THESIS

CLIMATE CHANGE ADAPTATION IN WILDLAND FIRE MANAGEMENT AND GOVERNANCE IN ALASKA

Submitted by

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ABSTRACT

CLIMATE CHANGE ADAPTATION IN WILDLAND FIRE MANAGEMENT AND GOVERNANCE IN ALASKA

In the sparsely populated landscape of Alaska, natural resource-dependent rural communities are experiencing the effects of a rapidly changing climate. Warming average temperatures have caused increases in wildland fire activity across the boreal and tundra regions of Alaska, and climate change projections forecast further increases in fire frequency, severity, and extent. These projections have resulted in dire predictions for the already-strained fire management capacity of the state and federal land management agencies. In a fire management system historically focused on the protection of isolated communities and valued resources, increasing fire activity is causing the need for adaptation in fire management approaches and decision-making structures. In this thesis, I explore priorities, challenges, and adaptation in fire management and fire governance in Alaska. I use a qualitative analysis of a series of interviews with fire managers and stakeholders in the Alaska fire management community to derive an understanding of potential adaptation options in a complex management system.

This thesis consists of three standalone chapters. The first of these chapters is a white paper that summarizes interview results. In this chapter, I identify four key issues to address in fire management in Alaska based on interviewee responses, including budgeting, staffing, the protection of remote values and subsistence hunting opportunities, and the potential for climate change adaptation and mitigation. The second chapter explores climate change adaptation in specific management approaches and the processes that may need to change to achieve those adaptations. I find that local collaboration, the integration of land and fire management

responsibilities within the statewide fire management network, and the consideration of recent science are significant controls on the system's capacity for adaptation. In the third chapter, I broaden the scope of my analysis to the multilevel fire governance system, seeking to understand how the organizational structures and institutions that support collective action will respond to the challenges of climate change. I find that existing adaptive mechanisms such as regular formal and informal communication among agencies and the presence of bridging organizations will be critical to successful adaptation across the state. Overall, these results show recognition within Alaska's fire management community of the urgent need to reevaluate management priorities, policies, and structures going forward.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Climate change is causing significant changes to wildland fire regimes in Alaska, straining the capacity for fire management in the state and federal land management agencies. Fire occurrence in Alaska is strongly linked to climatic variables (Duffy et al. 2005). Over the past few decades, with rapidly rising average temperatures at high latitudes, the frequency of fire events and area burned during large fire years has increased in boreal forest and tundra ecosystems across the state (Kasischke and Turetsky 2006; Kasischke et al. 2010; Kelly et al. 2013). Going forward, climate change models project further increases in average annual area burned and fire frequency, with a coincident lengthening of the fire season (Mann et al. 2012; Flannigan et al. 2016; Young et al. 2017). Much of the projected increase in area burned will occur in large fire years, during which fire management resources are spread thin (Rupp et al. 2016). Future hot and dry conditions in the boreal forest will increase the likelihood of fire weather that will support unmanageable fire intensities (Wotton et al. 2017), and increases in average annual fire extent will likely lead to significant rises in suppression costs (Podur and Wotton 2010; Melvin et al. 2017).

In Alaska, these climatic changes are intersecting with a unique social and management context. The state and federal land management agencies in Alaska jointly determine statewide fire management policy, and they have delegated suppression responsibilities to three protection agencies that operate across jurisdictional boundaries (AWFCG 2018). These agencies protect values for widely dispersed and diverse communities that are often dependent on subsistence use of natural resources (Nelson et al. 2008). Changing fire regimes will likely have negative effects on the availability of some wildlife habitat (Joly et al. 2012), high value timber (Soja et al. 2007), and ecosystem carbon storage (Pastick et al. 2017) due to low resilience in current dominant

vegetation types to increased frequency and severity of fire (Johnstone et al. 2010; Rupp et al. 2016). Meanwhile, the fire management agencies are facing growing risk to communities in the wildland-urban interface and the need to adapt management approaches to augment protection capacity (Trainor et al. 2009). Given these expected challenges, adapting fire management approaches will likely require changes at all levels of the fire governance system (Chapin et al. 2008).

This thesis explores the tandem need for adaptation in fire governance and fire management in Alaska. Climate change adaptation describes actions that adjust aspects of an ecosystem, management system, or social system to ameliorate the negative effects of climate change (IPCC 2014). Fire governance and management are examples of systems that can adapt or be the subject of efforts to adapt to climate change. Fire governance refers to collective decision making regarding management of wildland fire (Folke et al. 2005). My research sought to understand how the components of the governance system, including actors, organizational structures, and institutions, including laws, policies, rules, regulations, and norms, will respond to the effects of climate change (Chaffin et al. 2014). Fire management, on the other hand, consists of the planning and actions associated with modifying the characteristics of a wildland fire and its interactions with ecosystems and human communities (USDOI BIA et al. 2016). Fire management is nested within the fire governance system and constitutes the interface between the social system and the changing ecosystem (Wise et al. 2014). My research sought to understand potential adaptation in management approaches to continue to meet priorities and associated changes in the decision-making processes necessary to allow adaptation in approaches.

To understand the potential for climate change adaptation in fire governance and management, I used a qualitative study of fire manager perspectives on priorities, challenges, and options for management going forward. The bulk of this thesis presents and analyzes the results of a series of interviews with fire managers and stakeholders from organizations across the fire management system in Alaska (see Appendix A for a detailed description of interview methods and a pilot questionnaire used to develop interview questions). The use of a qualitative research approach facilitated the exploration of adaptation in a complex system dependent on decision making among a network of diverse actors. The use of semi-structured interviews allowed actors in the system to fully articulate their perspectives on challenges and needs in fire management (Yin 2016).

My study is a component of a broader, interdisciplinary Joint Fire Science Program (JFSP) research project, with my adviser as Principal Investigator. The objective of the JFSP project is to create sets of alternative management approaches through an iterative process of knowledge building among fire managers and researchers in a series of presentations, interviews, informal discussions, and formal workshops. The JFSP research team will then use these sets of alternative management approaches to quantitatively model the effects of management on future fire regimes and suppression costs under several climate change scenarios. The research team is using the spatially explicit Alaska Frame-Based Ecosystem Code (ALFRESCO) to model statewide patterns of change in boreal and tundra vegetation cover and fire regime characteristics, including annual average fire frequency and area burned (Rupp et al. 2000; Rupp et al. 2002). This thesis both informs that work and stands alone as a contribution to the literature on climate change adaptation in natural resource management and governance systems.

This thesis consists of three independently developed but interrelated chapters. Each standalone chapter addresses a separate component of the question of how fire governance and management will respond to increasing fire activity in Alaska. The following chapter, Chapter 2, is a summary of interview results in the form of a white paper for managers. In Chapter 2, I describe interviewee perspectives on current priorities for fire management, advantages and challenges associated with the current fire governance system, and future management needs. At the close of that chapter, I identify four key issues to address in the management system. In Chapter 3, I explore specific adaptations in fire management approaches in response to key issues and possible changes in decision-making structures and methods needed to achieve those adaptations. Chapter 4 frames the identified management issues in the theory of adaptive governance to understand specific governance structures and institutions that facilitate or hinder adaptations in fire management. I particularly examine adaptive mechanisms and interactions across levels of the governance system, from local collaboration to top down federal and state bureaucratic hierarchies. Finally, in Chapter 5, I briefly summarize and draw overarching conclusions from my three separate analyses of the interview data, with a look toward future research needs in Alaska and beyond.

CHAPTER 2: *CHALLENGES AND OPPORTUNITIES IN ALASKA FIRE MANAGEMENT: ADAPTING TO CLIMATE CHANGE*

Executive Summary

Under projected patterns of climate change, models predict an increase in wildland fire activity in Alaska, which is likely to strain the capacity of the fire governance system under current arrangements (Melvin et al. 2017; Pastick et al. 2017). The Alaska wildland fire governance system consists of the actors, networks, and institutions, including policies and laws, that influence wildland fire management. This system is already adjusting to the effects of a changing climate, but future climate change presents significant uncertainties with possible higher interannual variability in fire extent and severity that may necessitate new approaches to fire management (Kasischke et al. 2010; Rupp et al. 2016).

This report presents the results of interviews that we conducted as part of a broader Joint Fire Science Program (JFSP) project on the future impacts of climate change on fire management in Alaska. Our team assessed fire regime projections using the Alaska Frame-Based Ecosystem Code (ALFRESCO) model and interviewed fire managers to understand perceptions of challenges and strategies in the governance system, specifically regarding anticipated changes to fire regimes as a result of climate change. We synthesized our interview data to create future fire governance alternatives, which we will later input into the ALFRESCO model to project fire regime scenarios. Throughout this process, we are working iteratively with the fire management community, with the primary goal of understanding the implications of future management alternatives for fire regimes and whether changes to current management approaches may be desirable.

In interviews, our research objectives were to understand:

1. Current priorities for fire management and how these might change in the future;
2. Advantages and challenges associated with the current fire governance system, particularly in regard to adapting to climate change; and
3. Future needs, opportunities, and potential avenues for improving fire management and fire governance in Alaska.

We conducted 41 semi-structured, hour-long interviews with individuals from the fire and land management agencies, Alaska Native consortia, and boroughs. We then used standard qualitative methods to organize and analyze the data according to our research objectives. We are delivering these findings to our interviewees and the broader fire management community to gather feedback and refine our recommendations for facets of fire governance that may require change or policy attention in the years to come. We also used interview data to assess and characterize two future management alternatives, including (1) extending full and critical management option buffers around communities and known sites and (2) implementing large-scale fuel breaks, which correspond to reduced flammability for areas of treatment. We will evaluate these management alternatives in contrast to a baseline management approach that depicts a continuation of current management options. We will perform this evaluation using the ALFRESCO model to determine potential impacts of different management approaches on fire regimes and vegetation.

Interviewees indicated multiple management priorities to protect a variety of values held by the public, politicians, and ANCSA Corporations. We classified these values into three broad categories as follows:

1. Values requiring fire protection: human life and property, infrastructure, cultural sites, natural resources (e.g. timber), and carbon sequestration;
2. Values reliant on the occurrence of fire: maintenance of natural, fire-dependent ecological processes and conditions and the enhancement of wildlife habitat, especially for subsistence use, although agencies also may protect certain areas of old-growth habitat from fire to preserve subsistence opportunities (e.g. caribou winter range); and
3. Broader values not directly related to fire management: efficiency with the use of public funds for fire management and fire management as a source of employment.

Interviewees explained that the diverse values may conflict, and that during times of high fire activity, the agencies sometimes must prioritize suppression resources because not all values can be protected.

According to interviewees, the advantages of the current system include the strong relationships and communication among agencies, annual interagency meetings sponsored by the Alaska Wildland Fire Coordinating Group (AWFCG) to discuss needed changes to fire management, collaborative arrangements between the agencies and local governments and stakeholders, and the agencies' use of research and science to improve management.

Despite the advantages to the current interagency arrangements, interviewees also saw potential for improvement in some specific areas of communication among actors in the governance system. For example, interviewees mentioned the opportunity for more involvement with and education of the public, politicians, and ANCSA Corporations to improve communication of values and understanding of agency limitations. To improve planning and the communication of land management goals, interviewees said the jurisdictional agencies could be more involved in fire management planning, while the protection agencies could be more

involved in land management planning. Interviewees also discussed two challenges associated with periods of high fire activity, including lack of capacity to protect values that rely on suppression and the potential for more frequent extraordinarily large and high severity fires that may present too much risk to allow them to burn without the use of suppression tactics. Almost all interviewees focused primarily on the immediate challenges of limited staff and funding, which strain their capacity for all aspects of fire management.

Interviewees mentioned some possible changes in fire management policy and approaches that might be necessary to address anticipated challenges associated with climate change. These changes include: the minimization of conflicting and overlapping policies among agencies, broad changes in fire management option designations, and increased use of fuel reduction work. Interviewees discussed incongruence and inefficiencies among agencies in cabin protection policies and certification and permitting policies. Regarding future management approaches, interviewees explained that agencies may consider expansion of full and critical management option buffers around communities to mitigate elevated risk from extraordinarily large fires under climate change. Interviewees also discussed many potential benefits of increased use of fuel breaks and fuel treatments in a scenario of increased fire activity under climate change, including facilitating suppression around communities, being able to allow more natural burning on the landscape relatively near communities, and enhancing wildlife habitat.

In summary, our interview data shows that the fire governance system in Alaska is adaptive to change but faces some capacity limitations that may require changes in interagency policy, structure, or management goals. Based on the challenges and suggestions most commonly mentioned by interviewees, we recommend a focus on four key issues to address going forward: (1) budget processes and allocations; (2) staffing strategies to build capacity; (3)

values for protection that may present controversy or challenges; and (4) considerations of climate change adaptation and mitigation in fire management.

Introduction

Alaska's boreal forests and tundra ecosystems rely on the regular return of wildland fire to maintain ecological integrity (Kasischke et al. 2010). Rising temperatures and drying soils have recently caused an increase in the frequency of fires, average annual area burned, and average length of the fire season (Kasischke and Turetsky 2006; Kelly et al. 2013). Fire regime models project these increases will continue with future climate change (Young et al. 2017; Pastick et al. 2017). Higher severity fires will likely cause transitions in vegetation regimes, resulting in loss of ecosystem services to human communities (Chapin et al. 2008; Rupp et al. 2016). More frequent large fire years, with high numbers of ignitions and area burned, may strain the ability of Alaska's fire management agencies to protect properties, cultural sites, infrastructure, and valued natural resources (Kasischke et al. 2010). Federal and state funding for fire suppression will need to increase to sustain current management approaches if fire activity increases under climate change (Melvin et al. 2017).

