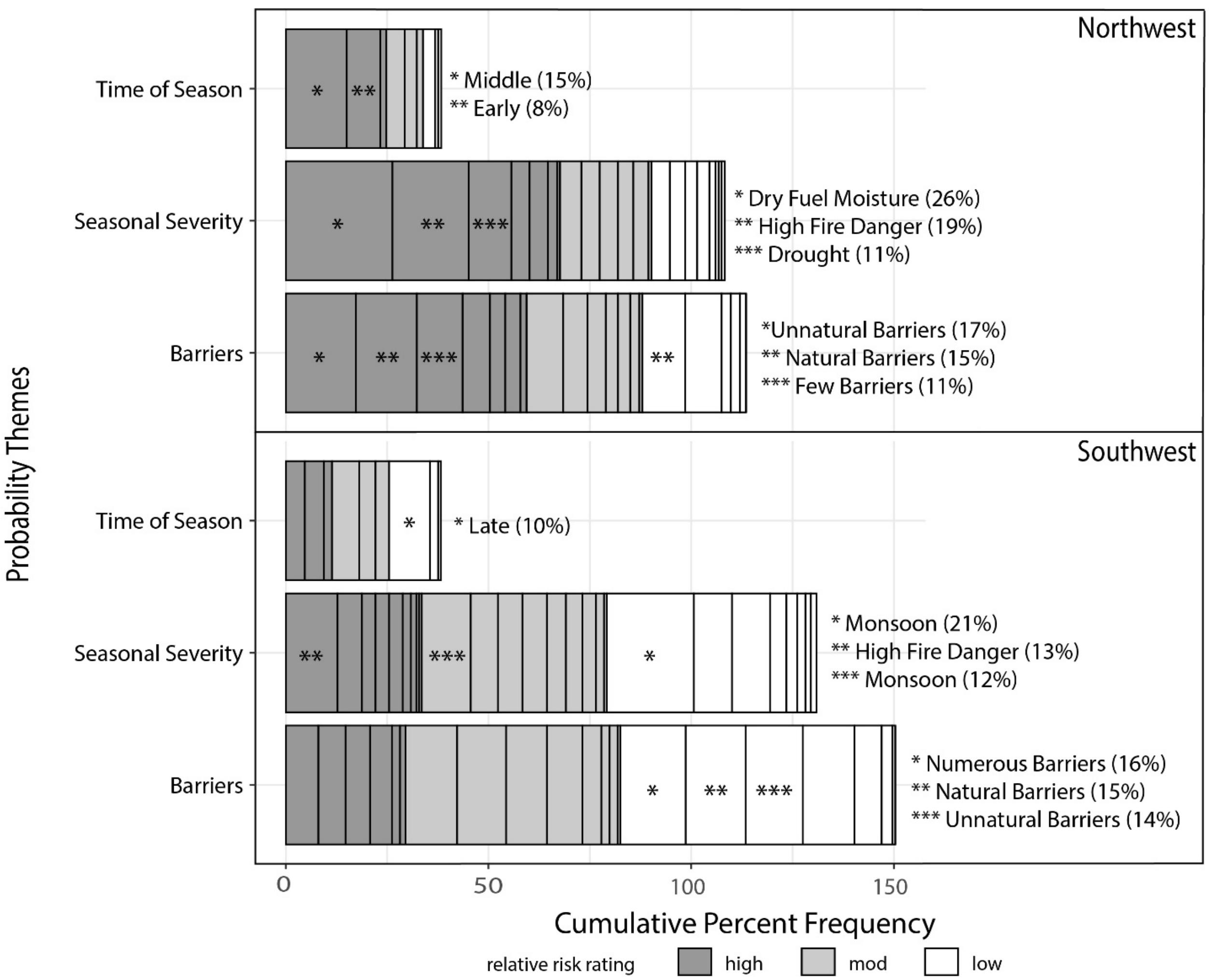

Figure 11. Cumulative percent frequency of codes summarized with ‘Probability’ themes by high, moderate and low relative risk ratings for the Northwest and Southwest GAs.

Discussion

These results provide a summary of the prevailing issues documented by primarily federal land managers during longer duration wildfires for all agencies in the Southwest and Northwest geographic areas from 2010 through 2017. The research sought to identify common factors that contributed to either high or low wildfire risk and to assess similarities and differences between the two regions with the most disparate risk profiles. The prevalence of precipitation, high fuel moisture and numerous barriers were ubiquitous on low risk fires in both regions. The timing and intensity of precipitation affects fuel moisture and subsequent area burned in forests of the western U.S. (Holden *et al.* 2018). These results support that land managers are making the familiar connection between precipitation and its' effect on fuel moisture resulting in fires with "small potential" and "low fire behavior". These fires occur late in the fire season when there is more certainty that the end is near. Options for contingencies leveraging "numerous" landscape barriers are also discussed.

Geographically dependent characteristics of low risk fires

There were some aspects of low risk fires that were geographically dependent. For example, the Southwest discussed a mild fire environment more than the Northwest because of the North American monsoon. The monsoon climatic pattern strongly affects fire weather in the Southwestern U.S. associated with sporadic periods of rain, typically occurring around the end of June or early July through September (Sheppard *et al.* 2002). It contributes to a hard-stop to the fire season precisely when most of the rest of North America is ramping up toward peak burning conditions and offers an element of predictability in fire activity. Excerpts from the qualitative data are included below as examples. These excerpts were selected for because they represent a perspective that is present in many of the entries and help illustrate the code.

When the monsoon was referenced in the Southwest, it was usually discussed in the context of reducing fire behavior and potential and was also mentioned in the context of certainty regarding the end of the fire season, i.e.

> Given the recent and forecasted monsoonal moisture this fire is not expected to grow much, if at all and fire behavior is expected to be low. Southwest, Low Relative Risk (1324491),
>
> We are starting to see the onset of monsoon moisture which indicates the peak fire season is drawing to a close. Southwest, Low Relative Risk (208194)

When precipitation with the monsoon was lacking, managers discussed the "inconsistent" or "atypical" conditions and associated them with higher levels of risk, i.e.

> Due to atypical monsoonal patterns, continued prolonged drought, and high temperatures, fuel moistures are very low and seasonal severity is extreme. Typically the area would have already experienced green-up from monsoonal moisture and fire activity would be minimal. Southwest, High Relative Risk (399320), or
>
> Due to sustained drought, seasonal severity would rank higher than average. Monsoon storms have been inconsistent. Southwest, Moderate Relative Risk (430489)

Landscape barriers from previous wildfires were discussed frequently in the Southwest and prescribed fire barriers were noted on low risk fires indicating that managers recognize the benefits of previous decisions that managed landscape vegetation when considering risk. The following example from the Southwest collectively exemplifies many of these common attributes:

> Overall relative risk is low, primarily because of the time of the year and the fact that we have received good monsoon rain in the last three weeks. There are minimal values to protect in this area, and fire behavior is expected to be low. The fire area has not burned in recent history, but is surrounded by numerous areas that have burned in wildfires or prescribed fires in the last 5 years. Southwest, Low Relative Risk (1293872)

The connections managers make between the presence of landscape barriers and risk are also supported by research efforts aimed at expanding decision-space on wildfires. For example, the dependencies between final fire perimeters and landscape features (topography, roads, ridgetops, fuel changes) were combined to develop an empirical model to predict locations where fire management efforts would be most successful at limiting fire spread (O'Connor *et al.* 2017). The formulation of management zones dependent upon barriers and insight from fire managers have subsequently been used to promote more options to manage wildfire in the Southwest (O'Connor 2019).

In the Northwest, despite the dominance of dry summer climate and the absence of a predictable fire season-end, there is evidence that when fire conditions are moderated by sporadic summer precipitation, the result is low to moderate relative risk related to lower fire behavior and spread potential, similar to what is referenced by land managers in the Southwest.

Low risk fires in the Northwest also had some unique aspects, such as high elevation, forested fuel types, vegetation within historical ranges, numerous and natural barriers, and smoke as the only social value. This excerpt from a Northwest wilderness fire provides an example of many of these common low risk attributes; for example,

> The fire is surrounded by rock on 3 sides, with a significant landslide on the 4th. Indices and fuels conditions are somewhere between average and slightly above average. At this time, only 3 smokes are showing between all 3, and there is no reason to believe, that this won't happen on the Jumbo as well. Should significant growth occur, it is anticipated that it will be up drainage away from private values, further into the Boulder Creek Wilderness. We are entering the last week of August, with the historical season ending event taking place in the next 2-3 weeks. Northwest, Low Relative Risk (2373735)

Although these conditions occurred less frequently in the Northwest, the excerpt illustrates remote fires with low spread potential burning at high elevation late in the season with few values at risk, representative of low risk fires.

Local values and climate distinguish high risk fires

High risk fires had fewer common factors shared between the GAs. There were a variety of hazard and probability codes that commonly described a challenging fire environment, but the similarities diverged for the discussion of values at risk. Important values at risk in the Northwest during high risk fires were housing, sage grouse habitat, and special management areas likely associated with grass fires. Wildlife habitat, usually associated with Mexican Spotted Owl habitat, was influential for Southwestern high risk fires. Housing and recreation values at risk were discussed ubiquitously across regions and risk levels.

Unlike the Southwest, the Northwest does not benefit from a consistent seasonal rain during the summer months (Holden *et al.* 2018), and is expected to experience increases in fuel aridity and wildfire activity associated with anthropogenic climate change (Stavros *et al.* 2014). Climate manifests as dry summers without predictable precipitation and is the foundation for the fire season leading land managers to frequently comment that fuels are dry and fire danger is high. The artifact of dry summers, departed vegetation condition, grass fuel types, and dry fuel moistures, coupled with the influence of specific values at risk that do not interact with fire in beneficial ways (housing and structures) are all associated with higher ratings of risk. The variety of factors influencing high risk in the Northwest is exemplified below:

> The relative risk is high due primarily to the potential for a high rates of fire spread and large fire growth. Fire behavior indices are above normal for the time of year. Natural resource concerns include general and priority sage grouse habitat, ACEC [coded as a special management area], and noxious weeds. There are moderate social/political concerns due to the ranches and private land scattered throughout the planning area and impacts to grazing and wildlife habitat. Fuels are primarily grass. Topography is rough and access is limited. Even though early in the fire

season fuels are reaching critical stages. This area is experiencing a persistent drought conditions. Northwest, High Relative Risk (1244021)

According to previous studies, most houses and structures do not respond favorably to wildfire (Cohen 2000; Calkin *et al.* 2014) especially when built with flammable materials. Both the number of people and homes in the wildland urban area increased from 1990 to 2010 (Radeloff *et al.* 2018) along with an increase of the likelihood and threat of wildfire for many western U.S. counties (Haas *et al.* 2013). This expansion has also increased the general jurisdictional complexity of federal lands juxtaposed to private inholdings and more populated areas with transboundary wildfire exposure between federal, state, and private entities all impacting communities (Ager *et al.* 2018). Increasingly, the focus on human vulnerability to wildfire is a major tenet of federal wildfire management and not one that can be readily ignored for land managers (Fischer *et al.* 2016). It is therefore not surprising that land managers are discussing housing and structures for all levels of risk in the populated and growing Northwest region.

Multijurisdictional fires were more likely associated with high relative risk in both GAs, suggesting that land managers could potentially expand decision-space by solidifying relationships and agreements pre-fire season with state, county and local partners. High risk, multijurisdictional fires appeared to be more complicated; for example, there were administrative complications along with issues related with competing land management objectives associated with different agencies as exemplified in the excerpts below:

> The fire is expected to involve several jurisdictions, cooperators, and special interest groups and agreements requiring significant negotiation need to be developed. Northwest, High Relative Risk (1279511),
>
> The western perimeter is 1.5 miles from the Forest Service boundary. The strategic direction for the fire is to prevent spread onto neighboring jurisdictions Northwest, Moderate Relative Risk (449060)

In many cases, pro-active measures to incorporate multiple shareholders to provide input into pre-fire planning processes are already occurring (Gilbertson-Day *et al.* 2018), stemming from efforts associated with cohesive strategy (USDA/USDI 2011), but the jurisdictional issue is still evident in the data, perhaps related to the different missions of the various federal and non-federal landowners.