To manage wildland fire, the land managers, land owners, and stakeholders participate in a fire governance system, consisting of the actors, networks, and institutions—including the rules, laws, regulations, policies, and social norms—that influence how fire is managed. In Alaska, the actors involved in fire management include federal and state land management agencies and Alaska Native Corporations (collectively called "jurisdictional" agencies), three separate suppression agencies (called "protection" agencies), Alaska's boroughs, and municipalities and other private landowners (AWFCG 2018). In addition to these individual

agencies, several interagency organizations and agreements coordinate fire management policies and operations, such as the Alaska Interagency Wildland Fire Management Plan, written and overseen by the Alaska Wildland Fire Coordinating Group (AWFCG) (USDOI BIA et al. 2016). While the fire governance system in Alaska has been facing a changing climate and adapting to the demands of more frequent large fire years over the past few decades, future climate change presents major uncertainties regarding fire extent and effects, with possible greater interannual variability and more years with high fire activity compared to the past (Kasischke et al. 2010; Pastick et al. 2017). To continue to protect key values, managers will likely require increased resources and workforce capacity (Melvin et al. 2017).

This report summarizes interviews we conducted as part of a larger Joint Fire Science Program project to understand how the fire governance system in Alaska will respond to the challenges of climate change. Our goals were to understand the following:

1. Current priorities for fire management and how these might change in the future;
2. Advantages and challenges associated with the current fire governance system, particularly in regard to adapting to climate change; and
3. Future needs, opportunities, and potential avenues for improving fire management and fire governance in Alaska.

This report presents our findings and offers some draft recommendations, based on interviews, in an effort to contribute to the interagency dialogue about preparing for the future of fire management in Alaska. We are also using the information gleaned from interviews to complete the next step of our project, which involves building different management alternatives into modeled fire regime projections using the ALFRESCO model to explore implications for operations and resources into the future.

Project Overview and Methods

This paper is a product of a Joint Fire Science Program (JFSP) project entitled Impacts of Climate and Management Options on Wildland Fire Fighting in Alaska: Implications for Operational Costs and Complexity under Future Scenarios. Principal Investigators include Courtney Schultz (Colorado State University [CSU]), Paul Duffy (Neptune, Inc.), and Nancy Fresco (University of Alaska, Fairbanks); Randi Jandt (Alaska Fire Science Consortium [AFSC]) is a project collaborator, and Tait Rutherford, who conducted the interviews, is a master's student in Forest Sciences at CSU. The project's broader objectives are to assess current fire regime projections, develop future management alternatives, and use these alternatives to create fire regime scenarios and explore their implications for management costs and decision making. We are using the Alaska Frame-Based Ecosystem Code (ALFRESCO) model to develop the fire regime projections (Rupp et al. 2000). The project involves several steps and products (see Table 1).

For the interviews that are the basis of this report, we recruited participants from AFSC general contact lists and the 2017 Interagency Spring Fire Operations Meeting attendee lists. We began by contacting individuals who our team believed could inform our research objectives, and we conducted additional interviews based on interviewee recommendations until we reached information saturation. We strove to obtain a diverse a set of perspectives and information. Data collection began with an online pilot questionnaire targeted to individuals who had participated in a February 2017, AFSC-sponsored webinar to introduce our project and the beta-version of our fire regime projections website; the questionnaire consisted of seven open-ended questions about current challenges in fire management and the usefulness of our fire regime projections

website (see Table 1). We received 20 responses to the questionnaire, and we used this information to develop and improve the website and to help structure our interview protocol.

Table 1: Project milestones and delivery dates.

Project Milestone	Description	Delivery Date
Introduction of project	Present project overview at the Interagency Fall Fire Review.	Oct. 2016
Introduction of initial fire regime projections website	Present webinar of beta-version of fire regime projections website. Available at https://www.frames.gov/partner-sites/afsc/events/previous-events/previous-webinars/duffy-schultz-feb-2017/	Feb. 2017
Online pilot questionnaire	Gather initial response to the fire regime projections website and perceptions of current challenges in fire management through an online questionnaire.	Feb.-Mar. 2017
Interviews	Conduct interviews with fire managers.	Mar.-Sep. 2017
Presentation of interview data	Present to the fire management community this practitioner's report summarizing our interview findings.	Oct. 2017 Interagency Fall Fire Review
Workshop: presentation and analysis of management alternatives	Present outputs of the fire regime projections model under future management alternatives in a workshop setting to explore implications of management alternatives.	Spring 2018 Interagency Spring Operations Meetings
Synthetic analysis and additional science delivery	Synthesize findings from all phases of our project for publications, policy briefings, and science delivery at conferences and via webinars.	Spring and Summer 2018

Interviews were confidential and conducted in accordance with requirements and approval from CSU's Institutional Review Board. Since March of 2017, we have conducted 41 interviews with individuals from the following organizations:[1]

- Alaska Department of Fish and Game (ADF&G)
- Alaska Department of Natural Resources Division of Forestry (DOF)
- Alaska Native consortia

[1] Some specifics omitted for confidentiality

- Borough emergency services departments
- U.S. Department of Agriculture Forest Service
- U.S. Department of Defense (USDOD) military bases, fire operations
- U.S. Department of the Interior (USDOI) Bureau of Indian Affairs (BIA)
- USDOI Bureau of Land Management (BLM)
- USDOI BLM Alaska Fire Service (AFS)
- USDOI Fish and Wildlife Service (FWS)
- USDOI National Park Service

We recorded and transcribed interviews, then systematically analyzed them using coding software that allows us to assign codes (i.e. labels) to excerpts of text and view all excerpts under each code and in context. Coding allows us to identify and analyze themes in the data. We also wrote brief summaries of each interview. We then created memos according to codes (e.g. "management priorities" or "capacity challenges") and associated excerpts. This process allowed us to collate and analyze the large amount of interview data to understand the fire governance system and reflect on what interviewees told us. We derived the results that follow entirely from interview analysis and interviewees' own statements.

Results

In this section, we summarize our interview findings. First, we identify constraints, pressures, and values that shape priorities and drive decision making for "the agencies," meaning the federal and state jurisdictional and protection agencies. In the second section, we discuss advantages and challenges associated with current governance structures and policies. Finally,

we examine strategies for the future that managers suggested to meet potential challenges posed by projected capacity limitations and climate change.

Current fire management priorities

Interviewees explained that the agencies set priorities based on state and federal law and external pressure from the public and politicians. Jurisdictional agencies manage fire in accordance with their mandates and missions under a variety of laws.[2] These laws include mandates to consider and balance public interests.[3] Within these laws, the agencies have some discretion over planning and prioritization, but as one interviewee explained, the laws and agency rules put significant limits on agency priorities:

> "Yeah, it's not really what [the agency] wants. [The agency] has some direction that has been established through the Department of the Interior, Congress, and the president. … We have a mission and we get a certain amount of ability to do things the way we think is best, but we're kind of held to the sideboards of various laws and public land orders and processes that are over our heads."

Interviewees also emphasized two federal acts that set parameters on prioritizing specific valued resources. The Alaska Native Claims Settlement Act of 1971 (ANCSA) requires that the federal government provide fire suppression to all Native Corporation land and all Native allotments. Under ANCSA, "So long as there are no substantial revenues from such lands they shall continue to receive wildland fire protection services from the United States at no cost" (43 USC 1620(e)). Native Corporations communicate directly with the protection agencies as jurisdictional agencies via ANCSA authority. The second federal law affecting fire management

[2] See, e.g.: 16 USC 668dd; 16 USC 1600 et seq.; 43 USC 1701 et seq.; 54 USC 100101 et seq.; AS 16.05.010 et seq.; AS 41.17.010 et seq.

[3] See, e.g.: 16 USC 1612(a); 16 USC 3191(d); 43 USC 1712(c)(9); AS 30.04.065(d)

is the Alaska National Interest Lands Conservation Act of 1980 (ANILCA), which requires that federal agencies prioritize subsistence use of natural resources by rural Alaskans over non-subsistence use (16 USC 3114). ANILCA also states that public lands use, consistent with existing land management principles, including fire management, should have as little impact on rural Alaskans dependent on subsistence uses as possible (16 USC 3112(1)).

Interviewees mentioned a wide array of values that influence fire management priorities. We have organized these values into three categories (see Table 2). The first category of values is reliant on protection from wildland fire, provided by a combination of suppression tactics and the use of fuel breaks and preparedness measures. Virtually all the actors within the governance system agree that protection of human life is the primary priority in fire management; the agencies value firefighter safety and the protection of communities and primary residences above all else. Interviewees consistently said that remote cabins or undeveloped Native allotments will sometimes receive lower priority than other property during periods of high fire activity because remote sites draw heavily on response resources relative to road-accessible areas. The agencies may suppress fires for various other reasons, including preservation of cultural sites, protection of tourist sites, or prevention of smoke pollution. ANCSA Corporations may protect swaths of forest as greenhouse gas pollution offset credits[4] or as timber for biomass.[5] Finally, a few interviewees mentioned the future potential for placing value on the protection of permafrost for

[4] See: Tribal Carbon Partners (2017)

[5] The protection of forest for economic reasons has sparked discussion among the agencies about invoking the "substantial revenue" limitation written into ANCSA (43 USC 1620(e)) due to the high cost of protecting large areas of timber. This would move protection of the land under state fiscal responsibility, however, which would fail to resolve the fundamental challenge associated with limited resources to protect values-at-risk.

carbon sequestration. As with the protection of carbon offset credits, interviewees expressed concern that protecting large areas of permafrost would entail a suppression capacity that currently does not exist.

Table 2: Interests and values that drive Alaska fire management.

Relationship to fire	Values
Values that require protection from fire	· Cultural and paleontological sites · Human life · Permafrost or timber for carbon sequestration · Property · Reduction of smoke pollution for health · Subsistence hunting opportunities (e.g. caribou winter range) · Timber as carbon emissions offset credits · Timber for biomass or other commercial purposes · Tourist sites and viewshed
Values that rely on fire	· Natural ecological processes · Subsistence hunting opportunities (e.g. moose browse) · Wildlife habitat enhancement
General fire management priorities	· Efficiency with taxpayer money · Employment opportunities in fire management

While maintenance of life, property, cultural sites, and tourist sites requires suppression, the agencies otherwise allow natural fire ignitions to burn. As most interviewees agree, Alaska offers a unique opportunity to allow natural fires to burn for ecological benefit due to the low population density relative to the conterminous United States. One interviewee explained, "Kind of the glory thing about Alaska is really across the board … [the agencies] have kind of the same vision on fire management and fire [being] good on the landscape." While climate change has increased fire activity, the agencies still try to allow fire on the landscape as often as they can. One interviewee said,

> "We don't seem to have gotten into the situation where we're trying to manage for some landscape that would occur in the absence of climate change. … Even though we may

> be experiencing more fires … we haven't said, well, our goal is to have this many acres burn over a ten-year period but then not some other number because this other number is inflated as a result of climate change."

Two agencies specifically manage for enhancement of wildlife habitat.[6] Interviewees mentioned that the U.S. Fish and Wildlife Service (FWS) and Alaska Department of Fish and Game (ADF&G) prefer to see natural fires burn when possible to create a diversity of habitat on the landscape. Where this is not possible, ADF&G would like to see increased use of prescribed fire to enhance wildlife habitat. On the other hand, while habitat enhancement usually implicates allowing fires to burn, the subsistence mandate in ANILCA complicates habitat management by requiring agencies to consider protecting habitat through suppression in certain areas. In particular, the ANILCA subsistence mandate has recently prompted the protection of caribou winter browse in old-growth black spruce forest in the Kanuti National Wildlife Refuge to maintain hunting grounds for nearby rural villages due to extensive loss of old-growth stands in that refuge in 2004 and 2005.[7] According to a few interviewees, this has created some value conflicts for the wildlife management agencies because it contradicts the natural processes paradigm and inhibits moose habitat enhancement.

Some interests are unrelated to increases or decreases in suppression, including careful use of resources and employment opportunities. Agencies said they try to spend public dollars efficiently; similarly, a few interviewees from the protection agencies said suppression operations must identify acceptable amounts of risk to be more efficient with resources. A second interest relatively unrelated to suppression is the desire for fire crew employment opportunities among rural Alaskans, especially Alaska Natives. Interviewees said Alaska Native

[6] See: 16 USC 668dd(2); AS 16.05.020(2)

[7] See: USDOI FWS (2012)

non-profit consortia try to maintain Type 2 Initial Attack crews or Emergency Firefighter (EFF) crews with Native preference hiring to create local employment opportunities. As part of this, the consortia or the villages will often push for suppression or for more fuel reduction projects to create work for the villages.

Prioritizing among values is a critical part of fire management and underlies many of the challenges that the agencies currently face, because they have not had the capacity to satisfy all interests and meet all requirements during recent large fire years. Large fire years may force agencies to balance protection of remote sites against saving resources for anticipated ignitions closer to inhabited areas. The agencies also cannot allow unbridled burning for natural processes; sometimes they must balance allowing a fire to burn on public land against risk of it spreading toward adjacent communities.

Advantages and challenges within the current fire governance system

a. Current advantages: adaptability and efficiency

According to interviewees, the effectiveness of the current fire governance system in Alaska lies in the strong relationships among the agencies. While interviewees mentioned several areas in which communication within the governance system could be improved, as we show in the following section, interviewees explained that the separation of the protection agencies from the jurisdictional agencies forces them to maintain constant lines of interagency communication. Protection agency fire management officers work hard to build good relationships with the jurisdictional agencies and landowners to constantly be aware of how they should respond to a fire in any location or situation. An interviewee explained,

> "Having that need for communication between the jurisdictional and the protection agencies, we have a pretty good working relationship with all the other agencies. … It's

> not one of those, 'I haven't talked to that individual in a couple of months.' It's, 'I haven't talked to that individual in a couple hours' about something."