Values at risk appeared to be less influential overall for the Southwest in comparison to the Northwest. Wildlife habitat and concerns with multijurisdictional fires occurred more for high risk fires. The Southwest also discussed fire weather amenable to large spread potential, such as

high fire danger, high seasonal severity, wind, red flag conditions, high temperature and extreme fire behavior to indicate high risk. Fires with these characteristics occurred in the early to middle of the fire season when there was still uncertainty regarding monsoonal moisture and fire season duration. Broadly, a challenging fire environment where "mitigation is ineffective" is represented. For instance, this early season, multijurisdictional fire demonstrates many of the concerns:

> Fire is likely to impact BLM/Private Lands. Drought conditions exist. Persistent wind events, large size due to wind and fuel conditions. Forecasted weather indicates high potential for large fire growth. Red Flag conditions predicted through Tuesday 4/26/11. Southwest, High Relative Risk (294117)

The strong and contrasting coupling of climate and risk between the Southwest and Northwest highlights the role climate change may play in future wildfire risk. Southwestern land managers clearly rely on the predictability of the monsoon to manage risk and the Northwest clearly suffers the consequences of a highly uncertain moisture regime each summer. Some research has suggested that precipitation associated with the North American monsoon could sharply decrease due to increased atmospheric stability and less wind associated with more uniform sea surface temperatures (Pascale *et al.* 2017). This, in turn, could result in significantly more large wildfires (> 24000ha), and more days with extreme conditions including very low fuel moistures and high fire danger for the Southwest (Stavros *et al.* 2014). If these conditions materialize, one might anticipate a change in the Southwest's affinity for low-risk. Based on the findings of this study, climate changes that result in more variability (or decreased predictability) will almost certainly increase operational wildfire risk even if objective probabilities of extreme events decrease. The constant threat of high consequence low probability events drives up operational risk.

The Northwest is predicted to experience an increase in more extreme fire days as climate changes. Fuel aridity is likely the cause of larger fires in forested ecosystems (Abatzoglou *et al.* 2017; Abatzoglou *et al.* 2018), in part, due to anthropogenic activity leading to increases in temperature and vapor pressure deficit (Abatzoglou and Williams 2016). An evaluation of climate from the Pacific Northwest from 1901 to 2012 showed increased warming, a long-term increase in spring precipitation and decreased summer and fall precipitation leading to larger climatic water deficits (Abatzoglou *et al.* 2014). Drought already plays a role in relative risk in the Northwest. Manifestations of future climate are expected to produce more unfavorable weather and fuel conditions amenable to fire spread, posing challenges for land managers in both GAs.

On the positive side, there is evidence in both regions that when managers get a break from high fire environment conditions with a favorable weather forecast or time of season, they find low

risk and consider a wider variety of management strategies. We hypothesized that manager confidence in the occurrence and effects of the monsoon would be a major aspect of Southwestern fire management that lent itself to lower risk and perhaps greater decision space when devising fire management strategies. However, we did not anticipate the same behaviors in the Northwest, where occasional sporadic moisture and certainty with respect fire season end worked together to produce some low risk and different management strategies.

Fire behavior is rarely extreme

Despite the inherent complexity of the fires on which a RRA is completed, the fire behavior is generally rated as moderate, low, passive or spotting fire behavior, with high or extreme fire described less than 6% of the time, even for this subset of more complex fires. Post-fire burn severity can provide some clues as to how wildfires actually behaved. For example, crown fire is assumed as high severity in forested ecosystems (Eidenshank *et al.* 2007). Two analyses of burned area and severity from 1984-2010 for large fires in the Western U.S., found significant increases in fire size and severity for the Madrean evergreen lowland forests, common in the mountains of the Southwest (Dennison *et al.* 2014; Picotte *et al.* 2016). Northwest fires in the Columbia Plateau/Snake Basin and Cascade Mountains also saw a general trend upward for burned area and number of large fires but not for severity (Dennison *et al.* 2014; Picotte *et al.* 2016). These studies show a general upward trend in fire activity that may or may not be associated with more extreme fire behavior. Certainly, in the 282 fires examined in this study representing the most complicated wildfires on federal lands, fire behavior was low to moderate most of the time, with a few larger fires exhibiting more complex fire behavior (described as 'extreme' with 'crown' fire runs) for isolated periods of time. High fire behavior was not a major factor in risk and this finding is consistent with the perspective that high/extreme fire behavior is rare and fleeting on a majority of wildfires.

Another way to conceptualize the factors influencing wildfire risk is to consider that a break in high fire environment conditions, when accompanied by precipitation associated with the monsoon, could provide land managers with some confidence that the values at risk likely won't be impacted by wildfire. Sporadic rain events or certainty with the end of the fire season due to the monsoon in the Southwest results in a mild enough fire environment coupled with barriers to fire spread, providing land managers confidence that the fire won't get to the values. We hypothesize this confidence is one aspect of Southwestern fire management that lends itself to greater decision space when devising fire management strategies. We expect the Southwest qualitative notes to discuss strategies other than suppression with higher frequencies than the Northwest for this reason and investigate this further in the next chapter

Conclusion

Unique to this study are results from wildfire risk assessments made during actual events, when risk was evolving, dynamic, uncertain, and inconclusive. Land managers articulated a range of factors to justify risk with common themes emerging for the two most risk-disparate geographic areas in the country The Northwest and Southwest both identified housing and economic concerns related to recreation and tourism as the most common values at risk. Both discussed the role of natural and unnatural landscape barriers; as well as high seasonal severity, especially in of the context of high fire danger and dry fuel moistures. However, the Southwest selected low and moderate relative risk with greater frequencies than the Northwest and the factors managers write about relate primarily to characteristics of the fire environment amenable to 'low fire behavior' and 'small potential', in part, due to precipitation associated with the North American monsoon. The Northwest found high and moderate risk with high frequency and it is not surprising that its land managers write more about values at risk, aspects of seasonal severity leading to greater fire spread and potential, and steep topography. Perspectives from both GAs highlight the critical role that climate plays in dictating weather, fuel moisture, and fire behavior when assessing risk during wildfires.

Importantly, the discussion of risk in both regions is focused exclusively on whether fire is expected to reach values, related to the probability of fire spread and the barriers that will impede this spread. In short, if there is a good chance fire will reach values, risk is high. Otherwise risk is low. There was no discussion of the actual or relative worth of values, the ability of values to resist fire, or the facility of the public to accept and deal with fire. In short, managers are doing their best to ensure that fire and values at risk don't interact. In the context of the oft-stated assertion that 'people need to learn to live with fire', these findings highlight the considerable gap that exists between this ideal and current practice.

Management Implications

Quiescent weather, landscape barriers, and late season fires result in low risk in both regions. There is a need to exploit these favorable conditions more frequently in order to opportunistically use unplanned and planned ignitions to accomplish long-term management objectives. As the consequences of climate change extend fire seasons and result in warmer, drier and longer summers for most of the western U.S. (Westerling *et al.* 2006; Jolly *et al.* 2015; Abatzoglou *et al.* 2017), there is greater uncertainty in weather, fuel condition, and thus fire behavior and spread. The results of this study add evidence in support of the idea that uncertainty restricts the decision space of managers to use fire for the maintenance of fire dependent ecosystems. However, management decisions that fail to adequately address the long-term risks posed by exterminating fires now, will leave the land in a less resilient state to burn with acceptable fire severities for the next, inevitable ignition later on. Given expected future climates, now is the

time to change how fire is managed, which likely means reducing risk and using different management strategies on at least some fraction of high risk fires.

Limitations

The results of this study must be synthesized within the constraints of the sampling methodology. The individual fires occurring from 2010 through 2017 were summarized at a regional scale to evaluate the collective characteristics of a geographic area that influence fire-fighting resource allocation, intelligence, and management direction. Finer spatial and temporal scales such as the unit-level, may expose patterns not unearthed at a regional scale. In addition, many long duration fires have multiple relative risk assessments to reflect the dynamic nature of wildfire. This study chose the records associated with the earliest and most commonly used relative risk rating to represent each wildfire, acknowledging that relative risk could change as wildfire conditions increase or abate over the course of a long duration fire. We surmise the RRA represents a mixture of land manager's risk perceptions and biophysical risk. Consequently, the qualitative data may diverge from measured, objective values at risk, hazard and probability. For instance, a land manager may write that fire danger was very high, but fire danger values were actually measured closer to 70^{th} percentile. The results should be evaluated within the context of factors influencing risk assessments that were important enough to voluntarily discuss by land managers during wildfires. Finally, the methodology represents decisions about coding that are judgments and when those codes are quantitatively analyzed, those subjective judgments can influence the quantitative results. Codes were standardized by using one individual with a fire management background to code the qualitative text and three check coders to check for internal coding consistency. In addition, the CART analyses were performed on both the individual codes and at broader scales representing themes. Results were similar regardless of the level of analysis (Appendix C).

Further Research

Data collected on wildfires in numerous mandated systems, forms, and databases collectively tell a story about the decisions surrounding one of the most influential moments on a landscape – a wildfire. Researchers should endeavor to tell these stories to land managers and administrators through exploration and analysis of these data. If managed strategically, wildfires can leave communities and the surrounding environment in a more resilient state than without that disturbance. Analyzing wildfire data ex post facto to identify decisions that lessened fire-fighter exposure, costs, and increased landscape resiliency, is a critical component to convincing both land managers and the public that wildland fire is an opportunity to gain benefit for long-term resilient landscapes.

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Appendix A

Fire behavior codes of the relative risk assessment categorized by the relative risk framework: hazard and probability. The total number of times codes were counted (n) are shown in white shapes. Gray shapes denote categories to summarize codes. There were a total of 282 wildfires from the relative risk assessment dataset that were coded simultaneously to produce 93 codes.

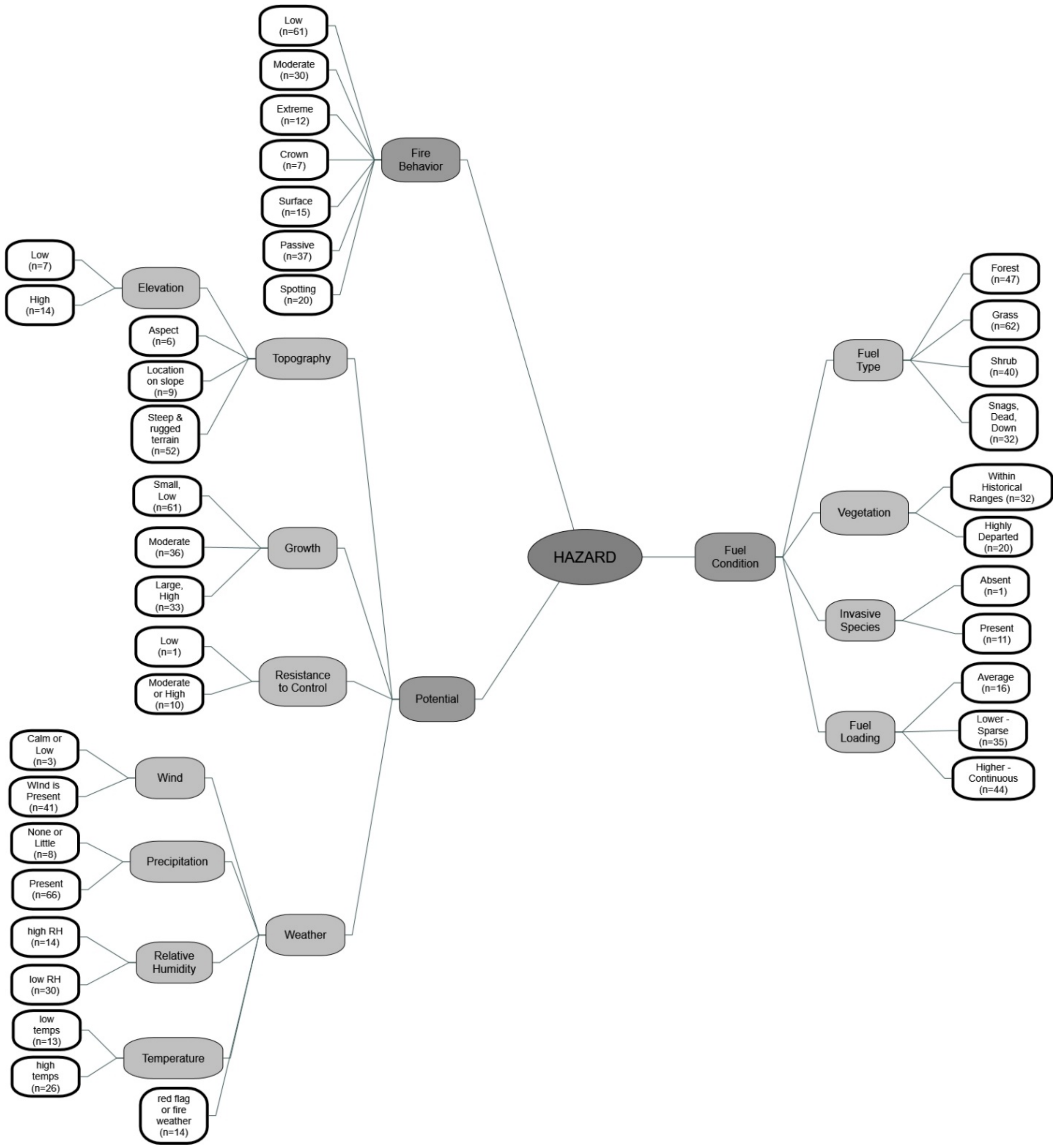

Figure 12. The Hazard Element is summarized by themes (Potential, Fuel Condition and Fire Behavior). The themes are further described by second and third-order sub-themes (light grey shapes), used to summarize types of codes, with the total number of wildfires associated with a specific code, denoted with white shapes.

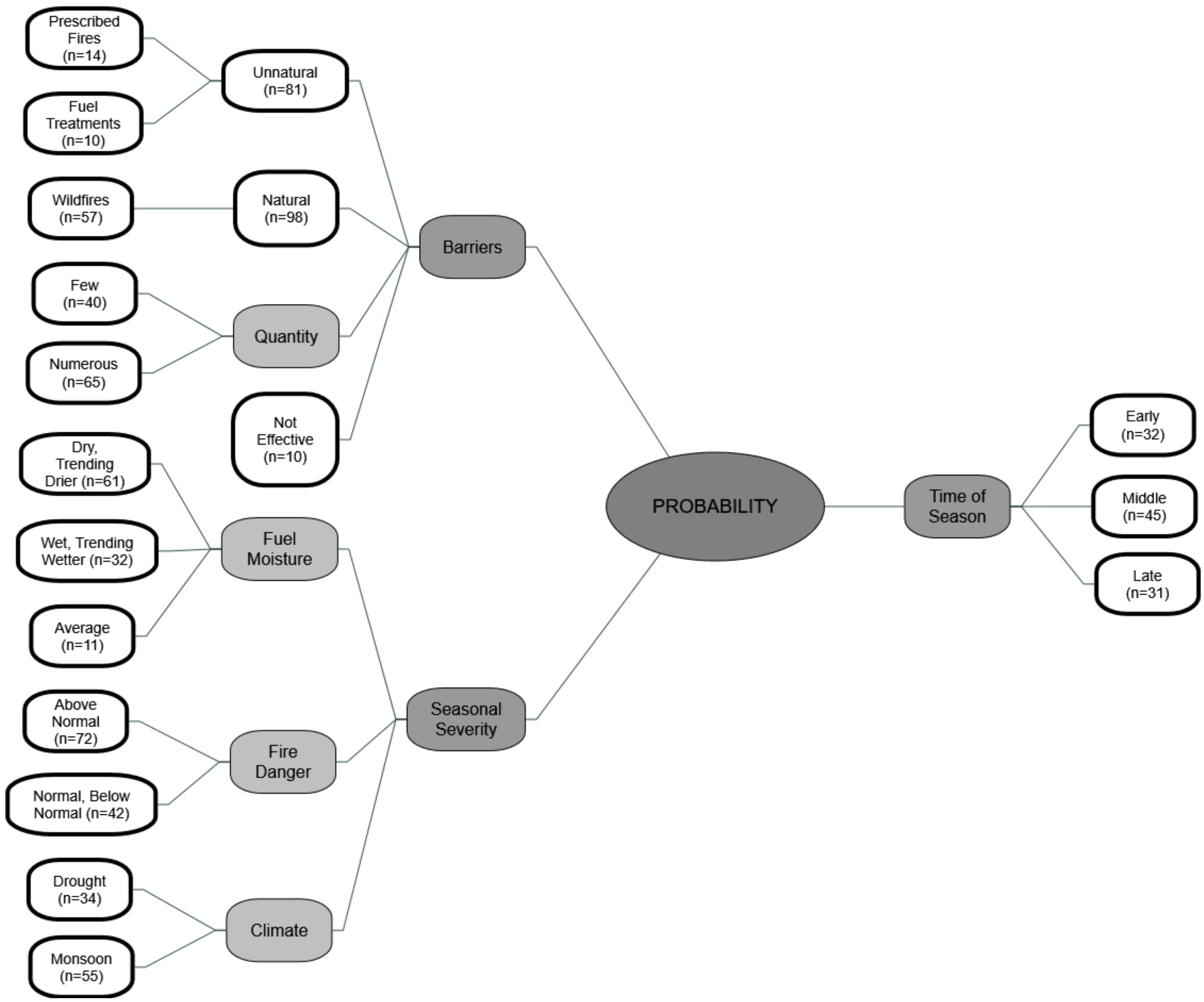

Figure 13. The Probability Element is summarized by themes (Time of Season, Seasonal Severity and Barriers). The themes are further described by second and third-order sub-themes (light grey shapes), used to summarize types of codes, with the total number of wildfires associated with a specific code, denoted with white shapes.

Appendix B

Table 6. Codes that occurred with low frequency, were not significant (chi-square>0.05) and were not ranked in either the Random Forest or CART analysis.

Element	Sub-code	Code Descriptor	Northwest							Southwest						
			Frequency (%)				Chi-sq.	RF MIR,	CART, Var.	Frequency (%)				Chi-sq.	RF MIR,	CART, Var.
			H	M	L	T	p-value	rank	Imp., rank	H	M	L	T	p-value	rank	Imp., rank
Hazard	fire behavior	crown fire behavior	3%	0%	0%	3%	0.223	NA	NA	1%	1%	0%	2%	0.177	NA	NA
Hazard	fuel condition	snag fuel types	8%	1%	2%	11%	0.204	NA	NA	2%	4%	5%	11%	0.657	NA	NA
Hazard	fuel condition	invasive species	2%	0%	0%	2%	0.478	NA	NA	2%	3%	1%	6%	0.238	NA	NA
Hazard	potential	low elevation	2%	0%	0%	2%	0.478	NA	NA	1%	3%	0%	3%	0.114	NA	NA
Hazard	potential	precipitation absent	1%	0%	1%	2%	0.384	NA	NA	1%	3%	0%	4%	0.143	NA	NA
Hazard	potential	high resistance	3%	0%	0%	3%	0.223	NA	NA	1%	2%	1%	4%	0.557	NA	NA
Hazard	potential	low resistance	0%	0%	0%	0%	N/A	NA	NA	0%	1%	0%	1%	0.444	NA	NA
Hazard	potential	high relative humidity	1%	0%	1%	2%	0.384	NA	NA	0%	4%	4%	8%	0.125	NA	NA
Hazard	potential	low temperature	2%	0%	2%	4%	0.216	NA	NA	0%	2%	3%	5%	0.179	NA	NA
Hazard	potential	aspect	2%	1%	1%	3%	0.894	NA	NA	0%	0%	1%	1%	0.186	NA	NA
Hazard	potential	slope	2%	2%	2%	5%	0.392	NA	NA	1%	0%	1%	2%	0.176	NA	NA
Hazard	potential	calm winds	0%	1%	0%	1%	0.231	NA	NA	1%	1%	0%	1%	0.498	NA	NA
Probability	barriers	ineffective barriers	4%	0%	0%	4%	0.151	NA	NA	1%	2%	0%	3%	0.210	NA	NA
Probability	barriers	fuel treatment barriers	2%	2%	0%	4%	0.169	NA	NA	0%	1%	3%	3%	0.124	NA	NA
Probability	seasonal severity	average fuel moisture	1%	1%	2%	3%	0.168	NA	NA	2%	1%	2%	5%	0.330	NA	NA
Probability	seasonal severity	moderate seasonal severity	0%	0%	1%	1%	0.079	NA	NA	1%	4%	3%	7%	0.378	NA	NA
Values	cultural resources	cultural resources absent	1%	1%	2%	3%	0.168	NA	NA	1%	2%	3%	7%	0.702	NA	NA
Values	economic concerns	economic concerns (mining, outfitters, agriculture)	5%	1%	1%	7%	0.445	NA	NA	2%	3%	1%	6%	0.597	NA	NA
Values	infrastructure	few or no houses	2%	3%	1%	5%	0.135	NA	NA	1%	1%	3%	6%	0.477	NA	NA
Values	infrastructure	highway infrastructure	7%	2%	1%	9%	0.447	NA	NA	2%	1%	1%	4%	0.284	NA	NA
Values	mitigation	mitigation effective	2%	0%	1%	2%	0.510	NA	NA	1%	4%	3%	9%	0.708	NA	NA
Values	natural resources	flora (whitebark pine, ecosystems)	5%	2%	3%	9%	0.247	NA	NA	1%	1%	1%	3%	0.836	NA	NA
Values	natural resources	natural resources	2%	1%	0%	3%	0.640	NA	NA	1%	1%	3%	4%	0.314	NA	NA
Values	social concerns	negative perceptions of fire	1%	2%	1%	3%	0.384	NA	NA	3%	3%	2%	7%	0.583	NA	NA
Values	social concerns	positive perceptions of fire	0%	0%	0%	0%	N/A	NA	NA	0%	3%	5%	7%	0.081	NA	NA

Appendix C

This CART model sought to classify the different levels of relative risk based on the presence or absence of the clustered themes to compare to the CART model derived from individual codes. The final CART model for both GAs was composed of 25 variables with values ranging from 0 to 5 representing the number of times different codes within the clustering units were present per wildfire. A separate CART was performed for each GA (n=133 observations for the Northwest, and n=149 observations for the Southwest). The 25 themes were lumped from individual codes as follows:

Values at risk codes were lumped into major themes: natural resources, cultural resources, infrastructure, social concerns, and economic concerns. Some codes were included without lumping. For example, 'proximity' of the fire to values at risk being close or far represents opposite meanings as well as 'mitigation' of the unwanted fire effects being effective or ineffective. These codes were included without grouping them to avoid conflicting interpretations.

Hazard codes were grouped according to topography, high and low fuel condition, fire behavior, and weather. 'Topography' included high and low elevation, aspect, slope and steep terrain. High fuel condition included vegetation that was highly departed and high fuel loading. Low fuel condition lumped vegetation within historical ranges and low and average fuel loading. Forested fuel types lumped forests and snag codes. Range fuel types lumped grass and shrub fuels. Low fire behavior included low and moderate fire behavior, small and moderate growth, low

resistance to control, passive and surface fire behavior. High fire behavior included crown fire, spotting and extreme fire behavior, large growth, and high resistance to control. Finally, the 'high weather' theme included windy conditions, little precipitation, low relative humidity, high temperatures and red flag conditions. 'Low weather' included calm wind, precipitation, high relative humidity and low temperatures.

Finally, probability grouped early and middle time of season into one time of season code. Late time of season was included as an individual code. The quantity of landscape barriers were included as individual codes representing numerous and few barriers. Types of landscape barriers were lumped including natural, unnatural, barriers from prescribed, wildfires, and fuel treatments. The 'high seasonal severity' theme included codes related to dry fuel moisture, above normal (high) fire danger, and drought. 'Low seasonal severity' combined moist (wet) fuel moisture, normal fire danger, and the monsoon.

The results from the CART model that used codes grouped into themes was similar to the CART performed on individual codes. In the Northwest, again, a lack of numerous landscape barriers remained the most important factor to determine high risk. Rangeland vegetation including grass and shrub fuel types was the second more important factor. High fire behavior was the third most important variable. In the Southwest, the results suggest that drivers of seasonal severity are the most influential set of factors to determine high versus low and moderate relative risk. Other aspects related to hazard (fire behavior, fuel condition and weather) were important factors to classify risk. Values at risk were not considered, nor were landscape barriers in the lumped, CART model. In the original CART, low fire behavior and high fire danger codes were the most influential to classify high, low and moderate risk.

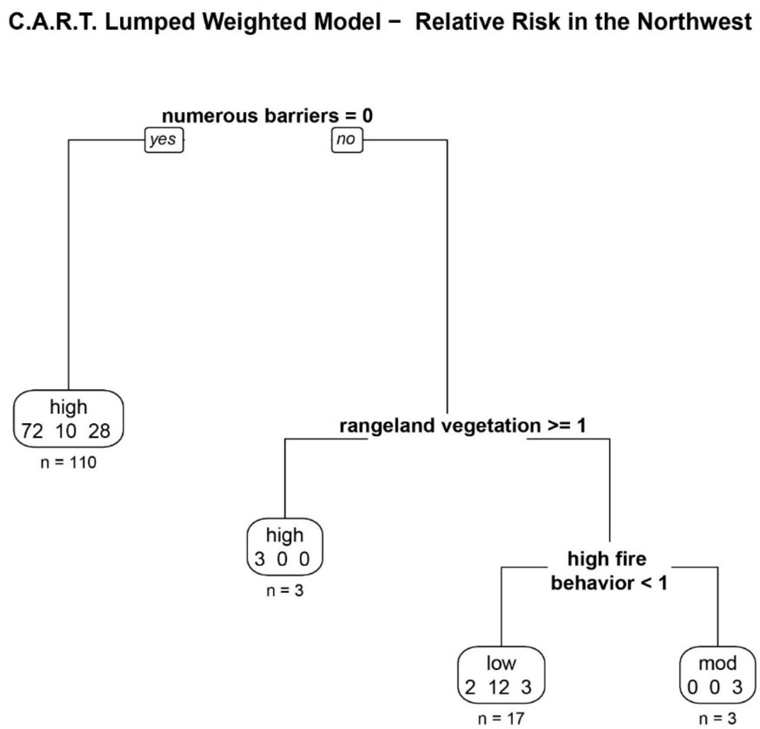

Figure 14. The classification and regression tree for the Northwest using themes related to hazard, values, and probability. Numerous landscape barriers was an individual code. Rangeland vegetation included grass and shrub fuel types, a hazard, fuel condition theme. High fire behavior included crown, spotting and extreme fire behavior, large spread potential, and high resistance to control.