In general, interviewees said that interagency coordination in Alaska is very healthy. Documents such as the Master Agreement and the Alaska Interagency Wildland Fire Management Plan (AIWFMP) codify the interagency system by clearly defining agency responsibilities. In the words of one interviewee, "The way the document is written, the Master Agreement that is, it clearly defines who is responsible for what. And that right there sets the stage for a successful relationship between the agencies. It's clearly defining who does what and who is responsible." In addition, interviewees noted that the biannual interagency meetings sponsored by interagency organizations such as the Alaska Wildland Fire Coordinating Group (AWFCG) allow the agencies to refine planning and operations.

Outside of the interagency system, interviewees said that the agencies benefit from collaboration with local governments and the public. The agencies make strong efforts to communicate to communities and private landowners how preparedness measures can help with protection. Fire prevention officers for Alaska Division of Forestry (DOF) host public education programs on fire preparedness and prevention throughout the state. In addition, local collaborative initiatives coordinate large-scale, cross-jurisdictional fuel breaks, preparedness, and recovery projects. Many interviewees cited the Kenai Peninsula's All Lands/All Hands group, which coordinates planning and resource sharing for fuel management between federal, state, Alaska Native, and local governments, as an ideal example of collaborative fire management.[8] A few interviewees also said that some of the agencies would like to set up groups like the Kenai All Lands/All Hands group in other areas, but that such collaborative work is often not feasible

[8] See: USFS et al. (2004)

outside of the more densely populated regions of the state such as the Kenai Peninsula or the Fairbanks area.

Interviewees mentioned a few mechanisms in the current governance system that enable adaptability to change. For example, the biannual interagency meetings allow agencies to continually refine fire management based on current circumstances and values. The agencies also try to use science and research to inform management decisions. An interviewee explained this effort to continually improve:

> "We're always preparing and trying to do forecasting of what we need and what we need to be doing to do our jobs correctly, safely, and then also looking at ways to do it better. Trying to stay aware of innovation, new tools, tools that maybe fire [management] hasn't used before, but bringing them into fire [management] to increase our abilities to be responsive and do our jobs better."

In part, this effort to improve operations and communication has resulted from a widespread realization among the agencies that they must anticipate climate change and the need to better understand its effects. One interviewee mentioned that "climate change . . . is causing the [jurisdictional agencies] to have to sit down and have more conversations with the [protection agencies] and look at fire science."

b. Current challenges I: Improving communication for planning

Despite the strong interagency relationships and collaborative arrangements that interviewees described as advantages to the current governance system, many interviewees identified specific areas in which lines of communication among various groups in the governance system could improve. Interviewees suggested including a broader array of actors in the governance system will improve communication regarding values and limitations. For example, a few interviewees mentioned that the inclusion of Department of Defense (USDOD)

agencies in the Master Agreement would facilitate billing between the protection agencies and USDOD. Interviewees also explained that despite current agency efforts, there is a need for more education and outreach. Interviewees said this would help with communication of values and priorities between the agencies and other groups in the governance system, including ANCSA Corporations, communities, and politicians. According to one interviewee, "[The agencies] need to be the conduit to provide some of the information. People, grants, and stuff like that, opportunities for people, to give them an incentive to do that kind of [preparedness] work. That is a challenge." At the same time, some agency interviewees suggested that the public and the ANCSA Corporations may have opportunities to involve themselves to a greater extent in fire management to improve preparedness and their understanding of the limits and priorities of the agencies.

Within the governance system, interviewees felt that some groups of agency personnel could become better involved in fire management to improve the system. Some interviewees, for example, suggested that the state jurisdictional agencies could consider fire risks when zoning and selling or leasing land. Many interviewees felt that the jurisdictional agency administrators could also be more involved in fire management. The jurisdictional agency administrators manage public lands resources and write the land and resource management plans that inform fire management planning. Involving jurisdictional agency administrators more directly in fire management would improve the communication of landscape goals to the protection agencies so that they could tailor suppression decisions and implement more targeted fuel management. Interviewees felt both that jurisdictional agency administrators need to work to involve themselves in fire management more and that the protection agencies need to reach out more to the jurisdictional agency administrators. One interviewee said,

> "We're having to consciously integrate between the Alaska Fire Service and [the] field and district offices, push them together basically to have those conversations. And I think as fire regimes are changing … the resources side [has] to sit down and have more conversations with the fire side and [look] at fire science."

An interviewee explained that some jurisdictional agency administrators have begun to attend the annual interagency fire management meetings in order to become more involved in fire management.

Many interviewees also felt that the jurisdictional agency fire management officers need to become more involved in the annual review of management option designations in the Alaska Interagency Wildland Fire Management Plan (AIWFMP). Some of the protection agency interviewees believed that significant inconsistencies in the management options map need to be addressed. For example, one interviewee explained that the agencies have not holistically reviewed the original management option designations:

> "And that's the problem with our fire plan, is that it was a product of ANILCA and that was the driving force in the funding to get these groups together to initiate the plan. … But there really hasn't been a mechanism to bring that same group together, the current participants, and review the management options."

A few interviewees from the protection agencies suggested the creation of an interagency, interdisciplinary team that would work exclusively on management option changes. Such a team would review the current management options map in detail, replacing the current annual review system, to fix any inconsistencies across management areas or needed changes based on changes in valued resources. As one interviewee described,

> "[I]t could be a multi-agency group. That's their task, to re-look at the fire plan and protection level. … They fully understand all the procedures they need to follow … and I think if you had a group that did that, it would get pretty good at going through that process."

On the other hand, interviewees from several agencies, including the Alaska Fire Service (AFS), felt the protection agencies could focus more on fuel management and land management

considerations. Several interviewees noted that the protection agencies are relatively specialized in suppression activity. In the words of one interviewee, "[AFS] is built to put everything out. That's changed over the years and we've tried to adjust a lot of our thinking and adapt to … science and jurisdictional management resource requests. We could do a better job at that." Many of the jurisdictional agencies would like to allow more fire on the landscape, but the protection agencies may not want to accept the risk of allowing natural fires to burn. An interviewee explained:

> "[The jurisdictional agencies try] to convince the suppression resources what the intent is there. What [the protection agencies] see when they arrive is the large fuel column next to a town. So just automatically they're trained to put fires out. … [I]t's really hard to get strategy to the boots on the ground in a timely manner. So, action was taken on the fire; perhaps less action would have been okay. But what would have happened in a no action? So, it's a balance."

c. Current challenges II: Capacity and resources

Interviewees emphasized that challenges in fire suppression arise during large fire years,[9] which pose a threat to multiple types of values, and models indicate they may become more frequent.[10] On the one hand, large fire years strain the capacity of the protecting agencies. The agencies are accustomed to dealing with these events about once per decade, but interviewees expressed concern that if the frequency of large fire years increases under climate change, the agencies will more often not be able to protect the valued resources that they intend to be protecting. One interviewee explained, "That's something you see in larger fire seasons up here is that resources become thin and incidents are prioritized so you can figure out where to allocate

[9] For an explanation of large fire years and annual variation in Alaska fire activity, see: Duffy et al. (2005).

[10] See: Rupp et al. (2016)

limited resources because it's not possible to give every incident what it may need or what it may want." On the other hand, even if the agencies were to have unlimited suppression resources, they worry that they might lose the ability to allow fire on the landscape, due to ecosystem transitions and risk to communities from unusually large and severe "megafires."[11] As one interviewee said, "If we start seeing huge megafires going on all the time, you know there's going to be resistance to allowing any fires to burn naturally because there's too much risk in it."

Most interviewees focused on challenges stemming from limited capacity; interviewees said that insufficient funding has affected operations, fuel management, and hiring. During large fire years, agencies in Alaska borrow equipment and staff from their counterparts in the conterminous United States, but borrowing will not be available if fire seasons lengthen in both the Lower 48 and in Alaska. An interviewee explained, "We're bringing resources up from the Lower 48 to supplement our resources. At some point in time, that pipeline's going to slow down [due] to the fact that they're having increasing [fire] activity, as well, and they're not going to be readily available." The protection agencies also are concerned that changes in shared interagency equipment and staffing policies under nationwide federal agency regulations will reduce operations capacity in Alaska. They want, for example, to make sure that fuel-efficient air tankers suited to the long-distance flights common in Alaska suppression operations remain available for use. It is also becoming more difficult for the protection agencies to afford EFF crews, due to requirements for increased training and growth in crew size. These specific issues are symptomatic of broader capacity challenges affecting Alaska as a result of nationwide regulations. An interviewee stated,

> "Nationally, there's been reductions in overall work force and an increase in number of technical positions and whatnot. We've made things more complex, in other words. And

[11] See: Stephens et al. (2014)

> so, you need more people to do the same job and with reduced numbers of people, it's making it more and more difficult to attain what our intent is and what we said we would do."

Interviewees mentioned that many of the agencies would like to implement more fuel breaks to ease potential suppression or enhance habitat, but funding for fuel reduction treatments is limited, especially in Alaska, where fuel treatments are unusually expensive and unlikely to encounter a natural ignition before regrowth. In remote areas, suppression is often cheaper than implementing a fuel break. An interviewee explained, "[I]n general, I think I could say that fires, especially in Alaska suppression-wise, are a lot cheaper than fuels work."

To ease funding challenges, interviewees suggested possible changes in budgeting processes or more pooling of funding sources among agencies. For example, many interviewees explained that fire budgeting for the Bureau of Land Management (BLM) uses risk-based statistical models designed for suppression operations in the conterminous United States; those models do not always apply well in Alaska where values to protect are different, the interagency governance structure is different, and suppression operations often focus on protection of sites rather than minimization of acreage burned. Other interviewees suggested consideration of innovative funding structures used by other states, such as purchasing insurance for the state suppression agency or implementing a flat annual tax on property located in the wildland-urban interface. Interviewees also explained that collaborative governance arrangements may help agencies and communities obtain money from federal grant pools for fuel management such as Cohesive Strategy funding. For example, municipalities and villages with Community Wildfire Protection Plans are more likely to be able to win federal grants. Interagency organizations such as the Kenai Peninsula All Lands/All Hands group have been able to pool money from various sources: while communities in the Kenai Borough can get federal grants, ADF&G can use

Federal Aid in Wildlife Restoration (Pittman-Robertson) Act funding for fuel management as habitat enhancement, the Chugachmiut Alaska Native non-profit organization can use Reserve Treaty Rights Lands program funding from the Bureau of Indian Affairs (BIA), and FWS and DOF can use their own operating budgets.

Limited funding is interrelated with staffing challenges. Interviewees expressed that funding directly affects the ability of agencies to retain staff and hire new staff. Many interviewees mentioned several other issues associated with staffing at multiple levels, including: lack of competitive pay in firefighting jobs relative to similar types of work; workforce demographic shifts toward white-collar careers, resulting in fewer recruits for firefighting jobs; consolidation of jurisdictional agency fire offices and closing of protection agency outstations; lack of experience among fire managers; a need for more flexibility in staffing regulations; limits on the sharing of staff across agencies; and lack of fire-related positions in jurisdictional agencies.

With the scarcity of personnel at many levels, interviewees said the agencies lose capacity for suppression operations and fuel management. A protection agency interviewee explained,

> "I think right now really [our primary challenge is] just the numbers of staff for the positions we've got. We're very, very lean. I think we were before we had budget cuts and even more so now. So, the lack of resources in terms of just people. And then also, we have a fairly high turnover rate so I think a lot of the experience that we had at one time, we don't have anymore. … I guess what that means … is we're in a never-ending training cycle."

To solve staffing issues, interviewees suggested more localized decision making on staffing levels, longer staffing seasons for seasonal employees, and easier processes for interagency hiring and staff sharing for projects.

Future management strategies

To improve on the current situation and address anticipated challenges associated with climate change, interviewees suggested some changes in fire management policy and approaches going forward. Interviewees explained that coalescing interagency policy in a few areas to prevent policy gaps, conflicts, or redundancies could improve the efficiency of the governance system. Interviewees emphasized two primary types of policy incongruence in the governance system, including remote cabin protection policy and the agency certification and permitting processes. Protection policy for remote cabins is not uniform across jurisdictional units. In addition, when the jurisdictional agencies do not have cabin protection policies (e.g. BLM), the protection agencies have their own policies on whether they should protect a remote structure. One interviewee explained cabin protection policy:

> "The issue with cabins, and it's constantly an issue up here, is whether or not a cabin is going to receive protection or not. … Each agency has a cabin protection policy, and not all the agencies are aligned with their cabin protection policies. Each agency is a little bit different. … Regardless, if it's inhabited, and even if it's in a no-protect area, [the protection agency] typically will take action on that. If it's not inhabited, and it's not in an area that receives protection, then [the protection agency] typically [doesn't] take action. … I mean, it gets to be pretty expensive, pretty fast if you protect cabins. I understand both sides of the coin. It's just, it's always going to be an issue for us."

The protection agency fire management officers are often reluctant to allow any structure to burn, but agency policy may dictate that they should not protect certain structures, such as an uninhabited trespass cabin.

The second area of policy incongruence is agency certification and permitting. Overlaps in administrative requirements create significant inefficiencies and delays in projects. For example, when agencies share air resources, they may not recognize each other's certification and safety inspections, and similar inspections may occur multiple times for a single use of an

aircraft. The agencies also do not recognize each other's personnel training certifications, such as ATV/UTV use training. As one interviewee mentioned,

> "I think one of the worst things is that we don't accept each other's training. That hamstrings us so much. … [A]s long as these policies are built for not for the intent but for the convenience and the risk management of something else other than intent, we're wasting time and energy and money."