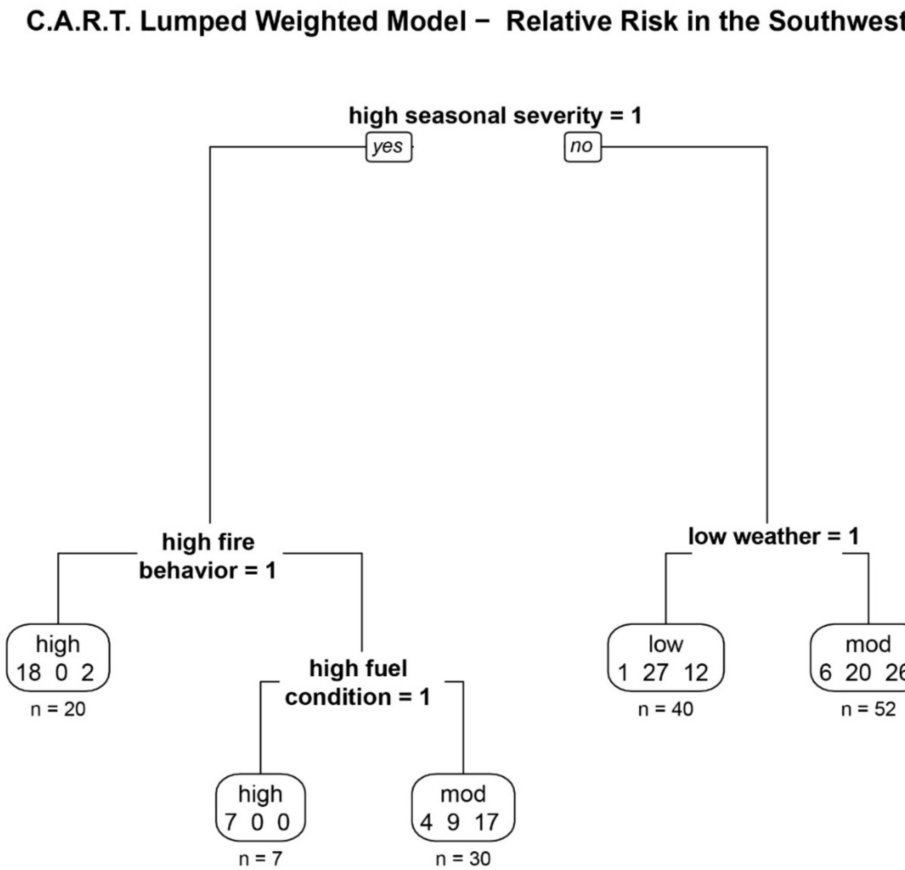

Figure 15. The classification and regression tree for the Southwest using themes related to hazard, values, and probability. High seasonal severity, a probability theme, included codes related to drought, high fire danger and dry fuel moisture. High fire behavior included crown, spotting and extreme fire behavior, large spread potential, and high resistance to control. High fuel condition included vegetation outside of historical ranges and high fuel loading. Low weather included precipitation, high relative humidity, low temperature and low wind speed.

Chapter 4

Wildfire management strategy and its relation to risk

Abstract

Changes in U.S. wildfire policy in 2009 blurred the distinction between fires managed explicitly for resource objectives and unwanted fires aggressively suppressed. By doing so, they simplified the process of 'doing the right thing in the right place at the right time' but made evaluation of management strategy and intent more difficult. In previous analyses of the factors driving operational risk on wildfires (Chapter 3), it became evident that managers, at least occasionally, discussed strategy when assessing risk. Here, qualitative data from operational risk assessments on wildfires in the Northwest and Southwest geographic areas were analyzed to understand the factors influencing management strategies and the association to risk. Overall, strategy was discussed explicitly in ~30% of risk assessments, suggesting that managers are connecting risk and strategy at least some of the time. Suppression strategies dominate this discussion, associated most commonly with high risk fires. Land managers even discuss an intent to suppress when it's untenable due to steep topography and remoteness. 'Other' strategies prevail (e.g., monitoring, confine, point protection) when risk is low or moderate, especially in the Southwest. The Southwest discusses a diversity of 'other' strategies and leverages landscape barriers to support different strategies while the Northwest discusses either resource benefit or suppression exclusively and does not overtly link barriers to strategy. These results indicate that strategy and risk are often connected and collectively illustrate an organization that is suppression-oriented, that uses 'other' strategies infrequently when risk is low. By inference, an expansion of using fire for resource objectives will require a reduction in risk and/or the increased application of 'other' strategies when risk is high.

Key Words: Northwest, Southwest, geographic area, qualitative data, WFDSS, relative risk assessment

Introduction

Federal fire policy in the United States is explicit; unplanned wildfire is to be managed as an essential natural process whenever possible but fire-fighter and public safety is the first priority (USDI/USDA 1995; Zimmerman and Bunnell 2000; USDA/USDI 2009). This creates tension for decision-makers who must weigh potential resource benefits against safety considerations and distribute resources effectively among multiple objectives. Additionally, federal fires are managed within different governance structures that couple fire-fighter organizations trained primarily to suppress fires with resource specialists trained to manage natural resources (Fischer *et al.* 2016; Steelman 2016; Schultz *et al.* 2019).

Understanding how decision-makers perform this balancing act is important for assessing how federal policy is being translated into on-the-ground management and for identifying potential opportunities to improve policy implementation. This research investigates data and methods for identifying fire management strategies employed on wildfires and the factors related to them. It does so by examining text fields associated with the federal Wildfire Decision Support System (WFDSS) Relative Risk Assessment (RRA) to understand how fire managers articulate fire management strategies in these records. Fires in the Northwest and Southwest Geographic Areas (GAs) are used opportunistically in this study as a follow-on to previous research contrasting the factors driving operational wildfire risk in the two regions (Chapter 3). Briefly, Northwest land managers utilize high risk to characterize wildfires more than other geographic areas and Southwestern land managers use low risk more than other regions (Chapter 2). These differences are partly attributable to the distinctive climate patterns of the two regions (Chapter 3). By examining strategy formulation among these risk-disparate regions, this research seeks to identify linkages between wildfire risk and strategy with the idea that low risk results in a higher diversity of strategies for managing fire and high risk constrains opportunities to manage in different ways. Implicit in this research is the differential role landscape barriers play in expanding decision space in the two regions.

For decades, the scientific community has strongly anchored the ecological arguments for the use of fire to restore historical fire regimes and to manage for increased hazards due to high levels of fuel loading (Stewart 1951; Dodge 1972; Chandler and Roberts 1973; Arno and Brown 1991; Covington 2000; Fule and Laughlin 2007; Reinhardt *et al.* 2008; North *et al.* 2012; Stephens *et al.* 2016). Considering the impacts of climate change on fire frequency and extent, coupled with longer fire seasons in many western U.S. ecosystems, (Westerling *et al.* 2006; Jolly *et al.* 2015; Abatzoglou *et al.* 2017; Holden *et al.* 2018) there is some urgency to use planned and unplanned ignitions to increase the resiliency of federal lands. How rare, large fires are managed is a key determinant of long-term landscape resiliency (Thompson *et al.* 2015).

However, inertia in traditional suppression-oriented responses remains and most wildfire agencies still appear to prefer suppression strategies over other fire responses for many reasons, thus reinforcing the wildfire paradox (Arno and Brown 1991; Calkin *et al.* 2015). External factors influencing decision making stem from governance structures (Fischer *et al.* 2016), uncertain environments (Thompson and Calkin 2011), status quo bias (Wilson *et al.* 2011), and social-political factors (Canton-Thompson *et al.* 2008). Influential drivers of fire management decision-making behavior stem from mental models addressing cultural aspects of a fire suppression organization that is encouraged to control fire (Thompson *et al.* 2018), stemming from fire doctrine that emphasizes "an aggressive approach toward accomplishment of objectives" (USDA/USDI 2019). Many of these internal and external factors perpetuate continued suppression responses to wildfires.

Notably, in areas such as the Pacific Northwest, the juxtaposition of management objectives related to resource extraction (i.e. timber harvesting, grazing) and conservation (i.e. preservation of old growth for spotted owl habitat) contribute to complex decision-making. Some have suggested that examining these systems through the lens of coupled human and natural systems (CHANS) may provide a better framework to resolve conflicts between production and conservation (Fischer 2013; Spies *et al.* 2014), with an emphasis on identifying critical interactions between decision-makers and ecological systems and developing alternatives that addresses dissent. Others have encouraged re-introducing wildfire within a landscape ecology framework to identify different spatial and temporal contexts where wildfire would be beneficial (Hessburg *et al.* 2015). In the Southwest, different factors have emerged as impediments to greater fire use. Management objectives related to the interaction of wildfire and the habitat of threatened and endangered species, concerns with fire burning outside of pre-defined boundaries, invasive species, and public support for using wildfire were challenges to using non-suppression wildfire strategies. To address these challenges, collaborations amongst different agencies and the public have been critical (Hunter *et al.* 2014).

Despite relentless effort over decadal time steps to change how fire is managed and better align practice with policy, it is not evident that significant progress is being made. There is no doubt that more fire is occurring (Dennison *et al.* 2014), but it is not clear how benefit is accruing or whether managers are intentionally managing for benefits or are achieving burned area despite their best intentions to avoid it. The increased difficulty in communicating strategies caused by the 2009 policy changes has so far prevented a meaningful accounting of fire management practices. That policy provided land managers freedom to manage for virtually any objective by eliminating specific categories of fires that constrained the use of wildfire in circumstances where it breached a predefined boundary or needed to be extinguished due to threat of the fire to values at risk (USDA/USDI 2009), but it has also produced persistent confusion in the articulation of objectives and strategies (Seielstad 2015). Federal agencies track the selection of strategies in wildfire reporting systems such as the ICS-209, but the complicated nature of fire management strategy, whereby some flanks are suppressed, others are confined using indirect tactics, while a portion is herded into a wilderness area for monitoring, is difficult to capture on a form (Pence 2016) and equally difficult to communicate to a confused public.

We surmise that the outcome of the relative risk assessment is a product of both biophysical risk as measured from a quantitative risk (Scott 2013) and land manager's risk perceptions that are influenced by a multitude of factors. Assumptions, recent memories, quality, skill and bias associated with professional judgments, perceived affect, and real risk are factors influencing risk perceptions (Tversky and Kahneman 1973; Alhakamil and Slovic 1994; Sjöberg 2000; Kahneman and Klein 2009; Johnson-Laird 2010). Unless otherwise noted, risk in this study is defined by the risk produced from the relative risk assessment.

The research addresses the following objectives:

1. Determine the prevalence of suppression strategies and the factors associated with them
2. Identify use of 'other' strategies such as confine, monitor, and point protection and the factors associated with them
3. Consider factors that expand decision-space during wildfires, e.g., landscape barriers

Methods

This analysis uses data from a risk assessment process mandated for specific federal wildfires that burn for long duration, are complex, or are being managed for resource objectives (USDA/USDI 2019) The Relative Risk Assessment (RRA) in the Wildland Fire Decision Support System (WFDSS) requires users to select radio buttons labeled as high, moderate or low for various characteristics related to values at risk , hazard and spread probability that contribute to an overall rating for relative risk; in addition, users are asked to provide qualitative notes to justify their selections (Taber 2013).

Data Collection

Qualitative text data from the RRA were collected from wildfires in two geographic areas (GA) with disparate risk profiles using a stratified random sample of 20% of the fires (Northwest (n=133 wildfires); Southwest (n=149 wildfires). The sample was stratified by federal agency and proportion of high, moderate and low relative risk to ensure representation of every agency and risk-level within agency. The general disagreement between the sample and population in terms of representation of strata was < 1% for agency representation and <4% for risk level. Details are provided in Chapter 3.

Coding

The analysis of text fields were informed using a grounded theory approach (Glaser and Strauss 1967; Corbin and Strauss 1990) whereby initial cases were evaluated for concepts and mapped to the four elements of the relative risk assessment (e.g., hazard, values, probability and relative risk). The excerpts were typically 1-3 sentences per relative risk element, with approximately 11% of users choosing to omit any text and a handful of users writing paragraphs for each element. The first author, who was the primary coder with an extensive background in fire management, attempted to capture the major themes discussed by land managers when characterizing risk on wildfires. As each wildfire (case) was evaluated, simultaneous codes were developed that were later categorized into broader classifications using the general framework of the relative risk assessment. This was an iterative process, requiring re-evaluation of the codes and their potential applicability to explain levels of risk. For instance, lumping and splitting of codes occurred, i.e. the 'elevation' code was eventually split to into 'high' and 'low' elevation, as it became apparent land managers were noting high elevation fires and docile fire behavior that could be amendable to low risk. NVIVO v11 coding software (QSR 2017) was used to

organize and categorize the codes and to map coding structures. Eighty-seven codes emerged that addressed causation (e.g. a certain event precedes others such as high fire danger leading to low fuel moisture), magnitude (e.g. small versus large), and main themes (e.g. broad categories to summarize related codes).

Eight additional codes emerged that aligned with general fire management concepts through the themes of Strategy/Tactics, Resource Availability, and Safety (Fig. 1). These codes related to fire management strategy form the basis of this study. It is important to note that none of the management concepts discussed by managers in this work were explicitly solicited by the relative risk assessment; instead, they reflect what land managers voluntarily chose to discuss in light of the relative risk rating.

Three individuals with fire management backgrounds randomly coded 5% of the sample to check the coding consistency of the initial coder and achieved a mean Kappa of 0.67 (moderate agreement). Lower kappa scores were often the result of a check coder missing an opportunity to denote a code that had been discussed in the qualitative text or the codes themselves were too broadly defined, leading to a different interpretation from the main coder. In some cases, these discrepancies necessitated further lumping of codes. Subsequently, the results of the quantitative analysis is an artifact of decisions made regarding the number of codes and the lumping and splitting of themes into one or more codes. Additional queries were run in NVIVO (QSR 2017) to minimize the main coder error associated with missing key concepts and to verify that each code was only represented once per wildfire record.

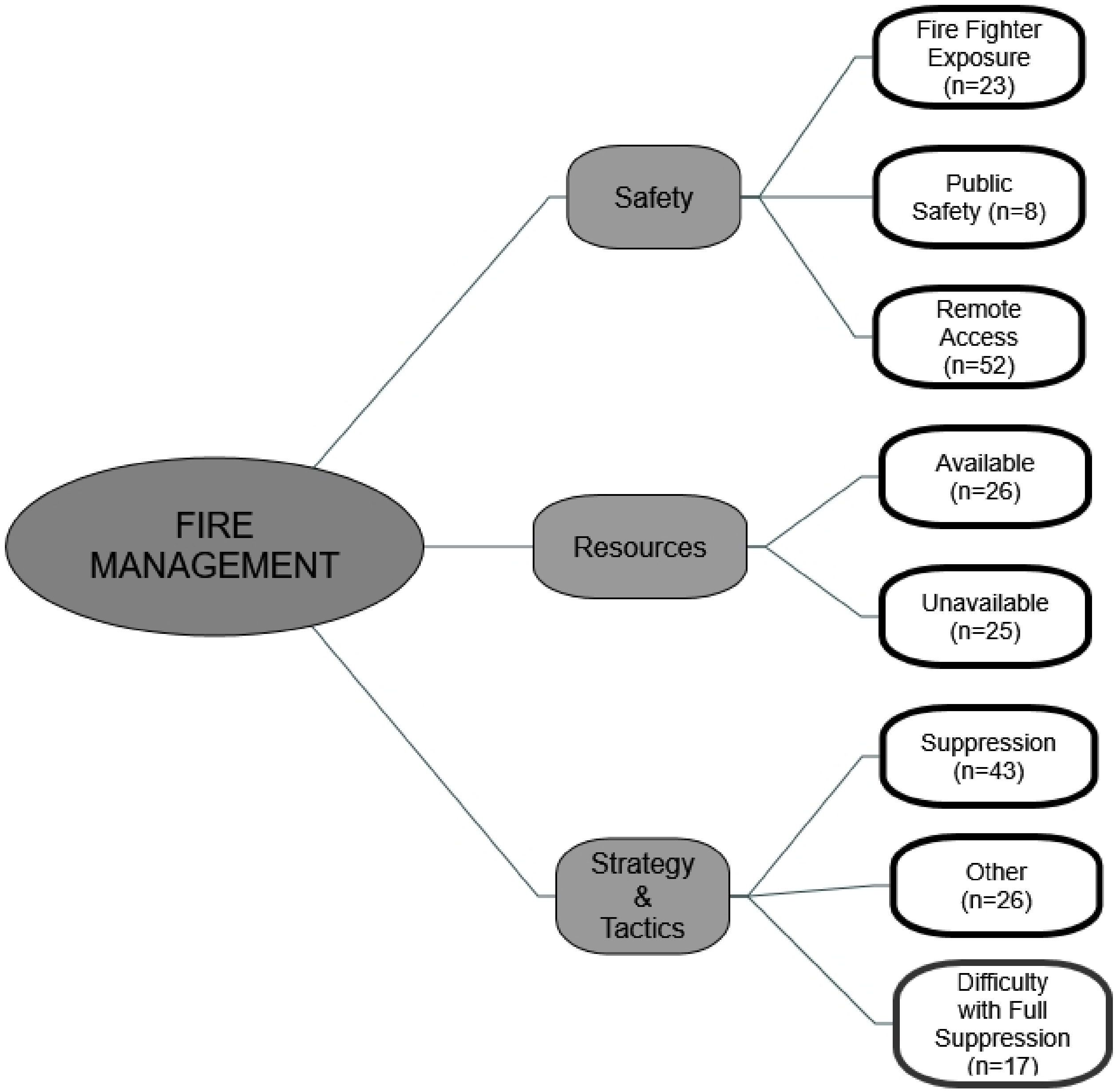

Figure 1. Example of codes used to develop the fire management themes and element. The total number of wildfires with a published relative risk assessments are denoted as (n) and include both GAs.

Defining Strategy

For this analysis, the classification of strategy followed the guidance from the Incident Command System – 209 form (NWCG 2017), which is a required venue for reporting strategy for large or long-duration wildfires. A "monitor" strategy is a process for collecting fire-related data and implies that no action is being taken to affect the fire; "confine" is intended to restrict wildfire to a defined area using natural and unnatural barriers; "point or zone protection" is intended to protect important points or areas from wildfire but not a whole perimeter; and finally,

“full suppression, contain or control” is a strategy to extinguish fires as effectively as possible, providing for fire fighter and public safety. In practice, full suppression strategies can be difficult to implement, because of fire-fighter exposure concerns. In some of these cases, full suppression strategies evolve to confine strategies, utilizing indirect tactics and placing firefighters on barriers (roads) where ingress and egress is more favorable and snag concerns are lessened. In this study, strategy is categorized as suppression, difficulty with suppression and other strategies and described in more detail below.

Suppression codes exhibited a clear intent that the decision maker wanted to suppress the fire and the expression reflected a degree of certainty regarding that intent, i.e. “we expect to contain the fire in 3 days” or “fire is lined and we expect the initial attack to be successful.” References to “tactics”, “control efforts”, “control lines”, types of resources commonly used on suppression fires: “dozers”, “aviation” resources, denoted suppression strategies. Concepts related to “difficulty with full suppression” were also used by land managers to communicate a desire to use a full suppression strategy; however, they documented constraints on why this strategy was difficult to implement.

The “other strategies” code represents evidence by land managers considering the use of fire to achieve multilayered strategic objectives and includes point protection, confine, or monitoring strategies. In some cases, a resource benefit objective was communicated and it was assumed a non-suppression strategy was implemented; for instance, “the fire is within the resource benefit zone”.

Data Analysis

Data analysis was a mixture of techniques to summarize the frequency of codes derived from the qualitative notes. First, the number of times a code occurred was summed and divided by the total number of sample fires per geographic area to summarize frequencies overall and by relative rating level. Pivot tables were generated for specific individual codes compared to the presence of the other codes to identify collinearity. In these instances, percent frequencies were computed as the total number of times the collinear codes were present divided by the total number of times the individual code in question was present. Second, Pearson’s Chi-square tests were performed on a 3 by 2 level matrix (3 levels of relative risk by 2 levels representing presence or absence for each of the codes). Some codes occur regardless of the relative risk rating and are present for all types of fires. P-values less than 0.05 suggest that the composition of the codes had unequal proportions of high, moderate and low relative risk ratings and were used more or less than expected for some ratings. All analyses were performed using R software (R Core Team 2019).

Results

How do fire managers articulate fire management strategy on wildfires?

Land managers discussed strategy on ~30% of wildfires. These fires were similar to fires where strategy was not mentioned(< 3% difference for all rating/element combinations) with one difference. On fires where strategy was discussed, the hazard element was rated moderate more than other fires (+12%) and low or high less than other fires (-6%). References to suppression dominate the discussion of strategy in both GAs, mostly associated with high relative risk although the Northwest discussed suppression commonly for moderate risk fires as well (Figure 2). 'Other' strategies were discussed on low and moderate risk fires in both GAs, but the Southwest discussed 'other' strategies at more than twice the rate of the Northwest. Neither GA discussed 'other' strategies in conjunction with high relative risk fires. Statistically, 'other' strategies occurred more than expected for low risk fires and less than expected for high risk fires in both regions (NW: p = 0.009; SW: p = 0.013), while suppression strategies occurred more than expected in the Southwest for high risk fires and less than expected for low risk fires (p=0.003). These findings support an association between high risk fires and suppression and low risk fires and alternative strategies for both GAs (Table 1).

Table 1. The percent frequency of observations divided by total fires; summarized by high (H), moderate (M), low (L) and total (T) relative risk; and p-values from Pearson's chi-square. Chi-square p-values significant at 0.05 are denoted by an asterisk.

	Northwest					Southwest				
Code Descriptor	Frequency (%)				Chi-sq.	Frequency (%)				Chi-sq.
	H	M	L	T	p-value	H	M	L	T	p-value
other strategies	0	2	2	5	0.009*	0	5	8	13	0.013*
suppression	8	7	0	14	0.019*	8	5	3	16	0.003*
difficulty with suppression	6	1	2	9	0.320	1	2	0	3	0.210

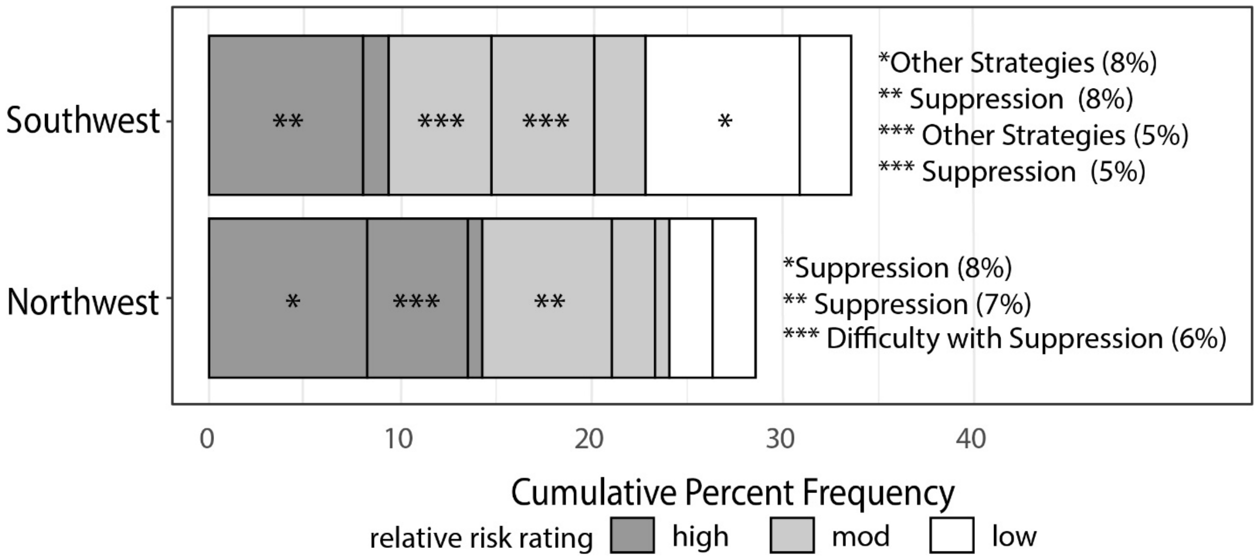

Figure 2. Graphical display of the different strategies associated with low, moderate and high relative risk fires in the Southwest and Northwest.

The factors associated with the prevalence of suppression strategies

Evidence of suppression was noted on 24 fires (16%) in the Southwest (Table 2) and was associated with unnatural, natural and previous wildfire barriers (54%, 46%, 46%, respectively), grass fuel types (46%), and economic concerns related to tourism and recreation (42%). Ninety-seven percent were moderate and high risk fires. A large majority occurred in April, May or June (21 fires) and most involved the USFS (n=17) with three fires showing evidence of being multijurisdictional.

The Northwest had 19 wildfires with evidence of suppression, associated with values (e.g., multijurisdictional concerns and housing/structures (53%, 47%, respectively)). Grass fuel types and high fire danger occurred ~ 40% of the time when suppression strategies were discussed, similar to the Southwest. Northwest suppression strategies applied to fires primarily occurring in July, August and September and involved a variety of agencies including the USFS (n=9), BLM (n=8), and ‘Other’ (n=5). Seven of these fires were multijurisdictional.

Table 2. Codes associated with suppression strategies from the relative risk assessment. Bold codes were common amongst both the Southwest and Northwest.