Interviewees also discussed two broad ideas for changes in management approaches to address anticipated challenges associated with climate change, including broad changes in management options and increased use of fuel management. These two ideas formed the basis for our future management alternatives with which we will modify our fire regime projections outputs using the ALFRESCO model. We talked with many interviewees about the possibility of broad management option changes in response to either higher risk or limited resources. These interviewees generally explained that the expansion of critical, full, and modified management option designations to avoid risk is much more likely than their reduction to avoid expense. On the other hand, interviewees also explained that expanding management option buffers around communities to reduce hazard to those communities during increasingly frequent times of high fire danger[12] is much more likely than designating wide swaths of forest under the full or modified management option to protect carbon sinks and avoid the occurrence of unusually large and devastating fires. Many interviewees expressed concern that excessive suppression would lead to fuel buildup and exacerbate future fire severity.

An additional fire management approach that interviewees discussed was an increased use of large-scale, cross-jurisdictional fuel breaks to address increased fire activity anticipated with climate change. These would facilitate potential suppression around communities and allow

[12] See: Flannigan et al. (2016)

some natural burning relatively closer to communities. While fuel reduction treatments are prohibitively expensive around many of the more remote sites and communities in Alaska, many interviewees said that the creation of fuel breaks around road-accessible communities and in more densely populated areas would make future suppression operations easier. Many interviewees cited recent successes of large-scale, cross-jurisdictional fuel breaks created by the Kenai All Lands/All Hands group on the Kenai Peninsula as evidence to support greater funding and collaboration for fuel breaks.

A few interviewees also explained the perceived benefits of increasing prescribed fire application in the future to accomplish both fuel reduction and habitat enhancement. As one interviewee said,

> "I see potential because habitat enhancement, prescribed fires, these two things can be paired with wildland fire mitigation for communities. We've got a lot of tiny communities or little groups of parcels that have structures on them that would otherwise have to be protected, so if we work with those allotments or other private landowners to protect them and then use prescribed fire near them, then prescribed fires will eventually add that fire protection on a larger scale. I think there is great potential to expand the use of fire."

One interviewee suggested that fuel management should be funded through the resource management budgets in the jurisdictional agencies in addition to through the protection agency budgets, because fuel management is currently underfunded through the protection agency budgets. Interviewees explained that while protection agencies possess the expertise to execute fuel treatments, jurisdictional agencies set landscape goals supported by specific fire-related outcomes. Many interviewees cautioned that although changing the agencies' approach toward fuel management in Alaska has potential benefits to many values, it must be balanced with the large expense that it may entail.

Discussion and Key Issues to Address

The Alaska wildland fire governance system's interagency arrangements favor adaptability and responsiveness to changing circumstances, including current resource limitations, but transformations in fire regimes may cause unsustainable capacity failures that would necessitate changes in fire governance. These could include changes in the values and priorities for management, interagency structure, or internal or external policy. To prepare for possible needed changes, the agencies will benefit from continuing to utilize their adaptive mechanisms, such as regular interagency communications, annual interagency meetings, and collaborative arrangements to review and improve the policies, structure, and management goals that are not working or may not work in the future. The agencies must continually maintain good relationships within the system and with the public and use the best equipment and science available to be able to respond to the challenges of a constantly changing environment.

We have identified four broad policy areas to address going forward based on the issues consistently discussed by interviewees:

1) Budgeting and funding. Funding already limits the protection agencies' ability to meet all their protection obligations. Interviewees stated that the tendency for legislatures to prefer to allocate emergency supplemental funding, rather than increase annual budgets, makes it difficult for them to plan and prepare resources effectively. Interviewees noted, however, that Alaska's wide swings in fire activity from year to year make it difficult to avoid either over-allocation or under-allocation on a rolling average. Some suggested that a separate USDOI funding prioritization model needs to be tailored to Alaska, rather than following that of the conterminous United States, because of the differences in values and suppression tactics between the two regions. Interviewees consistently mentioned limited funding as an issue for staffing,

training, preparedness, fuel management, and suppression. As fire extent and severity is expected to increase,[13] this problem will only become exacerbated. Managers either need more money or a review of value prioritization, because increasingly they may not be able to meet all their protection obligations. Additional exploration of how to improve upon current budgeting strategies is also warranted.

2) Addressing staffing challenges. Interviewees discussed several capacity challenges resulting from lack of staff and lack of expertise among managers. Some of the primary challenges mentioned by interviewees were needing more recruits, needing to hire staff for a period that matches the lengthening fire season, needing easier interagency hiring processes to share staff among agencies, and needing more localized discretion over staffing regulations to tailor capacity to expected needs.

3) Protection of remote sites and caribou habitat. Interviewees mentioned that some values generate controversy due to the high cost of protection. These are most often sites under the full or modified protection option that may receive lower priority for protection during large fire years when resources are limited. A few of the more controversial values listed by interviewees include remote uninhabited sites, such as cabins or Native allotments, and large areas of land, such as caribou winter range. At the same time, interviewees indicated the significant natural resource and subsistence use value of protecting cabins, Native allotments, and caribou habitat. This issue may benefit from some additional dialogue.

4) Climate change adaptation and mitigation. Interviewees discussed the possible need for broad changes in fire management approaches in the future to adapt the system to the challenges posed by climate change, including broader use of the full and critical management

[13] See: Flannigan et al. (2016); Rupp et al. (2016)

option designation to diminish risk and increased use of fuel breaks to facilitate suppression and natural burning under scenarios of increased fire activity. Interviewees also described increasing concern among the fire management community regarding mitigation of greenhouse gas emissions caused by wildland fire. For example, ANCSA Corporations have recently begun asking the agencies to protect some areas of forest as greenhouse gas emissions offset credits. Interviewees mentioned that staff within the agencies have begun to discuss the possibility of protecting permafrost as a carbon sink. Despite the benefits of emissions mitigation, interviewees explained that protecting timber and permafrost from fire would require significant risk monitoring efforts to determine which areas must be protected in full at any given time and significant expenditure for remote suppression operations. Considering the expected effects of climate change and the magnitude of Alaska's timber and permafrost carbon sinks, agencies have an opportunity to discuss critical climate change adaptation and mitigation measures in fire management.

CHAPTER 3: *ADAPTATION TO CLIMATE CHANGE IN THE ALASKA WILDLAND FIRE MANAGEMENT SYSTEM*

Introduction

Fire management describes the set of activities that intentionally modifies wildland fire likelihood, behavior, and risk to human values (USDOI BIA et al. 2016). Climate change and growing human populations are causing significant challenges for fire managers as fire activity increases and the number of values at risk expands (Adams 2013; Schoennagel et al. 2017). As the climate warms, fire regimes will likely shift in ecosystems across the world (Liu et al. 2010; Moritz et al. 2012; Flannigan et al. 2013). Climatic changes will affect the frequency of lightning ignitions, extreme fire weather, and large-scale oceanic and atmospheric patterns that control long-term trends in fire activity (Beverly et al. 2011; Romps et al. 2014; Freeborn et al. 2016). Far northern latitudes are experiencing particularly rapid rising average temperatures, and models project continued trends of increasing fire activity across the circumpolar boreal region during the 21st century (Flannigan et al. 2009; De Groot et al. 2013). These trends will magnify current fire management challenges and may present new challenges going forward.

Alaska is facing many of these same changes in fire regimes and a need for adaptation in fire management approaches. Alaska's sparse and diverse communities are vulnerable to the rapid climatic changes occurring in the region due to their reliance on natural resources for subsistence use (Nelson et al. 2008; Kofinas et al. 2010). Increases in statewide fire activity over the past few decades and future fire projections have accentuated the need for climate change adaptation in these communities (Kasischke et al. 2010; Knapp and Trainor 2015). In response to these widely recognized challenges, prior studies have examined climate change vulnerabilities in Alaskan communities and touched on potential adaptation approaches for fire management at

the community and statewide scale (Chapin et al. 2008; Trainor et al. 2009). Despite this long-standing recognition of climate change adaptation needs, more recent research has highlighted the continued anticipation of severe future capacity limitations for fire management agencies in Alaska (Melvin et al. 2017). Our research builds on these prior studies by directly exploring climate change adaptation from the perspective of fire managers in Alaska. We present here manager perceptions of statewide management priorities and pathways toward achieving needed changes in management approaches.

Background: Effects of Climate Change on Fire and Valued Resources

The occurrence of fire in Alaska is closely tied to climatic variables (Duffy et al. 2005). Climate, meaning long-term patterns in temperature and precipitation, controls several facets of fire activity, including fuel availability, ignition probability, and fire behavior (Freeborn et al. 2016). In the North American boreal forest, the likelihood of short-term hot, dry weather events that drive fire ignition and spread is dependent on long-term climatic patterns (Wang et al. 2015). In Alaska specifically, the occurrence of two extraordinarily large fire years in 2004 and 2005 and observed increases average fire frequency and area burned has generated interest in the linkages between future climate change and fire activity in the state (Kasischke et al. 2010; Kelly et al. 2013). Temperature is the strongest determinant of fire occurrence in Alaska, and increases in fire frequency will occur as climate change exceeds certain temperature thresholds for fire activity (Young et al. 2017). Warming average temperatures will increase the average dryness of fuels in the boreal ecosystem regardless of changes in precipitation, causing a heightened probability of large fire events (Flannigan et al. 2016). Climate projections for Alaska predict increases in statewide average annual fire frequency, area burned, and fire season length during

the first half of the 21st century (Mann et al. 2012; Rupp et al. 2016). Models project particularly large increases in fire activity in the tundra regions of Alaska due to warming temperatures and drying fuels (French et al. 2015; Hu et al. 2015). These fire regime projections have caused anticipation of exceedance of fire management capacity in the state and a need for adaptation (Chapin et al. 2008; Melvin et al. 2017).

In association with observed and anticipated increases in fire activity in Alaska, researchers have identified several impacts to valued natural resources. Increases in area burned have caused shifts in dominant vegetation in the boreal and tundra regions toward more early-seral vegetation cover, with a decline in age class diversity across the landscape (Mann et al. 2012). In tundra regions, fires cause transitions from graminoid to shrub tundra (Racine et al. 2004; Rupp et al. 2016). In the boreal forest, higher fire severities due to deeper burning in peat soils may facilitate widespread shifts to long-term dominance by deciduous species (*Populus* spp. and *Betula* spp.), rather than the historically dominant black spruce (*Picea mariana* [Mill.] Britton, Sterns, and Poggenb.) (Johnstone et al. 2010; Beck et al. 2011). Warming climates and changing fire regimes also have the potential to cause state shifts across the boreal region from forest to grassland and from tundra to forest due to changing regeneration dynamics and shifting climate envelopes (Scheffer et al. 2012; Alexander and Mack 2017). Post-fire vegetation age classes are associated with different habitat types for subsistence use by rural Alaskan communities (Nelson et al. 2008). Caribou (*Rangifer tarandus* [Linnaeus, 1758]) and moose (*Alces alces* [Linnaeus, 1758]) are two examples of primary subsistence mammals that are affected differently by fire. Caribou tend to occupy older graminoid tundra and black spruce stands that have not experienced fire during the last half-century where they can forage for slow-growing reindeer lichens (*Cladonia* spp.) (Jandt et al. 2008; Joly et al. 2010). Moose, on the

other hand, tend to browse young deciduous stands approximately 10-30 years post-fire (Kofinas et al. 2010; Joly et al. 2012). Fire activity and climate change may also cause a decline in growth and regeneration of white spruce (*Picea glauca* [Moench] Voss), which serves as the primary timber species for both commercial and subsistence use (Wurtz and Gasbarro 1996; Soja et al. 2007; Morimoto et al. 2017). A final object of significant attention in the literature has been the potential for the release of soil and biomass carbon sinks into the atmosphere during and after fire, especially in areas underlain by permafrost (Abbott et al. 2016; Pastick et al. 2017). This carbon release may cause a substantial positive feedback to the global atmospheric greenhouse gas effect (Schuur et al. 2008; Mack et al. 2011). These effects of changing fire regimes on natural resources and carbon sinks will have a strong influence on fire management in Alaska.

Literature: Adaptation and the Alaska Fire Management System

Climate change adaptation in Alaska will require recognition of the complex ecological and social relationships in the state. Fire management constitutes an interface between linked ecological and social systems (Spies et al. 2014; Steelman 2016). In an ecological context, adaptation refers to the amelioration of negative effects of climate change on human systems via anticipatory management actions, ranging from the creation of barriers to avoid change to facilitated transitions (Millar et al. 2007; IPCC 2014). An adaptation outcome can target changes in the environment or changes in human uses of the environment (Gunderson 2000). The design of adaptation mechanisms to achieve these outcomes depends on specific desired conditions within individual management contexts, meaning outcomes for the ecosystem are linked closely to social variables in a governance system (DeRose and Long 2014). Components of the governance system, including the organizational structures, actor networks, and institutions

involved in collective decision making regarding an ecosystem, are additionally adaptable in response to external stressors such as climate change (Folke et al. 2005; Chaffin et al. 2014). Decision making in the design of adaptation mechanisms follows adaptation pathways, meaning the adaptive capacity in a system depends on prior decisions and current decisions shape future adaptability (Wise et al. 2014). Climate change adaptation in fire management in Alaska is tied closely to the structure and history of Alaska's fire management and governance systems.

The fire management organizational network in Alaska consists of several state and federal agencies, which have come together in a unique interagency structure to more efficiently manage fire across the sparsely populated state. State and federal land management agencies and Alaska Native Claims Settlement Act (ANCSA) Native Corporations, collectively known as "jurisdictional agencies," set management objectives and determine values to protect. Three "protection agencies" execute fire suppression activities for the jurisdictional agencies. The U.S. Department of the Interior Bureau of Land Management (BLM) Alaska Fire Service (AFS) fights fire north of the Alaska Range across jurisdictions; the Alaska Department of Natural Resources Division of Forestry (DOF) fights fire south of the Alaska Range across jurisdictions, excluding on U.S. Forest Service (USFS) land; and USFS fights fire on the Chugach and Tongass National Forests (AWFCG 2018). This arrangement allows the protection agencies to efficiently suppress large-scale fires that often burn across jurisdictional boundaries (Todd and Jewkes 2006).