Northwest

Code	Suppression (n)	Percent of Suppression
suppression strategies	19	100%
multijurisdictional	10	53%
housing, structure values	9	47%
high fire danger	8	42%
grass fuel type	8	42%
middle time of season	7	37%
natural barriers	7	37%
resources available	7	37%
general social concerns	6	32%
dry fuel moistures	6	32%
commercial infrastructure	6	32%
unnatural barriers	6	32%
small potential	6	32%
remote access	6	32%

Southwest

Code	Suppression (n)	Percent of Suppression
suppression strategies	24	100%
unnatural barriers	13	54%
grass fuel types	11	46%
natural barriers	11	46%
barriers from wildfires	11	46%
tourism, recreation values	10	42%
high fire danger	9	38%
wildlife values	9	38%
shrub fuel types	9	38%
values far from fire	8	33%

Suppression strategies where implementation was difficult

The Northwest had twice the number of fires where difficulty with implementing a full suppression strategy was discussed, compared to the Southwest (Table 3). High seasonal severity may have contributed to difficulty using a suppression strategy; for example, high fire danger and dry fuel moisture each occurred ≥50% of the time in the Northwest. Both GAs also discussed wilderness, remote access concerns and steep topography more than 50% of the time for these fires. Threatened and endangered species, wildlife, and tourism/recreation were the most common values noted in the Northwest, while government infrastructure and proximity or values being far from the fire, were most commonly noted in the Southwest.

Table 3. Codes associated with the difficulty with implementing suppression strategies from the relative risk assessment. Bold codes were common amongst both the Southwest and Northwest.

Northwest			Southwest		
Code	Difficulty with Suppression (n)	Percent of Difficulty with Suppression	Code	Difficulty with Suppression (n)	Percent of Difficulty with Suppression
difficulty with suppression	12	100%	**difficulty with suppression**	6	100%
natural barriers	9	75%	low elevation	5	83%
high fire danger	7	58%	**remote access**	4	67%
remote access	7	58%	**steep topography**	4	67%
wilderness	6	50%	government infrastructure	4	67%
dry fuel moistures	6	50%	**wilderness**	3	50%
steep topography	6	50%	values far from the fire	3	50%
threatened and endangered species concerns	5	42%			
wildlife	5	42%			
tourism, recreation	5	42%			
early time of season	5	42%			
unnatural barriers	5	42%			
few barriers	5	42%			

Factors associated with using 'other' strategies

In the Pacific Northwest, 5% of the sampled fires had evidence of strategies other than suppression (Table 4). These fires were associated with a subdued fire environment. They occurred in forested fuel types (67%), when fire behavior was low (67%) or with low spread potential (50%). Natural and unnatural landscape barriers and presence of precipitation were also discussed for half of these fires. Economic concerns related to impacts to recreation and tourism were the only values discussed (50%). The fires started almost exclusively in August and involved only the U.S. Forest Service (n=3) and the National Park Service (n=3), with one of these fires being shared by both agencies. Spatially, they were evenly split between the west and east side of the Cascades. All were either moderate or low risk (Table 1).

Table 4. Codes associated with the "other strategies" from the relative risk assessment. Bolded codes were common amongst both the Southwest and Northwest.

Northwest			Southwest		
Code	Other Strategies (n)	Percent of Other Strategies	Code	Other Strategies (n)	Percent of Other Strategies
other strategies	6	100%	**other strategies**	20	100%
forest fuel type	4	67%	**low fire behavior**	16	80%
low fire behavior	4	67%	monsoon	13	65%
tourism, recreation	3	50%	**unnatural barriers**	12	60%
unnatural barriers	3	50%	**precipitation**	12	60%
natural barriers	3	50%	numerous barriers	11	55%
precipitation	3	50%	wildlife values	8	40%
topography, slope	3	50%	**forest fuel type**	7	35%
low spread potential	3	50%	high fuel moisture	7	35%
high fuel loads	3	50%			

Mild fire environmental conditions were similar in the Southwest when land managers discussed strategies other than suppression for twenty fires (13%). Low fire behavior (80%) was the most common factor associated with 'other' strategies (Table 4). References to the monsoon (65%), precipitation (60%) or high fuel moisture (35%) provide hints as to why fire behavior was low. Unnatural landscape barriers (60%) and many barriers (50%) also provide clues to how land managers are considering using strategies other than suppression. Values were discussed sparingly, except for wildlife (40%). These low or moderate risk fires involved the U.S Forest Service (n=15), the BIA (n=4) and National Park Service (n=4).

Factors that *expand* decision space during wildfires - barriers

The results highlight the ubiquitous nature of landscape barriers. Both GAs discuss natural (35%) and unnatural barriers (25% NW; 32% SW) with high frequency (Table 5). There is evidence that the Southwest may be benefitting from a legacy of past wildfires and prescribed fires. For instance, the Southwest references previous wildfires for 41 fires (28%) and these references occur for all levels of relative risk but about half for low relative risk fires (Table 4). Barriers from prescribed burning were also more prevalent in the Southwest (n=13) associated with low

(n=10) and moderate (n=3) relative risk. Wildfire barriers were also present in the Northwest (12%), with prescribed fires discussed sparingly (1%), and fuel treatments barriers more prevalent than in the Southwest (5%). The majority of the references regarding barriers from past management actions were associated with high or moderate risk fires.

Table 5. A summary of the type of barriers by the Northwest and Southwest geographic areas. Percent is computed as n/133 for the Northwest, and n/149 for the Southwest.

GA	Relative Risk	Natural Barriers		Barriers from Fires		Unnatural Barriers		Barriers from Prescribed Fires		Barriers from Fuel Treatements		Ineffective Barriers	
		n	*pct*	n	*pct*	n	*pct*	n	*pct*	n	*pct*	n	*pct*
Northwest	high	20	*15%*	9	*7%*	23	*17%*	0	*0%*	3	*2%*	5	*4%*
	low	14	*11%*	3	*2%*	2	*2%*	0	*0%*	0	*0%*	0	*0%*
	mod	12	*9%*	4	*3%*	8	*6%*	1	*1%*	3	*2%*	0	*0%*
	total	46	*35%*	16	*12%*	33	*25%*	1	*1%*	6	*5%*	5	*4%*
Southwest	high	12	*8%*	9	*6%*	8	*5%*	0	*0%*	0	*0%*	2	*1%*
	low	22	*15%*	19	*13%*	21	*14%*	10	*7%*	4	*3%*	0	*0%*
	mod	18	*12%*	13	*9%*	19	*13%*	3	*2%*	1	*1%*	3	*2%*
	total	52	*35%*	41	*28%*	48	*32%*	13	*9%*	5	*3%*	5	*3%*

Discussion

Fire managers discuss strategy with some regularity in the relative risk assessment. While acknowledging some limitations, there does appear to be an association between risk and strategy and the results provide a starting point for further evaluation. The value of analyzing strategy using qualitative text is the myriad of factors associated with its selection, even when limited by small sample sizes. Because the RRA provides explanations of many factors influencing risk, the context around the selection of strategy is better understood. Multiple factors associated with the selection of strategy were explored by leveraging the 87 codes from the RRA (Appendix A).

Before providing and discussing specific examples of strategy and associated risk factors, it is worth reiterating limitations. First, this study's results must be synthesized within the constraints of the sampling methodology which was limited to 20% of wildfires in two regions. Complete coding of all wildfires fires from 2010 through 2017 would produce a much more in depth understanding of strategy, but coding is an extensive time commitment and it was not possible to complete on all 5,000 fires available in WFDSS. However, with continuing advancements in machine learning of speech and text, it may soon be possible to objectively classify larger datasets efficiently. Second, the individual fires in the record were summarized to the scale of a geographic area to better evaluate the collective characteristics of a region, relevant to fire-fighting resource allocation, intelligence, and, in part, management direction. Finer spatial scales

would likely contribute to other interesting patterns among agencies and units that more directly link to environmental and cultural patterns. Third, many long duration fires have multiple relative risk assessments reflecting the dynamic nature of wildfire. This study chose the records associated with the earliest and most commonly used relative risk rating to represent each wildfire, acknowledging that relative risk could change as wildfire conditions increase or abate over the course time. We surmise the RRA represents a mixture of land manager's risk perceptions and biophysical risk. Consequently, the qualitative data may diverge from measured, objective values at risk, hazard and probability. For instance, a land manager may write that fire danger was very high, but fire danger values were measured closer to 70^{th} percentile. The results should be evaluated within the context of factors influencing risk assessments that were important enough to voluntarily discuss by land managers during wildfires. Because decision-makers make decisions based on their own perceptions which may or may not represent actual truth (Johnson-Laird 2010), it was assumed that these data could inform aspects of how land managers conceptualize risk and strategy during wildfire events. Finally, the methodology represents decisions about coding that are judgments and when those codes are quantitatively analyzed, those subjective judgments can influence the quantitative results. We attempted to standardize the codes using one individual with a fire management background to code the qualitative text and three check coders to check for internal coding consistency.

Inferring fire management strategies from the relative risk assessment

Strategy was coded to identify the intent behind management strategies: 1) suppress and thus keep fires as small as possible; or 2) use wildfire and eventually put the fire out (confine); protect values at risk (point protection); keep an eye on it (monitoring). The latter strategies are collectively termed 'other' strategies. It was also assumed that "multiple objectives" implied something other than suppression. In addition, wildfires that included mention of "resource benefit" were also included in this code and may have involved a range of strategies on how land managers hoped to achieve this objective. It may be more commonly accepted to communicate the objective of using fire for resources rather than articulating the action to achieve it. For instance, when alternatives to suppression strategies were framed as only monitoring in a hypothetical scenario, respondents considered this strategy only sparingly (Calkin *et al.* 2013). The present study found more discussion of resource benefit than all 'other' strategies except 'confine' in the Southwest; however, these "strategies" were still used sparingly (Table 6).

Table 6. The frequency (n) of different non-suppression strategies sampled for 133 Northwest wildfires and 149 Southwest wildfires.

	Other Strategies (n)					
Geographic Area	Confine	Point Protection	Monitoring	Multiple Objectives	Resource Benefit	Total
Northwest	0	0	1	0	5	6
Southwest	7	4	1	3	5	20

A number of factors were associated with fires on which "resource benefit" was discussed that might create more decision space for land managers, including precipitation, low values, and barriers present to contain the fire if needed. Excerpts from the qualitative data are included below to provide a more detailed description of some of the key findings. These excerpts were selected because they represent a perspective that is common to many of the entries and help illustrate the code. For example; a land manager discusses a myriad of factors supporting the use of fire to achieve a resource benefit objective;,

> Fire in the wilderness playing natural role… Weather is moderating with presence of wet thunderstorms almost every afternoon. Late season with monsoons at any time, indices are still around 90th %, starting to trend down, few natural barriers to spread other than 2004 Willow fire to NE. Southwest, Moderate Relative Risk (210715)

Another land manager comments on a lack of public values at risk, the availability of unnatural barriers and expresses a belief in using fire;

> No infrastructure or private lands in proximity to fire. Burning in RNA (research natural area) where fires are supposed to be allowed to burn. Road system to west/downslope could be used as barrier. Northwest, Moderate Relative Risk (3258176)

About half of the Southwest "other strategies" codes were classified into "confine" and "point protection" strategies (Table 5). In contrast, the Northwest used "other strategies" exclusively to support resource benefit objectives or monitoring strategies. There were no gray areas, where strategies other than the two extremes (resource benefit versus suppression) were chosen. Point protection strategies were discussed only in the Southwest, coincident with a mild fire

environment. The example below notes that point protection strategies are leveraging low fuel loading due to a previous wildfire which could arguably be considered a barrier to fire spread:

> …protection and mitigation of the known sites will occur...the tower is not flammable and the cabin is wrapped with fire shelter material." Fuel condition is low because "the area was treated with fire in 2003 with previous areas of moderate and high severity being used as barriers. Southwest, Moderate Relative Risk (1549682).

The Southwest used confine strategies more than any other strategy except suppression. Some challenging considerations usually were present during confine strategies, but there were additional factors that made this a tenable strategy such as the presence of barriers and a mild fire environment. For example, for a fire burning in a proposed prescribed burn unit where an environmental assessment (EA) had been completed, land managers expressed concern that the "wildfire may burn with a higher severity than what was anticipated". Despite this concern, there were many aspects supporting a decision to use fire, including positive social perspectives ("there is community support for the application of fire in the areas to improve range conditions."), precipitation (wetting rains have been experienced on the fire on June 24th that may reduce fire activity,"), some certainty that fire season would end soon ("The average start date of the monsoon for the area is July 8th") and barriers ("There are numerous roads and trails that have been prepared in anticipation of being used to burn off of and hold the fire within a predetermined perimeter." Southwest Low Relative Risk (193309).