Under this system, the agencies designed a four-tiered statewide planning protocol for communication of initial attack direction from the jurisdictional agencies to the protection agencies. The four management options, from highest to lowest priority for resource allocation, are: "critical," for communities located at the interface with lands at risk of wildland fire (i.e. the

"wildland-urban interface"), inhabited property, critical infrastructure, and National Historic Landmarks; "full," for cultural sites, recreation areas, remote structures, and high-value natural resources; "modified," for lower-priority natural resources and as a buffer around "full" and "critical" areas; and "limited," for large-scale landscapes where the jurisdictional agencies prioritize the maintenance of ecosystem health and natural ecological processes. The default response for ignitions in an area designated "critical" or "full" is immediate deployment of suppression resources, though circumstances may warrant manager discretion regarding management approaches to fires in "full" areas, especially when suppression capacity is low. Under the "limited" option, the agencies generally let fires burn until they threaten an area under a higher management option priority (AWFCG 2018). Historically, the use of the "limited" option has allowed the fire management agencies to maintain natural disturbance processes across the majority of Alaska (Todd and Jewkes 2006). Managers treat lands under the "modified" option similarly to those in "full" until a predetermined date during the fire season when managers expect fire activity to die down, at which point they begin to treat these lands similarly to those in "limited" (AWFCG 2018).

Fire managers in Alaska use a specific set of fire management tools and approaches to meet objectives. Fire management tools in Alaska include: the prevention of human ignitions; the suppression of fires (including both direct attempts to extinguish a fire or change a fire's direction of spread and the protection of points or lines on the landscape [USDOI BIA et al. 2016]); fuel reduction, prescribed fire, and "fire use," meaning allowing lightning-ignited fires to burn for ecological health benefits (Seielstad 2015); post-fire restoration, including erosion prevention and enhanced regeneration; and the planning, training, public outreach, and administrative activities associated with each of these (USDOI BIA et al. 2016). Fire managers

in Alaska use each of these tools to achieve specific management goals in accordance with federal and state law and statewide interagency policy. Management objectives delineated in statewide fire management policy include the protection of human life, property, natural resources, and cultural values, the maintenance of ecosystem health, and the cost-effective use of fire management resources (AWFCG 2018).

Despite this diversity of objectives, fire management in Alaska has been largely single-faceted. The protection agencies have historically focused on suppression to protect the widely dispersed values on the landscape; for remote sites, the agencies have generally employed point protection, allowing the land in "limited" to burn around those points, while in areas under the "full" and "critical" management options, the protection agencies have generally immediately extinguished fires (Todd and Jewkes 2006; Trainor et al. 2009). This approach has led to a reduction in area burned in "full" and "critical" areas (Calef et al. 2015). Climate change projections, however, anticipate that the number of days that support fire intensities that exceed suppression capabilities will become more frequent in the boreal forest, rendering suppression infeasible regardless of the availability of resources to fight fire (Wotton et al. 2017). In addition, increases in fire activity will cause disproportionately large increases in suppression resource needs, leading to dire predictions for future management capacity (Podur and Wotton 2010; Melvin et al. 2017).

Suppression-based fire management approaches in Alaska may need to shift as the climate warms. In response to climate change, much of the fire management literature has focused on community adaptation and forest structure restoration in dry, frequent-fire ecosystems where suppression since Euro-American settlement has caused significant fuel buildup in the western contiguous United States (e.g. North et al. 2012; Calkin et al. 2014;

Schoennagel et al. 2017). In frequent-fire ecosystems, prescribed fire and fuel management typically reduce risk to values by mitigating future fire severity in targeted areas (Stephens et al. 2014). Understandings of adaptation needs are more limited in ecosystems such as Alaska's boreal forest and Arctic tundra, which are dependent on the occurrence of infrequent, high-severity fire (Kasischke et al. 2002; Allen and Sorbel 2008), and where state transition is the primary concern under future climates (Stephens et al. 2013; Johnstone et al. 2016).

The literature has evaluated several options for changes to management approaches in Alaska and in boreal ecosystems generally. As in the dry western United States, creating breaks in the most flammable fuel types can aid suppression and reduce risk to values, and use of fuel management by the fire management agencies in the boreal forest has grown (Melvin et al. 2018). Fuel treatments and prescribed fire can replace highly flammable old-growth spruce stands with less flammable younger spruce stands or deciduous cover types (Girardin and Terrier 2015; Beverly 2017). To support forest health in boreal regions, fuel management can replicate secondary disturbance to maintain resilience through landscape heterogeneity (Girardin et al. 2013). Fuel reduction treatments, however, do not effectively change area burned or reduce the occurrence of higher intensity fires at a large scale (Cary et al. 2017), and they do not typically reduce carbon loss in stands (Campbell et al. 2011). In rare intensive management scenarios, to prevent loss of spruce cover, especially valuable white spruce stands, managers may choose to enhance regeneration after fire or harvest (LeGoff et al. 2005; Allaby et al. 2017; Morimoto et al. 2017). In general, the protection agencies will likely need to shift the management focus away from suppression to a diversity of management tools that directly address objectives such as the reduction of risk to values and landscape resilience (North et al. 2012; Calkin et al. 2015). Existing evaluations of the need for management adaptation in Alaska have suggested the need

for changes to the management options plan, risk mitigation on private properties, and community organization and cross-boundary collaboration for increased fuel management (Chapin et al. 2008; Trainor et al. 2009).

Research Objectives and Methods

In this study, we explored the issue of climate change adaptation in fire management in Alaska using a qualitative analysis of manager and stakeholder perspectives on two aspects of the fire management system: (1) statewide management priorities under climate change and associated adaptation in management approaches; and (2) systematic challenges and pathways to adapting approaches. We distinguish between adapting approaches, meaning management tools such as suppression or fuel management, and adapting components of the fire management system, such as manager networks and culture. While existing evaluations of the need for adaptation in fire management in Alaska touch on potential adaptations in approaches, our research more deeply examines these approaches at a statewide level and adds an exploration of manager perspectives on needed institutional and organizational changes. Our statewide perspective captures the primary geographic bounds on the network of protection and jurisdictional agencies, in which most fire management decision making occurs.

We collected data using semi-structured interviews with members of the Alaska fire management community. These interviews were components of a broader iterative knowledge building process, which involved several steps of presentations, collaboration, and feedback between our research team and participants. Our qualitative methods allowed us insight via local practitioner expertise into the uncertain future of a management system nested in a complex historical and social-ecological context (Arts et al. 2013). We sampled for interviews using

Alaska Fire Science Consortium lists of fire and land managers, firefighters, scientists, and stakeholders from the following organizations (we omit some specifics to maintain participant confidentiality): Alaska Department of Fish and Game; Alaska Department of Natural Resources Division of Forestry; Alaska Native organizations; borough emergency services departments; U.S. Department of Agriculture Forest Service; U.S. Department of Defense military bases, fire operations sections; U.S. Department of the Interior (USDOI) Bureau of Indian Affairs; USDOI Bureau of Land Management (BLM); BLM Alaska Fire Service; USDOI Fish and Wildlife Service; and USDOI National Park Service. We sampled purposively from participants we believed would best be able to contribute to our research objectives, but sought representation from all organizations involved in decision making in fire management in Alaska. We contacted additional participants using recommendations from prior interviewees, and we recruited participants until saturation, when new interviewees could no longer give new information (Patton 2015). We conducted 41 total interviews.

Interviews lasted one hour and consisted of open-ended questions and discussions to allow interviewees to express their own perspectives to the extent possible (Yin 2016). We asked interviewees about their current priorities and challenges and possible future approaches. We analyzed interview data using coding and memoing techniques modified from grounded theory to organize and describe patterns in the data (Corbin and Strauss 2015). We analyzed the data based on pre-determined themes connected to our research objectives (Braun and Clarke 2006). As part of the knowledge-building process between the research team and participants, we have produced a report and policy briefing for presentation to and feedback from managers, stakeholders, and policymakers to further develop and refine our analysis (Rutherford and

Schultz 2017; Rutherford et al. 2018). Throughout the research process, we have adhered to protocols developed with the approval of our organization's Institutional Review Board.

Results

Current priorities and associated approaches

During interviews, several current priorities surfaced frequently in relation to the expectation of elevated fire activity under climate change. These focus areas are: improving community protection and risk reduction in the wildland-urban interface; exploring ways to improve policy or management tools for the protection of remote or undeveloped Native allotments and remote private cabins; and facilitating subsistence use opportunities, primarily for moose and caribou habitat and spruce timber or biomass use (see Table 3). The frequency of discussion of these issues during our data collection indicated that these have become a common focus among the fire management community. In addition to the primary focus areas, some participants also mentioned the potential use of fire management to protect ecosystem carbon sinks in permafrost or in timber (see Table 3). This would mitigate the positive feedback between increased fire activity and climate change. With each of these current and potential priorities, participants discussed associated management approaches and needed changes in those approaches.

Table 3: Current key priorities for Alaska fire management identified by participants.

Management priority	**Possible approaches going forward**
Risk reduction and protection of communities in the wildland-urban interface	Expansion of "critical" and "full" protection buffers around communities; creation of large-scale breaks in flammable fuels around communities to aid suppression; community preparedness, including defensible space
Protection of remote values, including Native allotments and permitted cabins	Identification of all remote sites in the interagency Known Sites Database; efficient point protection and risk

	acceptance commensurate with the value of the protected site
Ensuring the availability of subsistence values, including moose and caribou habitat and white spruce stands	Prescribed fire and fire use to promote early post-fire age classes near communities; initial attack suppression to protect known caribou habitat and white spruce stands near communities
Carbon sequestration in ecosystem carbon sinks, including permafrost and timber (*potential priority*)	Initial attack suppression of fires in and around identified high-priority ecosystem carbon sinks

Participants identified continued suppression, creation of large-scale fuel breaks, and increased preparedness measures as likely approaches to ensure protection of and risk reduction for communities in the wildland-urban interface. Where managers anticipate an increase in fire danger and the likelihood of large fires moving quickly across the landscape due to continuity, warming, and drying of fuels, many participants saw the need to expand "critical" and "full" initial attack suppression areas around communities. In addition, many participants emphasized the benefits of large-scale fuel breaks near communities to aid suppression. Participants explained that the agencies would need to critically examine the placement of fuel reduction treatments and make use of existing fuel breaks as much as possible during suppression operations. To support this idea, a few interviewees told anecdotes of recent successful fuel breaks on the Kenai Peninsula. Participants also frequently discussed the need for community preparedness through the creation of defensible space and the use of nonflammable building materials. Community protection primarily involves adapting the extent of current approaches to the anticipated extent of fire, with a shift in emphasis toward fuel management, rather than continued reliance on suppression.

To protect remote points on the landscape including Native allotments and private cabins, participants suggested the need for both improved planning and more efficient point protection

tactics. In the planning process, many interviewees indicated that the interagency database of small points on the landscape, called the Known Sites Database, is not complete, making it difficult for the protection agencies to know what action to take on remote fires. In addition, some participants acknowledged that point protection is often not efficient due to aversion to risk of property damage among fire management officers. Interviewees said that some managers place suppression resources on point protection for long periods of time, when quick burnout methods could be more efficient and more commensurate with the value of the protected point (for selected interviewee quotations, see Figure 1). Adapting approaches for point protection primarily involves improved efficiency.

"We're talking more about [accepting] risk in the kinds of things that you have available and are paying for, for given danger level. If you're at a moderate … danger level, some of our stations will staff much differently than another station that's at the same danger level. That's usually based on personal experience in the managers on the station; that gets down to personalities, and those are the things that are hard to manage. It's not cut and dry, you do this or you do that. That's the level of risk I'm trying to quantify. … [Many managers] would argue [that] if we have an air tanker or a load of jumpers, an agency crew, and extra [Emergency Firefighters] in our back pocket, we'll be more successful in our initial attack. That's where that experience piece comes in. Maybe it will, maybe it won't."

Figure 1: Interviewee perspectives on risk acceptance and operational efficiency.

Participants indicated that the maintenance of subsistence use opportunities will require fire use and suppression to support a diversity of age classes and forest cover types on the landscape within the hunting and timber harvest ranges of rural Alaskan communities. Interviewees primarily discussed the protection of moose and caribou hunting opportunities. Participants from state and federal wildlife management agencies said that they would like to see an increase in fire on the landscape to promote early seral moose habitats near communities, either through broadcast burning or natural fire use. To reconcile the allowance of fire on the landscape with the goal of community risk reduction, interviewees explained the need for fuel

breaks around communities to increase decision space for fire management officers. To enhance moose habitat and age-class diversity near communities, managers would need to accept the risk inherent in allowing fire on the landscape. For caribou, on the other hand, many participants indicated significant worry about declining abundance of critical reindeer lichens due to widespread burning. Participants said that some jurisdictional agency units have moved areas of tundra and old-growth black spruce into the "modified" management option near communities traditionally dependent on caribou hunting. This action has designated large swaths of land as priorities for initial attack for much of the fire season. The issue of subsistence hunting has resulted in adaptations toward both more suppression and more fire use, depending on locally specific needs for age class diversity across the landscape.

The final climate change issue identified by participants was the protection of carbon sinks, which invariably involved protection of large areas of tundra or forest via initial attack suppression. Participants said that this is not currently an actionable priority for the agencies, but that recent research on carbon emissions from permafrost and the movement by some ANCSA Native Corporations to sell timber as carbon offset credits in the California carbon market has generated discussion among managers regarding the potential need to mitigate greenhouse gas emissions from ecosystem carbon sinks (see Figure 2). Participants explained that the needed adaptation in management approaches would be a significant suppression effort in tandem with constant monitoring of location of and risk to permafrost.

"If we decided carbon sequestration was really important [and] we just needed to not let any fires burn up here, we could put the whole state into 'full' protection. And, what would that change about how we manage fire up here? I'm guessing it wouldn't change as much as you would expect because it's not likely we're going to get a ton more resources or money to put all those fires out. So, we're still going to have to prioritize … and we're still going prioritize stuff that's threatening life, and communities, and property, and that type of stuff."

Figure 2: Interviewee perspectives on managing fire to protect ecosystem carbon sinks.

Challenges and needed adaptations

Addressing current priorities by adapting management approaches entails several challenges at the statewide organizational and institutional level. According to participants, the primary barrier to increasing suppression and fuel management operations and enhancing planning outcomes is limited financial and staff capacity (see Figure 3a and 3b). Interviewees said that suppression capacity has been especially strained during recent large fire years, and that lengthening fire years across the western and northern regions of North America will reduce the protection agencies' ability to rely on interstate or international resource sharing during large fire years. Participants explained that adding priorities to interagency policy such as the protection of carbon sinks might be desirable, but would be operationally infeasible due to current suppression capacity limitations. Participants noted staffing challenges stemming from the consolidation of fire management offices, the loss of expertise with retirements, a lack of new recruits to fill positions, and the large and growing amount of training requirements, which has made it difficult for the agencies to support the Emergency Firefighter (EFF) Program (see Figure 3b). The Alaska Fire Service (AFS) has had additional problems with the application of national-level Bureau of Land Management (BLM) budgeting models to the Alaska system due to differences in management approaches and organizational structure between Alaska and BLM units in the contiguous United States. At a local level, Alaskan communities have encountered difficulty winning fuel management grants from federal sources, such as the National Cohesive Wildland Fire Management Strategy, limiting their ability to carry out risk reduction treatments around communities.

a. "We don't have control over our budgets, we don't have control over what the fire season is going to do. We don't have control over whether, 'If we're busy, is someone else going to be busy?' What you ultimately have to do is prioritize the resources that you have and try to

direct them toward the most important incidents or issues first. That's something you see in larger fire seasons up here is that resources become thin and incidents are prioritized so you can figure out where to allocate limited resources, because it's not possible to give every incident what it may need or what it may want."

b. "There's been reductions in overall workforce and an increase in the number of technical positions and whatnot. We've made things more complex, in other words. And so, you need more people to do the same job and with reduced numbers of people, it's making it more and more difficult to attain what our intent is and what we said we would do."

Figure 3: Interviewee perspectives on capacity challenges.

While resource capacity is strongly limiting, participants identified several key points in the fire management system at which fire managers can enhance their capacity regardless of budgets or staffing. Broadly, these levers for change include collaboration and community outreach, the integration of land and fire management within and across agencies to improve planning outcomes, and the consideration of current science in management decision making. The first of these, collaboration and community outreach, is imperative to achieving large-scale fuel breaks and community preparedness to reduce risk. Formal collaboration across organizations at regional and local levels allows resource sharing to support fuel management. Many participants cited successes by the Kenai Peninsula All Lands/All Hands collaborative group as an exemplary instance of cross-boundary pooling of resources to implement large-scale fuel breaks around communities. Several fuel breaks on the Kenai Peninsula have proven successful in reducing the intensity of advancing fires during recent incidents. The collaborative group has also engaged in public outreach and education regarding defensible space and the fireproofing of structures. A few participants said that the agencies are promoting similar collaborative efforts in other areas of the state, but that such arrangements are only possible in the most densely populated regions where organizations and communities face common landscape and fire management challenges. More remote communities must continue to rely on

suppression from the agencies or create a self-sustaining need and capacity for fuel management by using biomass generators.

The second major challenge facing the agencies is improving planning outcomes by integrating land and fire management decision making in the planning process. Participants emphasized that the fundamental organizational division between the jurisdictional and protection agencies makes it difficult for the protection agencies to meet land management goals and identify values during extended attack situations and especially during large fire years (see Figure 4a). Participants said that this divide makes detailed, pre-loaded information in the Wildland Fire Decision Support System (WFDSS) and good working relationships among fire management officers critical in Alaska. Many participants also identified a feeling of compartmentalization of land and fire management responsibilities between agency administrators, resource advisory staff, and fire management officers within the jurisdictional agencies (see Figure 4b). This divide inhibits the targeting of fire management approaches for resource benefit. With increasing fire activity across the landscape, participants said that jurisdictional agency administrators need to clarify for fire managers desired ecosystem conditions that might be threatened under future fire regimes. This will allow the agencies to move beyond the status quo, in which the fire management agencies simply protect identified structures and high value stands and allow the rest of the landscape to burn. At the same time, some participants mentioned that better communication between jurisdictional agency administrators and fire managers might help move protection agency culture toward a greater risk acceptance regarding burning near valued resources. This integration of land and fire management would require a cultural shift within both the resource program managers and the fire managers (see Figure 4c). An alternative change suggested by a few interviewees entails the

shift of prescribed fire and restoration treatment responsibilities from the protection agencies to the jurisdictional agencies to combine the resource benefit aspects of fire management. This would leave the protection agencies to remain focused on suppression and risk reduction. This strategy, according to participants, would obviate the planning challenges associated with the divide between the protection and jurisdictional agencies. Under either strategy, participants emphasized that greater integration of land and fire management will help agencies in the fire management system better meet objectives by increasing ecosystem resilience to exogenous challenges.

a. "[The protection agency fire management officer], as that fire gets larger, [has] to make sure that they have continued to recognize that these additional jurisdictions have possible values that are threatened, and that can be difficult if you've got a lot of fire landscape, just keeping track of every one of them and making sure that all the jurisdictions are appropriately notified."

b. "It can be a bit of a challenge in regard to having staff available to support incident management teams. And then also in regard to having resource advisers … out on the ground to help support our fire suppression and fire management decisions. I think that that's something that we struggle with a bit, and … we need to be part of a more integrated team."

c. "The challenge is that … because suppression has been such a dominating part of the fire program [in Alaska], it's difficult to get [to the] management side of it, which is growing. We really did not have that [in Alaska] historically, so there really wasn't that type of interaction in just adjusting culturally to bring that aspect of the fire program into the mainstream of resource management and make it more integrated and not segregated. … And our challenge, and this is a management challenge, is to bring those more in tune together. In some [management areas] it's more successful than others. A lot of that is based on personalities, and perspectives, and culture."

Figure 4: Interviewee perspectives on the integration of land and fire management within and across agencies.

The use of fire science is a final area that participants identified as a method to successfully adapt management outcomes. Participants often indicated that managers currently integrate relevant research into management considerations whenever appropriate. Participants

said that the Alaska Fire Science Consortium (AFSC) facilitates communication of science needs from managers to researchers. AFSC then hosts meetings for researchers to present and discuss research findings with managers. Current discussions regarding caribou and moose habitat enhancement and the prevention of large-scale permafrost melt stemmed from attention to those issues within the scientific community after several large fire incidents in the 2000s. Interviewees also often said they are actively seeking information regarding the effectiveness of fuel breaks to be able to adapt them to changing conditions and community needs. The awareness of current science has allowed managers to understand both novel priorities and the appropriate approaches to those needs. Participants frequently referred to the need to adapt to a changing climate with a view toward adaptation in the fire management system (see Figure 5a and 5b). This attention to science has spurred discussions within the fire management community of their anticipated capacity limitations and future priorities, and the need to foster local collaboration and integrate land and fire management to improve climate change adaptation outcomes.

a. “[T]he effects of climate change are generally widely accepted [in Alaska], and much more broadly acknowledged than in some of the states where I've worked. I think it's definitely something that's taken very seriously here. We understand that our fire season is increasing. … If you look over the course of a number of years, the fire season is getting earlier, going later. We're getting bigger and very intense fires, so there's a lot of concern there.”

b. “We're always preparing and trying to do forecasting of what we need and what we need to be doing to do our jobs correctly, safely, and then also looking at ways to do it better. Trying to stay aware of innovation, new tools, tools that maybe fire [management] hasn't used before, but bringing them into fire [management] to increase our abilities to be responsive and do our jobs better. … [W]e have additional expertise to be able to look at being strategic and looking at innovation and having people available to test new tools, new ways of doing business and trying to stay current or in front of the power curve as far as fire suppression and fire management.”

Figure 5: Interviewee perspectives on the importance of science for climate change adaptation in fire management.

Discussion

Our study shows strong awareness in the fire management community of the challenges of climate change and the potential need for adaptation in fire management approaches. Fire managers anticipate an increase in fire activity and continually increasing suppression expenses. With these changes, managers recognize that the values that are hardest to protect currently, including the wildland-urban interface, remote sites, and large areas of wildlife habitat, are the values that will continue to be most difficult to protect in the future. Managers indicated that future management will need to adapt through changes in management tools, such as more efficient suppression tactics in point protection scenarios, increased fuel management to reduce risk to values and create age-class diversity in vegetation across the landscape, and improved planning processes to identify values. These changing approaches face capacity barriers, especially in the unique geography and organizational structure of Alaska. Communication of budget and staffing needs, community organization to obtain fuel management grants, and collaboration to find innovative ways for interagency resource sharing might help overcome capacity issues. Managers are also looking to refine the planning process through the integration of land and fire management considerations and the use of up-to-date fire science to better manage fire and understand desired conditions across rapidly changing landscapes.

Our study corroborates and extends prior research on the need for climate change adaptation in fire management in Alaska. In an assessment of the vulnerability of rural and urban Alaskan communities to climate change, Trainor et al. (2009) showed the need for novel approaches to risk reduction and planning in communities and the importance of continually updating the statewide management plan. Chapin et al. (2008) identified a need for increased local collaboration and opportunities for the use of biomass power generation in remote

communities to motivate risk reduction treatments. Like these studies, we heard from participants about the need for increased fuel management around communities, more involvement in the creation of defensible space by private landowners, and identification of values in the planning process. Our interviewees discussed the potential for biomass generators in remote towns to encourage the creation of fuel breaks. Our study adds to this list a description of the growing concern among managers regarding the protection of ecosystem carbon sinks. We also go beyond the identification of needed management outcomes by showing systemic challenges to adaptation and needed shifts in institutions and manager culture. We corroborate the finding of a need for local collaboration by Chapin et al. (2008), but additionally find that managers see immense benefits to resource sharing for cross-jurisdictional fuel breaks, as has occurred in the Kenai Peninsula All Lands/All Hands collaborative group. We also introduce the manager perception of the need for integration of land and fire management decision making in the face of increasing fire activity and the importance of the manager-researcher connection via the Alaska Fire Science Consortium. These are critical components of the adaptive capacity of the fire management system in Alaska. Other research has identified the need for use of ecological expertise on the ground during fire management operations (Noss et al. 2006), and the need for scientifically and socially informed targeting of fuel reduction treatments (Schoennagel et al. 2017). Alaska's fire management community will benefit from awareness across organizations of these adaptation needs.

Decision making for climate change adaptation

To achieve changes in the complex and uncertain Alaskan fire management context, fire managers will likely need to transform their decision-making space. Discussion regarding the

need to integrate land and fire management responsibilities within and across agencies indicates recognition among managers of the importance of decision-making context and the nesting of management actions within a broader organizational and institutional context (Wise et al. 2014). Collaboration and broad participation in the identification of both management priorities and management approaches will help managers to meet diverse objectives across the fire governance system. Adaptation in management now will allow the agencies to sustainably meet community protection, ecosystem service, and ecosystem health goals going forward.

Managers can shape the process of decision making and knowledge building in several ways. Forums for interagency information sharing and deliberation might benefit from the purposeful inclusion of researchers, agency administrators, and fire managers from both the jurisdictional and protection agencies to foster integration of land and fire management decision making. Within these forums, the use of tools such as structured analysis of uncertainty (Peterson et al. 2003), collaborative and interdisciplinary knowledge building (Salter et al. 2010), and formal decision-making processes (Marcot et al. 2012) could help the agencies move forward on issues that have commonly inhibited broader changes in management approaches, such as the protection of Native allotments. The tradeoffs and uncertainty associated with managing for the multitude of values have created a “wicked problem” in Alaska, in which managers often disagree about how to conceptualize and approach management issues (Chapin et al. 2008). The complex situation will likely require innovative and distributive approaches to funding, staffing, and decision-making responsibilities. Support for adaptation will also likely come from continued collaboration with the Alaska Fire Science Consortium and communication of policy needs to lawmakers. Research can provide support for the monitoring of ecosystems for changes that can signal exceedance of thresholds for management objectives, such as loss of caribou

habitat, spruce regeneration, or permafrost (Moritz et al. 2013). In general, a broadening of participation and responsibilities in fire management may augment the adaptability of the system.

Conclusion

In this study, we presented an analysis of pathways for future adaptation in Alaska fire management using perspectives from fire managers and stakeholders on current priorities and challenges and potential changes in approaches. We have situated our study in a statewide, interagency management context, recognizing the varying effects of history, norms, policy, and ecosystem dynamics at different geographic scales and levels of governance (Moseley and Charnley 2014; Williams 2017). Alaska's unique interagency structure and sparse, natural resource-dependent population shaped current management approaches and will strongly influence the climate change adaptation process. At the same time, the study of adaptation and mitigation in fire management can inform decision making in other ecological and social contexts in the United States, where managers are facing the combined challenges of a warming climate, expanding development into the wildland-urban interface, and rising costs of fire management resources (Calkin et al. 2015). Climatic changes are occurring more rapidly in high northern latitudes, serving as early cases for the processes of change in social-ecological systems that must eventually occur elsewhere (Brunner and Lynch 2010).