Indirect suppression strategies provide opportunities to re-introduce fire into at least a fraction of the landscape. This is rarely the objective of the chosen strategy but is a by-product of it and careful execution of burn outs from roads and other types of barriers to implement indirect suppression tactics may be one way to both achieve objectives, safeguarding communities from the threat of wildfire, but also leaving adjacent vegetation treated as a result of the management actions implemented during the wildfire. Previous research has found there is an awareness of the importance of vegetation refugia to maintain ecosystem health especially in light of the external stressors of climate change for many species (Dobrowski 2011; Morelli *et al.* 2016; Martinez *et al.* 2019). Fire managers implementing tactical wildfire responses such as burn-outs must be cognizant of the importance of maintaining unburned and low intensity patches to provide seed source to rejuvenating forest because high severity areas in some locations are not returning to their previous lifeform (Davis *et al.* 2019).

Suppression strategies were associated with high values, multiple jurisdictions, and early season ignitions and expressed as intent to put the fire out with evidence of resources controlling the fire. For example; one land manager writes, "…without mitigation actions, the fire is expected to reach the values", which include "many structures or private properties [that] could be

threatened." Subsequently, the "Fire is lined and expect IA to be successful," [Northwest, High Relative Risk (1279511)]. Suppression was also associated with early season fires. For instance, managers of a fire in the Southwest discussed a short duration fire held at 130 acres, utilizing barriers, ("forward [fire] spread has been checked by natural features") and acknowledged that "time of season is the beginning of a historic fire season", suggesting a main driver to suppress was due to an ignition that occurred too early which would require significant management for long duration. Subsequently, "resources on scene made good progress holding the perimeter" Southwest, Low Relative Risk (2119602)

Another theme that emerged with suppression fires was the need/desire to suppress when fires cross jurisdictional boundaries. In these examples, the fire is spreading from one federal agency to another, with the U.S. Forest Service being the recipient;

> Forest Service request full suppression on this incident, due to early season fire. Southwest, High Relative Risk (507030)
>
> The western perimeter is 1.5 miles from the Forest Service boundary. The strategic direction for the fire is to prevent spread onto neighboring jurisdictions. Suppression actions would be required on the FS side of the boundary due to values at risk and fire activity neighboring the Park.Northwest, Moderate Relative Risk (449060)

Pre-fire seasoning fire planning with shareholders and adjacent agencies is critical to managing fire in these complicated landscapes. Recent research efforts also demonstrate that investments developing these partnerships could help land managers have more decision space during wildfires and are currently being made in both the Northwest and Southwest (Schultz *et al.* 2012; Gilbertson-Day *et al.* 2018).

In this study, land managers discussed suppression more than any other strategy even when it was not possible to implement a suppression strategy. This idea was described as "difficulty with suppression". In these cases, land managers demonstrated a desire to suppress fire, but they couldn't for a variety of reasons. A challenging fire environment (remote, dry, high fire behavior) was commonly noted to explain why suppression would be "prolonged", "limited", or "hampered". However, some low risk fires in the Northwest provided a justification for a non-suppression response due to fire fighter exposure concerns. For instance, the excerpt below provides a lengthy justification for why managers did not take "direct action" associated with a suppression strategy for a wilderness area approximately 45 miles northeast of Seattle, Washington.

> The fire is located in a place that is extremely dangerous to put firefighters (110% slope, directly above what appear to be cliffs), with no egress in the case of rapid fire growth. The use of unsupported helicopter operations would be limited, beyond reassuring the public, and would place aircrews at significant risk, with no safe place to land in case of mechanical failure. There will likely be a significant amount of public and political interest, as well as pressure to take direct action, which in this case is not advised. Northwest, Low Relative Risk (2373735)

There also appear to be concerns with how the public perceives non-suppression strategies. In this example, negative perceptions of fires were assumed due to fire activity elsewhere;

> The fire is visible from highway 530 and in light of the fire situation on the east side of the state, it's likely that a lack of perceived effort will generate controversy with the local public. Northwest, Low Relative Risk (2373735)

Land managers discuss low values at risk, an abundance of barriers to stop fire spread, nearing the end of fire season, generally low fire behavior and negative public perceptions of fire for these examples. Notably, these managers do not communicate a need to use fire in wilderness to "preserve its natural condition" (The Wilderness Act 1964), instead focusing on reasons why suppression can't be implemented, emphasizing fire-fighter exposure and social concerns. It is worth acknowledging that fighter exposure concerns are legitimate. Since 1910, 1,128 fire-fighters have died while working on wildfires (NIFC 2018). Exposure concerns encompass all aspects of working in wildland fire including transport to and from a wildfire. Increasingly the federal agencies are conducting mandatory training to reaffirm that fire-fighter and public safety are the primary objectives of any wildfire. Discussion and training on how to implement that objective has resulted in weighting the risks of direct and indirect tactics when suppression strategies are warranted. It is likely that land managers in the examples provided above are raising legitimate fire fighter exposure concerns related to committing resources in remote locations. However, the absence of any discussion of strategy to achieve any land management objective is a hallmark of the data examined in this study. On the other hand, wilderness was discussed in 50% of these cases for both GAs, suggesting there may be decision space within a planning document (e.g. LRMP) to use wildfire to achieve resource objectives.

Perceived lack of public support to use non suppression strategies also influences decision making; however a previous review of two wildfires found that although agency personnel believe the public desired more suppression, the public was mixed on this strategy with some opting for greater use of fire to create more resilient landscapes (Steelman and McCaffrey 2011). Internal and external factors that influence land managers to use or suppress wildfire have been documented (Black *et al.* 2008) and the current study provides continued evidence of this

struggle. Agency disincentives stemming from liability and casualty risks and little tolerance of management errors are likely contributing to a continued suppression focus (North *et al.* 2015). Addressing the limits of the current wildfire governance system may also be warranted (Steelman 2016; Schultz *et al.* 2019). Changes to organizational structures within wildfire systems that promote accountability of using fire rather than extinguishing it would help land managers use strategies other than suppression (Thompson *et al.* 2015). For example, land managers could explain why a suppression strategy is preferred in wilderness and other areas where land and resource management plans support the use of fire, as they were required to do in the old Wildland Fire Implementation Plan (WFIP). Additionally, involving local shareholders to work with agency personnel may provide a better context for the need for fire in wilderness areas adjacent to communities, as some of these locals have vested interest in long-term ecosystem health of adjacent federal lands, both for recreation and housing values (Donovan *et al.* 2007).

The role of landscape barriers that expand decision space on wildfires

A common theme discussed with strategy was using barriers to fire spread, which served to expand decision space during the formulation of strategies in both GAs. The Southwest appears better poised to benefit from favorable climatic patterns due to the monsoon which lends an element of predictability to the occurrence of precipitation and the season-end. The monsoon has laid the foundation for land managers to "use" prescribed and wildfire over time and there is evidence that land managers in the Southwest are using previous fires to confine new ones within pre-defined containers, as discussed in (Teske *et al.* 2012; Hunter *et al.* 2014; Parks 2015; Prichard *et al.* 2017). Excerpts from fires in the Southwest serve to illustrate these points; for example,

> The fire is burning in the old Duquesne fire from 2011. The fire has laid down enough this afternoon for crews to go direct on a large portion of the North and east flanks. A burnout operation is planned for a portion of the west flank. Southwest, High Relative Risk (1239561)

> Low fuels loads in the fire area and low ERCs for the Forest are expected to continue to result in low to moderate fire severity for this fourth entry burn (2011 Miller, 2003 Dry Lakes Complex, 1993 Straw). Southwest, Low Relative Risk (3091330)

In addition, the Southwest mentions a patchwork of former prescribed and wildfires limiting unwanted fire spread and contributing to low and moderate relative risk;

> The fire area has not burned in recent history, but is surrounded by numerous areas that have burned in wildfires or prescribed fires in the last 5 years. Southwest, Low Relative Risk (1293782)

While discussed sparingly, fuel treatment barriers were more prevalent in the Northwest than the Southwest and provided value to decision makers by either directly impacting fire spread or in the consideration of contingencies. For example, in the excerpt below, the fuel treatments may have not directly interacted with the wildfire, but they appear to have assisted land managers in considering options to "restore the natural role of fire in the ecosystem".

> Barriers immediately adjacent to the fire are few, but extensive fuel treatments and a major road exist along the park boundary to the east and north. Northwest, Moderate Relative Risk (1652732)

They also provided greater decision space during suppression fires by slowing fire spread, i.e.

> …transition of fire spread [was] slowed by NFP (National Fire Plan) & CWPP (Community Wildfire Protection Plan) fuels treatments. Northwest, High Relative Risk (1573472)

It is plausible that the quantity, type, and placement of fire spread barriers on landscapes are contributing to the ability of land managers to avoid unwanted fire effects and spread. In addition, barriers in combination with weather (precipitation) extend their influence and longevity by increasing fuel moistures of both live and dead fuels and creating a mild fire environment less amenable to fire spread and severity. There is a wealth of research that has evaluated biophysical factors contributing to fire severity in the western U.S. with mounting evidence of live fuel loading and moisture as salient predictors of fire severity (Cansler and McKenzie 2014; Parks *et al.* 2018). Wildfires are limiting the severity of subsequent wildfires in the Southwest for up to 15- 22 years (Parks *et al.* 2013). Their benefit is extended by the timing and intensity of precipitation events leading to lower fire severity (Holden *et al.* 2007). In this study, land managers appear to connect many of these biophysical interactions with barriers when characterizing primarily low and moderate risk wildfires, especially in the Southwest. If large contiguous areas of high fire severity are unwanted, fire managers can influence the continuity and arrangement of fuels from management decisions to use wildfire, prescribed fire and fuel treatments. These management investments appear to provide a benefit later on when the next ignition occurs, at least as documented by land managers in the relative risk assessments on active wildfires.

Conclusion

Management Implications

There is a cost to suppressing fires at the smallest size possible, which comes in the form of long-term land degradation and ecosystem health (Stephens *et al.* 2016; Schultz *et al.* 2019) for many of the forested landscapes that are in a fire deficit (Parks *et al.* 2015; Vaillant and Reinhardt 2017). It is evident from discussions of fire management strategy and related factors in the RRA that managers are using fire as a tool on some wildfires but suppression largely dominates. Nearly every wildfire could be viewed as an opportunity to treat the unnatural build-up of fuels and reintroduce some element of disturbance into fire-adapted ecosystems if managers are able to identify and leverage quiescent weather and barriers that might work together to allow some form of fuels management. This could occur more commonly if incident objectives were consistently tiered from well-designed resource plans and communicated in the documents where firefighters obtain their work orders, e.g., the Delegation of Authority and the Incident Action Plan. A consistent message through the different wildfire documents and workflows would lend itself to prioritizing resource objectives as well as protection. Land managers must continue to look for opportunities to use wildfire to improve vegetation conditions adjacent to communities (Reinhardt *et al.* 2008). Explicit support for innovative thinking regarding land management from top level leadership could encourage and recognize decisions that safeguards high values at risk (including public and fire-fighter lives) while maintaining ecosystem resiliency. It is difficult to balance strategies that address both resource and protection objectives simultaneously (Schultz *et al.* 2019), because they often stem from divergent incident objectives and stakeholders; but this balance is critical to achieve long-term management goals tied to landscape resiliency

Further Research

A trove of data are available in WFDSS that the relative risk assessment only peripherally addresses. For example, the Organization Assessment (OA) provides discrete ratings and qualitative notes directly related to fire management strategy and tactics, implementation difficulty, multijurisdictional fires, influence of the media, public safety concerns, the impact of closures, smoke management concerns, and political concerns. Data from the OA would complement the results of this research from the RRA. Coupling the WFDSS dataset with other federal datasets such as the ICS-209 could additionally help identify patterns and trends amongst federal wildfire managers and their decisions without eliciting their responses using surveys. Linking other federal data sets with WFDSS data could provide a holistic perspective on the selection of strategies and may identify greater detail on the factors unearthed with this initial study.

Further inquiry into the political, social and cultural aspects influencing fire management practices in the Southwest should also be explored. While this region is poised to benefit from

seasonal rains during fire season, there may be other factors that are influencing an agency culture that are amendable to evaluating diverse options to use fire. Perhaps other social and cultural factors are enabling land managers to articulate strategies other than suppression when communicating strategies to the public. These factors should be identified and communicated so they can be considered in other parts of the country. The investment in planning frameworks as part of the Cohesive Strategy to engage shareholders in the management of federal lands appears to be contributing to more decision space during the formulation of fire management strategies. Concurrently, identifying these factors that are facilitating the use of wildfire in the Northwest is pivotal to changing the cultural, social and political factors that are inhibiting a greater range of fire management strategies.