The interdependence between fire management approaches and research is evident in Alaska. Continued monitoring of changes in fire regimes and novel effects on values will be critical to support planning and adaptation in fire management. In addition, qualitative and

collaborative studies to examine issues and build an understanding of adaptation pathways will assist managers in decision making as they move toward an uncertain future.

CHAPTER 4: *ADAPTING WILDLAND FIRE GOVERNANCE TO CLIMATE CHANGE IN ALASKA*

Introduction

Global climatic changes are driving a need to reevaluate environmental governance structures (Cosens et al. 2014). Adaptive governance theory suggests opportunities for natural resource managers to support the resilience of linked ecological and social systems while facing uncertain futures and exogenous challenges (Dietz et al. 2003). Despite a burgeoning theoretical foundation, the adaptive governance literature lacks diverse empirical applications (Huitema et al. 2009; Chaffin et al. 2014; Arnold et al. 2017). In this study, we develop an empirical application of adaptive governance to the problem of climate change adaptation in fire management in Alaska. The adaptive governance literature addresses many of the challenges faced in wildland fire management but has rarely been applied as an analytical lens to fire governance (Djalante et al. 2011; but see Almstedt and Reed 2013, Spies et al. 2014, Abrams et al. 2015, Steelman 2016).

Alaska's ecological and social context provides a particularly valuable opportunity to explore adaptation in both fire governance specifically and environmental governance in the Arctic more broadly (Brunner and Lynch 2010). Rapid climatic changes at high northern latitudes have affected fire regimes across boreal and tundra ecosystems in Alaska (Kasischke and Turetsky 2006; Kasischke et al. 2010; Kelly et al. 2013). Climate change models forecast increases over the twenty-first century in statewide average fire size (Flannigan et al. 2016), fire frequency (Young et al. 2017), and annual area burned (Pastick et al. 2017). Research also projects longer fire seasons and an increase in the frequency of abnormally large fire years (Rupp et al. 2016; Pastick et al. 2017). Changes in fire regimes will likely produce shifts away from

historical ecosystem structures and a loss of associated ecosystems services, including transitions in dominant vegetation composition (Johnstone et al. 2010; Bret-Harte et al. 2013), declines in certain wildlife populations (Nelson et al. 2008; Joly et al. 2012), and large-scale permafrost melt (Mack et al. 2011; Zhang et al. 2015). These projected increases in fire activity will likely exacerbate the costs of fire management (Melvin et al. 2017). Alongside these challenges, Alaska's isolated and diverse communities are dependent on its natural resources and concerned about adapting to climate change (Kofinas et al. 2010; Knapp and Trainor 2015). A unique set of fire management organizations and institutions faces this complex ecological and social context (Chapin et al. 2008).

Adaptive Governance

Adaptive governance theory describes adaptation in environmental governance systems (Chaffin et al. 2014). We define environmental governance as the execution of collective decision making about the use or protection of a natural resource or ecosystem (Folke et al. 2005). In Alaska, the wildland fire governance system is the set of agents, including organizations and individual actors, and institutions, including laws, policies, rules, regulations, and norms, involved in collective decision making regarding fire management (Chaffin et al. 2014). Fire management refers to the set of activities that intentionally modify wildland fire likelihood, behavior, and risk (USDOI BIA et al. 2016).

Broadly, scholars of adaptive governance propose several features of governance systems that support adaptation in the face of complexity, uncertainty, and change. These features include collective learning and adaptive management, collective action, and long-term social memory (Folke et al. 2005; Olsson et al. 2007; Pahl-Wostl et al. 2007). Collective learning in a

governance system can result in the improvement of policies and practices to facilitate adaptation (Armitage et al. 2007; Pahl-Wostl 2009); it involves individual and group changes in values, beliefs, or actions based on experience (Reed et al. 2010; Heikkila and Gerlak 2013). Learning is also a component and product of adaptive management, which is a process of monitoring ecological conditions and management effects to generate knowledge in the face of rapid and uncertain ecological change (Folke et al. 2005; Williams 2011). Collective action describes self-organized actors working together to directly solve issues regarding the sustainable management of common resources (Ostrom 1990, 2009). Adaptation is more likely when affected actors understand and cooperatively participate in governance change (Huitema et al. 2009). Long-term social memory refers to accumulated experience among a group of actors, which enhances resilience through knowledge of prior challenges and responses (Davis and Reed 2013; Wilson 2015).

Adaptive governance scholars have identified multiple structural, legal, and social indicators of adaptive features (see Table 4). In adaptive governance systems, a networked organizational structure enhances learning, collective action, and social memory. In an effective adaptive network, authority is spread across multiple governing scales through nested, diverse, and redundant organizations that are strongly coordinated and collaborative and have a free flow of information (Olsson et al. 2004; Huitema et al. 2009; Koontz et al. 2015). Collaboration and the flow of information through such a network depend on connections both across and within organizations (Bodin and Crona 2009) and the presence of interorganizational institutions or groups that facilitate transfer of information among actors, known as “bridging organizations” (Crona and Parker 2012). Social capital, including leadership and managerial skill, also enhances the development and function of these adaptive organizational structures (Folke et al. 2005;

Olsson et al. 2007). A network with these characteristics is polycentric (Pahl-Wostl and Knieper 2014; Carlisle and Gruby 2017). In general, polycentric networks facilitate learning and increase adaptive capacity in a system (Tompkins and Adger 2004). Ideally, diverse, redundant organizations experiment with varied policies and governing tools toward the same goal, thereby engaging in several learning processes that collectively have a greater chance of success (Pahl-Wostl 2009; Carlisle and Gruby 2017).

Table 4: Organizational structure, legal and institutional design, and social dynamic supporting adaptive governance.

Adaptive governance characteristics	**Evidence in structures and behaviors**
Organizational structure	
· Network governance · Nesting · Scale fit (spatial) · Information flow	· Connections between state and non-state actors with varying purview · Venues for communication and collective learning across levels, scales, and types of actors · Bridging organizations between managers and researchers to connect assessment data to action · Structures and venues to consider problems at different spatial scales · Leadership and managerial skill · Opportunities for information sharing across actors and communities
Legal and institutional design	
· Scale fit (temporal) · Balanced flexibility and stability	· Monitoring and modeling of management and ecosystem response · Long-term investment in institutions · Investment in a diversity of management strategies across jurisdictions and actors · Authority nested in federal, state, and local governments · Formal devolution of some management and policymaking responsibility to regional and local actors
Social dynamic	
· Understanding of need to adapt · Willingness to adapt	· Mutual trust and legitimacy among actors with diverse values · Shared management priorities among actors and communities · Perceived legitimacy of governance structures and processes

Fit between governing institutions and ecological scales in a complex network is another critical aspect of adaptive governance (Chaffin et al. 2014). Local governance, when coupled with action at other levels, may enhance scale fit by diversifying the set of scales at which governance occurs (Cash and Moser 2000). In a multilevel system, the nesting of networks can support collaborative governance at local scales within the hierarchical structure of existing bureaucracies (Folke et al. 2007; Wyborn and Bixler 2013). State-run hierarchies can support democratic accountability, legitimacy, and stability in networked governance (Huitema et al. 2009; Morrison et al. 2017). At the same time, they must have the flexibility to ensure diversity and self-organization of local-level governance networks (Craig et al. 2017). Achieving collective action under top-down controls depends on the localization of formal rulemaking authority (Ostrom 2009). Policy design tools to support local collaborative governance in land management might include long-term investment, legally binding devolution of authority and responsibility, broad management guidelines rather than rigid targets, and mechanisms to ensure public participation (Garmestani and Benson 2013; DeCaro et al. 2017*b*). Ultimately, the success of local collective action also depends on social context, meaning actors within the system and the public must perceive adaptive processes as legitimate and recognize diverse values and the need for governance change (Olsson et al. 2008; DeCaro et al. 2017*a*).

Background: Alaska Wildland Fire Governance System

The organizations involved in fire governance in Alaska include local governments, Alaska Native organizations, and federal and state land and wildlife management agencies. Three specialized “protection agencies” are responsible for fire suppression on all public and private lands in Alaska. These agencies work in coordination with federal and state land managers and

Alaska Native organizations, collectively called “jurisdictional agencies” (see Figure 6). The protection agencies are the U.S. Bureau of Land Management (BLM) Alaska Fire Service (AFS), the U.S. Forest Service (USFS), and the Alaska Department of Natural Resources Division of Forestry (DOF). AFS manages fire across jurisdictions north of the Alaska Range, while DOF covers the southern regions of the state. USFS is responsible for fire management in the Chugach and Tongass National Forests. USFS and DOF additionally serve as jurisdictional agencies on USFS and private lands (see Figure 7; AWFCG 2018). The protection agencies are separate from the jurisdictional agencies because, in the 1960s and beyond, newly designated federal management units generally elected to use existing BLM fire management infrastructure (Hull and Leask 2000; Todd and Jewkes 2006). In addition, after statehood in 1959, the Alaska state government over time assumed suppression responsibility for southern regions from BLM (Todd and Jewkes 2006).

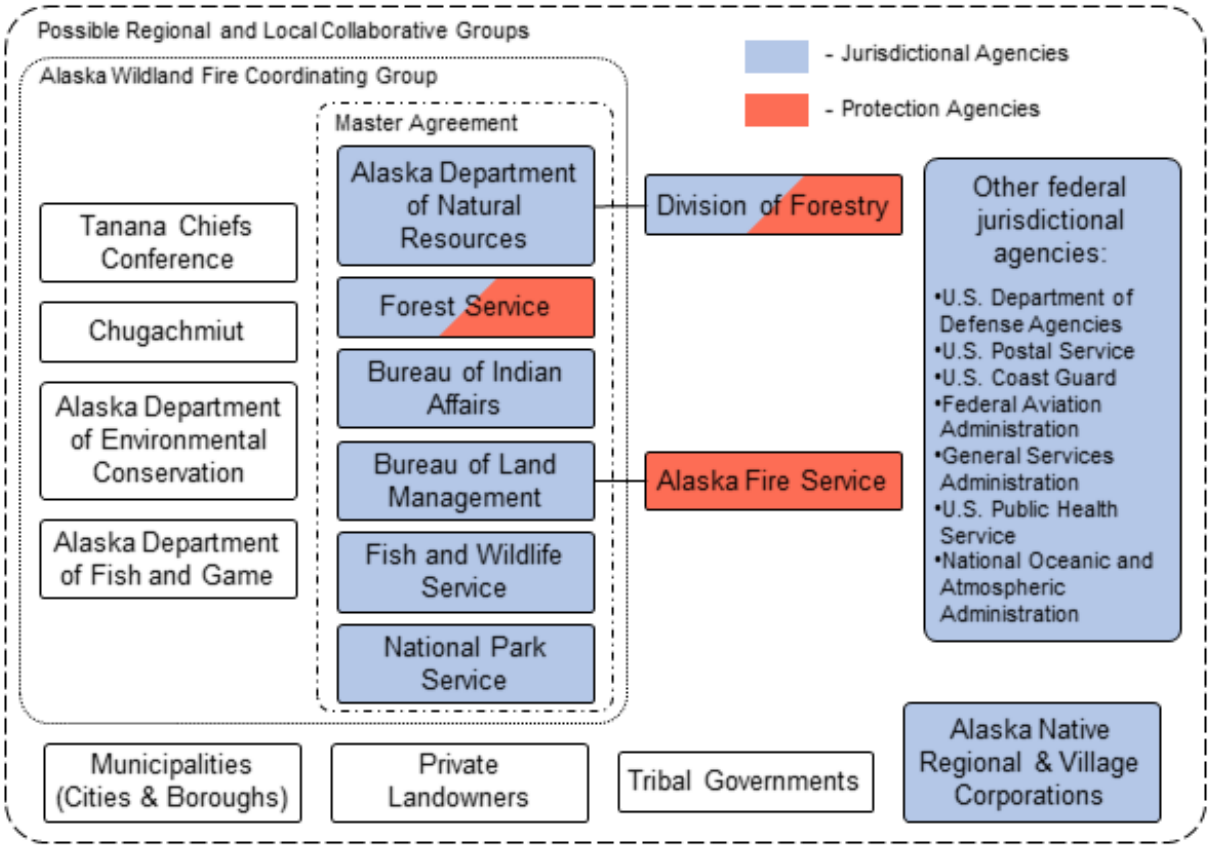

Figure 6: Alaska wildland fire governance system structure. Boxes represent organizations, agencies, and stakeholders involved in wildland fire governance in Alaska (AWFCG 2017). Dotted lines enclose organizations involved in actual and potential interorganizational agreements and groups.

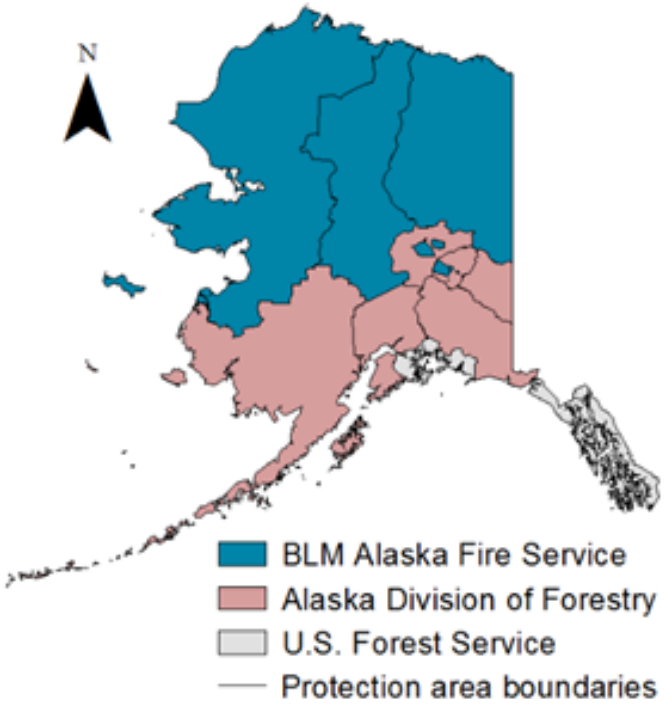

Figure 7: Map of protection agency zones. Shaded sections in map represent areas of suppression responsibility for the Alaska Fire Service, Alaska Division of Forestry, and U.S. Forest Service. Lines within shaded sections delineate administrative divisions for each protection agency.