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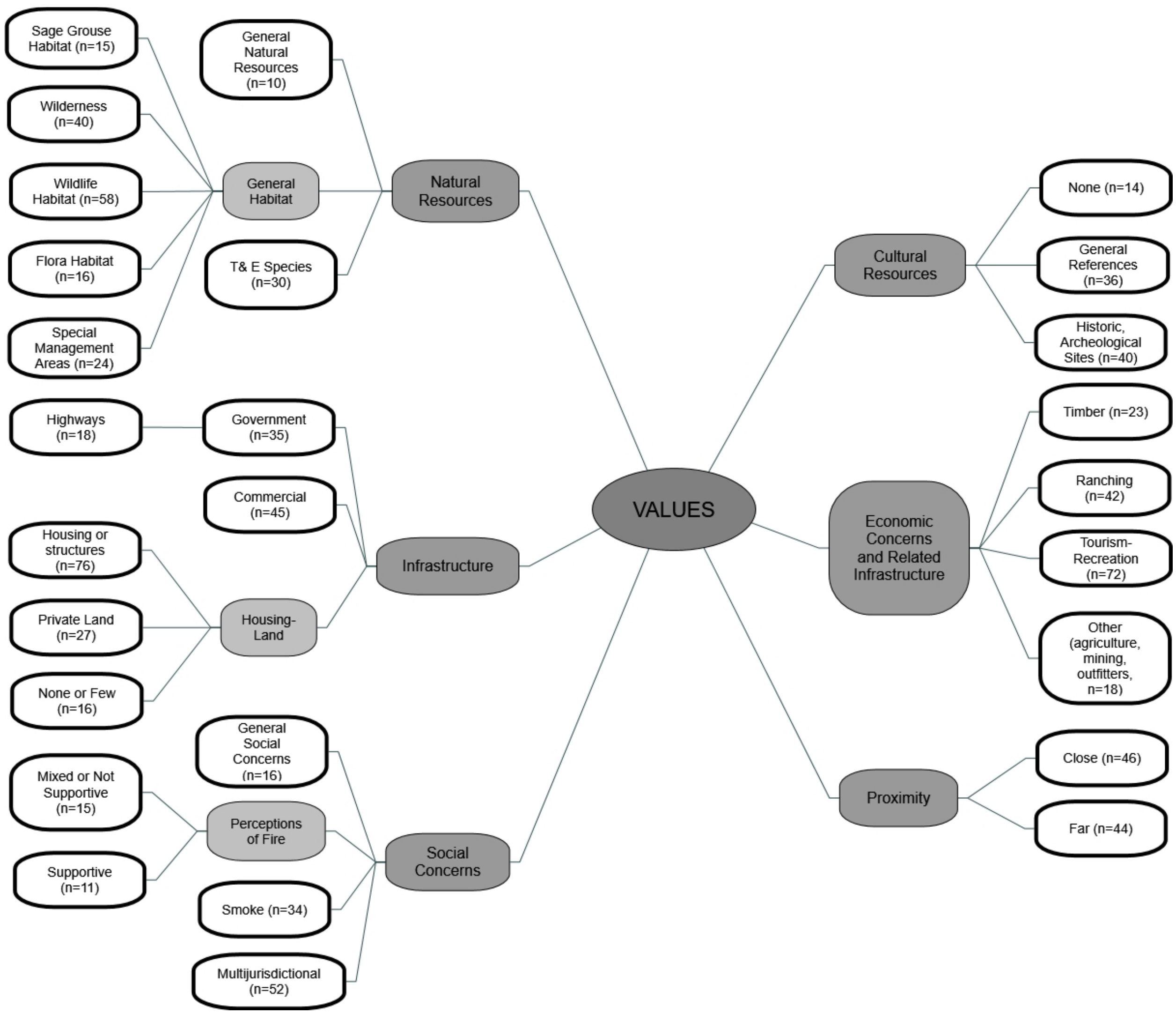
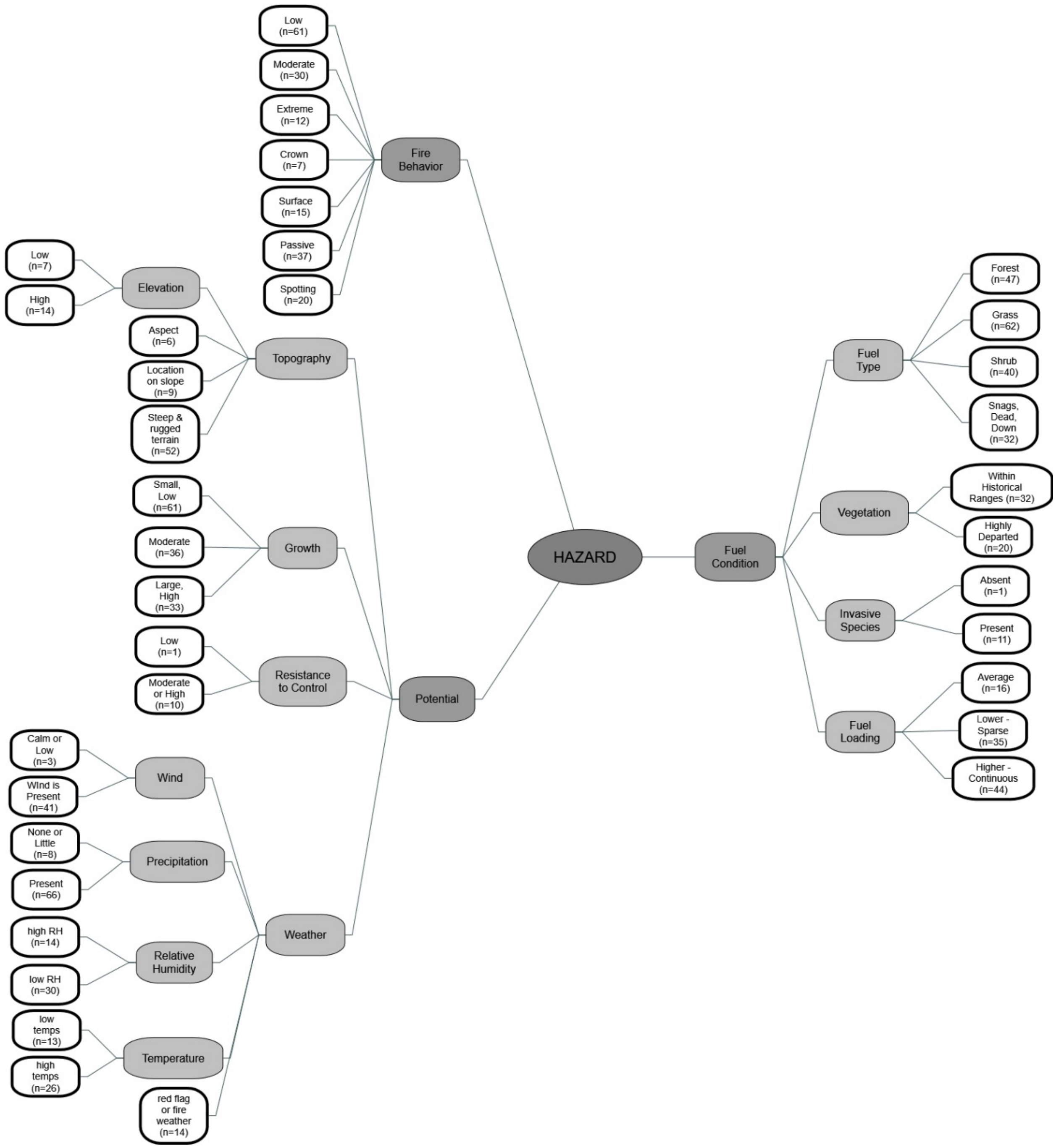
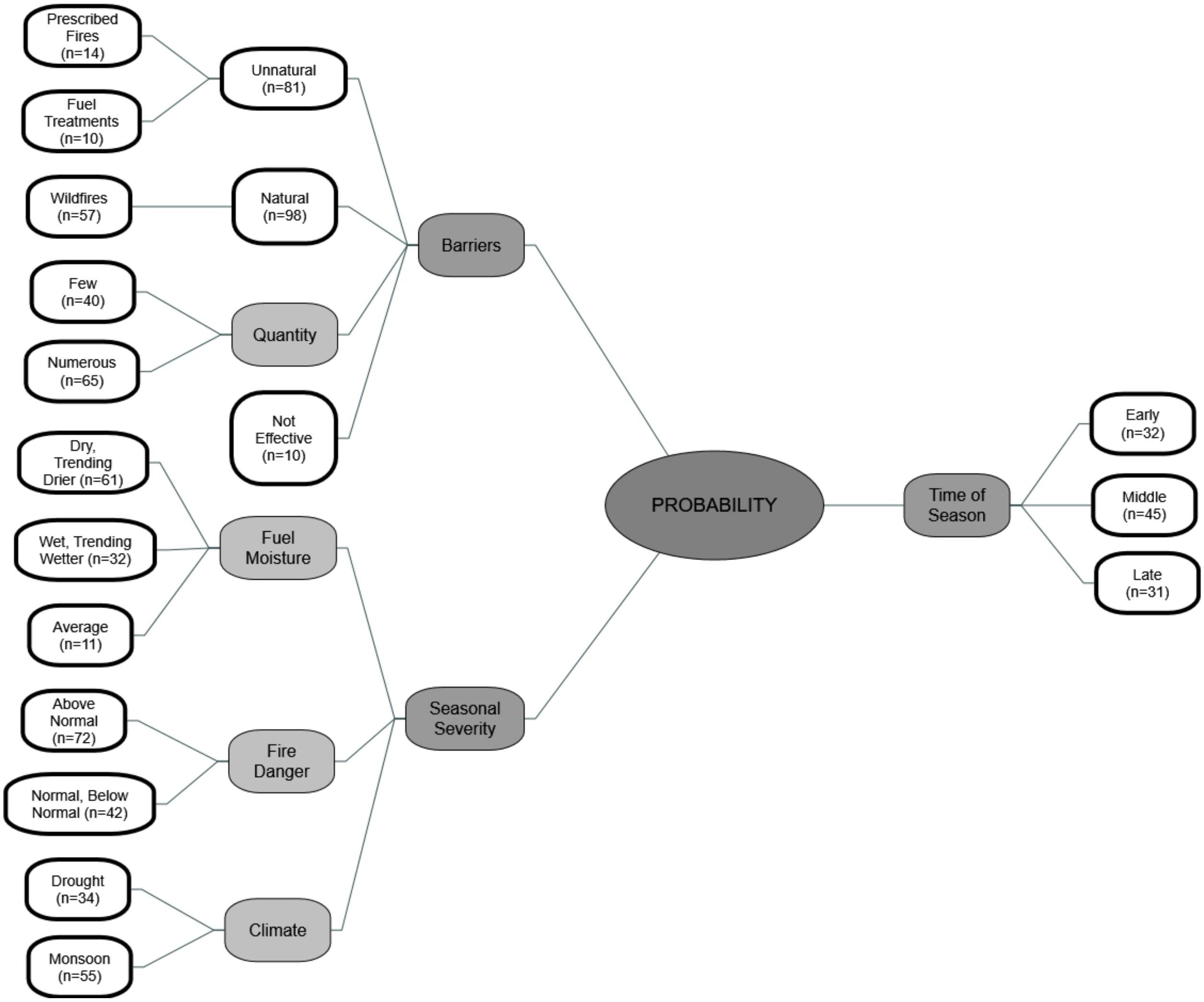
Appendix A

Codes of the relative risk assessment categorized by the relative risk framework: values, hazard and probability. The total number of times codes were counted (n) are shown in white shapes. Gray shapes denote broader categories to summarize codes. There were a total of 282 wildfires from the relative risk assessment dataset that were coded simultaneously to produce 93 codes. The methods of how qualitative text were coded are documented in detail in Chapter 3.





HAZARD
Fire Behavior
Low (n=61)
Moderate (n=30)
Extreme (n=12)
Crown (n=7)
Surface (n=15)
Passive (n=37)
Spotting (n=20)
Potential
Topography
Elevation
Low (n=7)
High (n=14)
Aspect (n=6)
Location on slope (n=9)
Steep & rugged terrain (n=52)
Growth
Small, Low (n=61)
Moderate (n=36)
Large, High (n=33)
Resistance to Control
Low (n=1)
Moderate or High (n=10)
Weather
Wind
Calm or Low (n=3)
Wind is Present (n=41)
Precipitation
None or Little (n=8)
Present (n=66)
Relative Humidity
high RH (n=14)
low RH (n=30)
Temperature
low temps (n=13)
high temps (n=26)
red flag or fire weather (n=14)
Fuel Condition
Fuel Type
Forest (n=47)
Grass (n=62)
Shrub (n=40)
Snags, Dead, Down (n=32)
Vegetation
Within Historical Ranges (n=32)
Highly Departed (n=20)
Invasive Species
Absent (n=1)
Present (n=11)
Fuel Loading
Average (n=16)
Lower - Sparse (n=35)
Higher - Continuous (n=44)


Prescribed Fires (n=14)
Fuel Treatments (n=10)
Unnatural (n=81)
Wildfires (n=57)
Natural (n=98)
Few (n=40)
Numerous (n=65)
Quantity
Not Effective (n=10)
Barriers
Dry, Trending Drier (n=61)
Wet, Trending Wetter (n=32)
Average (n=11)
Fuel Moisture
Above Normal (n=72)
Normal, Below Normal (n=42)
Fire Danger
Drought (n=34)
Monsoon (n=55)
Climate
Seasonal Severity
PROBABILITY
Time of Season
Early (n=32)
Middle (n=45)
Late (n=31)