This organizational structure shaped current statewide fire governance institutions. In the late 1990s, to simplify translation of land management goals to the protection agencies, the agencies wrote a consolidated Alaska Interagency Wildland Fire Management Plan (AIWFMP) for unified operational direction. In 2010, the agencies also combined prior bilateral interagency contracts into a single Alaska Master Cooperative Wildland Fire Management and Stafford Act Agreement (Master Agreement), which officially authorizes the transfer of suppression responsibility from jurisdictional agencies to protection agencies and delineates associated administrative arrangements, such as interagency cross-billing processes and biannual interagency meetings to update operations or planning (USDOI BIA et al. 2016). The agencies delegate representatives to a committee that coordinates interagency meetings and planning, called the Alaska Wildland Fire Coordinating Group (AWFCG 2018).

The AIWFMP outlines a unique initial attack plan that classifies the entire state into four levels of suppression priority, called management options, including "critical," "full," "modified," and "limited" (see Table 5). The jurisdictional agencies, with consultation from the protection agencies, prioritize values under these options from "critical," for the highest priority areas, down to "limited," for areas where the agencies will let fires burn unless they threaten higher priority sites. The AIWFMP lists many of the values for protection under these designations, including human life, property, natural and cultural resources, and ecological integrity (AWFCG 2018). The protection agencies manage about two-thirds of Alaska under the "limited" management option due to the low density of valued sites and communities across the state; this has allowed for the persistence of natural fire regimes to a high degree in Alaska (Todd and Jewkes 2006).

Table 5: Fire management options (AWFCG 2017).

Management option	**Default initial action**	**Priority**	**Values**
Critical	Deploy resources to protect sites and suppress fires immediately	Contain fires at the smallest acreage possible	Wildland-urban interface; inhabited property; critical infrastructure; National Historic Landmarks
Full	Deploy resources to protect sites and suppress fires immediately (given resources are not needed to protect areas in critical option)	Contain fires at the smallest acreage possible	Cultural sites; recreation areas; remote structures; high-value natural resources; any other structures or high-value areas not in critical option
Modified	Same as "full" before a predetermined date (usually after peak fire season); same as "limited" thereafter	Same as "full" before a predetermined date (usually after peak fire season); same as "limited" thereafter	Suppression buffer zones adjacent to full or critical; low-priority valued natural resources (e.g. caribou winter habitat)

Limited	Surveillance and small, remote site (“point”) protection	Allow fires to burn to the extent possible to support natural ecological processes	Large-scale landscapes with low density of values

Legal parameters on Alaska fire governance derive primarily from state and federal legislation. Each jurisdictional agency follows its own organic act and associated rulemaking that mandates fire management planning and consideration of public interests (e.g. 16 United States Code [USC] 668dd; 16 USC 1600 et seq.; 36 Code of Federal Regulations [CFR] 13 et seq.; 36 CFR 219 et seq.; 43 CFR 1610 et seq.; 43 USC 1701 et seq.; 50 CFR 36 et seq.; 54 USC 100101 et seq.; Alaska Statutes [AS] 16.05.010 et seq.; AS 41.17.010 et seq.). The protection agencies have Alaska-specific fire management policy to clarify the execution of these acts in agreement with the AIWFMP and the Master Agreement (e.g. 620 U.S. Department of the Interior Departmental Manual [DM] 5; Alaska Department of Natural Resources Department Order [DO] 017). In addition to these laws, federal agencies have created national interagency fire policy (e.g. USDA and USDOI 2009; USDA and USDOI 2014). The Alaska Native Claims Settlement Act of 1971 (ANCSA) and the Alaska National Interest Lands Conservation Act of 1980 (ANILCA) also shape fire policy. ANCSA created the Alaska Native Corporations and stipulates that the federal government must sponsor fire suppression on all Alaska Native Corporation, Native allotment, and other BIA trust land (43 USC 1620(e)). ANILCA mandates that use of federal public lands should have as little impact as possible on subsistence use by rural Alaskans, indicating that the agencies must consider subsistence hunting, gathering, and timber use values when designating fire management options (16 USC 3112(1)).

Research Objectives and Methods

Our research sought to understand the following facets of Alaska's fire governance system: (1) current fire management values, priorities, and structures, (2) potential management adaptations to climate change, and (3) governance barriers to adaptation. To explore these subjects, we engaged with actors in the system in an iterative, collaborative process of knowledge development through interviews, presentations, and meetings, allowing us to gain an intimate perspective (Arts et al. 2013). The bulk of data collection occurred in interviews with fire and land managers, firefighters, scientists, and stakeholders at all levels of the governance system. We purposively sampled from contact lists provided by the Alaska Fire Science Consortium (AFSC), meaning we recruited participants who we believed would most likely be able to contribute to our understanding of our research questions. As part of this method, we used snowball sampling, meaning we contacted further prospective participants based on recommendations from previous participants, and saturation sampling, meaning we continued to recruit participants until they were no longer able to provide new information (Patton 2015). We interviewed individuals from the following organizations (we omit some specifics to maintain participant confidentiality): Alaska Department of Fish and Game; Alaska Department of Natural Resources Division of Forestry; Alaska Native organizations; borough emergency services departments; U.S. Department of Agriculture Forest Service; U.S. Department of Defense military bases, fire operations sections; U.S. Department of the Interior (USDOI) Bureau of Indian Affairs; USDOI Bureau of Land Management (BLM); BLM Alaska Fire Service; USDOI Fish and Wildlife Service; and USDOI National Park Service. Throughout the participant sampling and data collection processes, we adhered to protocol approved by our Institutional Review Board.

We conducted and recorded 41 semi-structured, hour-long interviews using a set of open-ended questions that allowed the interviews to flow conversationally and participants to fully articulate ideas from their own perspectives (Yin 2016). We asked interviewees about current priorities and challenges in fire management and future directions to meet those challenges. We organized and analyzed interview responses using coding and memoing methods modified from grounded theory (Corbin and Strauss 2015). We conducted a thematic analysis, meaning we coded using predetermined themes based on our research questions and existing theory, rather than building codes directly from the data (Braun and Clarke 2006). To understand governance barriers to adaptation, while we did not measure learning, collective action, or long term social memory, we analyzed our results using the structural, legal and social variables that support adaptive governance characteristics (see Table 1). Throughout the coding and data collection process, we wrote memos about individual interviews and sets of excerpts to further organize our thoughts and record any new ideas. We published a practitioner report and presented our results at interagency meetings in Fairbanks (Rutherford and Schultz 2017). We used this presentation as an opportunity to further refine our analysis through group discussion and collaborative knowledge building. Our collaborative and participatory research in this project operationalizes the function of AFSC and its parent federal grant program, the Joint Fire Science Program, as bridging organizations between researchers and fire managers in Alaska's fire governance system.

Results

In this section, we explore participants' insights on current and future fire management in Alaska. We first identify the values and priorities of actors and organizations in the system, their

formal and informal communication strategies, and the system's current networked structure. We then report participants' understandings of the challenges created by climate change and their speculations on how fire management might transform to meet those challenges, including both climate change adaptation and mitigation. We close by observing aspects of the current governance system that actors perceive as barriers to adapting management to climate change.

Values and structures in fire governance

According to participants, the Alaska Interagency Wildland Fire Management Plan (AIWFMP) delineates priorities and values for fire management. Broadly, these are, in order of priority: firefighter and public safety; the values to be protected, as expressed in laws, agency rules, and public interests; and operational cost-effectiveness, given the agencies' finite capacity and reliance on public funding. Participants also identified underlying management values, including collaboration and practicality in decision making, and the overall improvement of fire management. Participants emphasized that different agencies collaborate because they share values; an interviewee said actors across the system "have the same vision on fire management." Another interviewee talked about the importance of "being strategic and looking at innovation and having people available to test new tools, new ways of doing business, and trying to stay current . . . as far as fire suppression and fire management." These management values encourage awareness of developments in fire management technology and science to help agencies improve management and policy.

Participants said the cohesiveness and efficiency of the system results from the strong lines of communication among organizations. "Working relationships" among the agencies, said an interviewee, are very good because personnel constantly communicate. Participants noted that

formal documentation systems provide a baseline for effective communication by keeping actors aware of updates to planning and decisions. These formal systems, such as the AIWFMP and the Known Sites Database, which locates any small valued points on the landscape, are regularly reviewed and refined to improve communication. At the same time, participants indicated that phone calls are the most efficient and preferred method of communication during emergency response. Actors also meet face-to-face twice annually in pre- and post-season interagency meetings in Fairbanks. An interviewee said that these spring and fall meetings allow actors to discuss and resolve issues as a group. According to participants, formal and informal face-to-face interactions, both in the biannual meetings and as a result of the concentration of many fire management offices in Anchorage and Fairbanks, facilitate relationships critical to good fire management.

Participants also described boundary spanning activities to broaden the network to the public and researchers. Many participants praised an existing All Lands/All Hands collaborative arrangement among communities and agencies on the Kenai Peninsula. An interviewee described the collaborative group as a forum for diverse organizations to "talk about how [they] can help each other achieve ultimately very similar objectives." The group pools financial, workforce, and land resources to create large-scale, cross-jurisdictional fuel breaks. Many participants also discussed agencies' efforts to engage in public education and outreach about defensible space and wildfire preparedness to improve community resilience. Regarding the integration of fire science into management, participants described a strong relationship between the agencies and researchers, facilitated by the Alaska Fire Science Consortium (AFSC). According to participants, the agencies communicate their research needs annually to AFSC, which then hosts presentations on current science and connects managers to researchers and new scientific

information throughout the year. An interviewee talked about the importance of "having a robust fire science" program involved in fire management to improve agencies' capacity to respond to uncertainty under climate change.

Needed adaptations in fire management

Participants consistently mentioned that increases in fire activity are causing major management challenges. These increases strain the system's finite suppression capacity during large fire years and elevate risk to some values. An interviewee said that actors have a "sense of nervousness as far as not being able to handle this new fire load." According to participants, capacity limitations most often impact lower priority values, such as agencies' ability to manage natural ignitions for ecosystem health or habitat enhancement, but that very large fire years occasionally force agencies to triage higher priority values that are often difficult and costly to protect, such as remote structures.

Participants identified two possible management responses to climate change. Increased fuel management was a common response among participants. Many interviewees cited two cases of fuel breaks successfully reducing the intensity of fires approaching communities in the Kenai Peninsula, allowing firefighters to protect those communities. An interviewee from the state Division of Forestry (DOF) intimated that fuel breaks around populated areas are "something that [s/he] would like to do more of," and another said that it "has been a real frustration" that the state has never allocated funding toward fuel management. A second management response identified by participants involved changes to initial response planning to expand immediate suppression action to ignitions farther out around communities and protected sites. An interviewee said this would "accommodate the additional frequency and the potential

size" of future fires, though it would likely require an increase in fuel management to address potential fuel loading.

Participants also discussed the possibility of climate change mitigation by reducing the release of greenhouse gases from ecosystem carbon sinks, including timber and permafrost. Many interviewees were skeptical of mitigation, because protecting large areas of forest or tundra solely to prevent ecosystem carbon loss would be impractical given current limited management resources. The agencies have not yet designated any areas for protection of carbon sinks. Participants noted, however, that staff in the federal and state jurisdictional agencies have discussed carbon sequestration, indicating the growing consideration of the relationship between management and climate change among actors in the system.

Governance challenges

As climate change creates new challenges, participants expressed that actors in the system have an opportunity to improve many aspects of fire governance. Despite strong lines of communication among agencies, interviewees noted that some issues surface annually without resolve. For example, a few participants discussed the failure of the biannual interagency meetings to resolve legacy inconsistencies across management options from the original planning process. To address this, some participants suggested the formation of an interagency group dedicated exclusively to management option changes. Another persistent issue mentioned by participants was the prioritization of the protection of remote private properties, such as remote cabins and Native allotments, which demands significant suppression resources. A few interviewees mentioned the possible need to reassess the default "full" management option

designation for all allotments: “It’s a federal requirement, but it's not achievable, really, and we need to look at doing something different with that.”

Some participants described issues with political communication, particularly regarding budget requests and prioritization of funding. An interviewee explained that state legislators meet with DOF “to understand what [they] do, [and] how [they] do it,” and lawmakers “have been very supportive of the fire program . . . but not to the point that it’s been a priority for them legislatively or budgetarily [sic].” According to a few participants, a component of this prioritization is the state legislature’s political preference to fund fire suppression using supplemental funding to avoid increasing up-front budget appropriations. For the Alaska Fire Service (AFS), participants described that suppression budgeting is difficult because national-level Bureau of Land Management (BLM) budgeting models allocate funds based on metrics of suppression priorities in the conterminous United States, such as minimization of area burned. These metrics do not apply well to AFS strategies, which focus heavily on the protection of small points within areas where they will otherwise let fires burn. Participants indicated that AFS is trying to communicate to BLM staff that Alaska requires a unique budgeting process because current national budgeting models have not allocated enough funding for AFS to protect all values during recent large fire years. In addition, the fallback of interstate resource sharing has become limited at times by lengthening fire seasons nationwide.

Participants explained that the separation of the protection and jurisdictional agencies has caused some compartmentalization of responsibilities, resulting in a lack of fit between land management goals and fire suppression and fuel management. A few interviewees suggested a need for greater involvement from federal jurisdictional agency staff in fire operations, and others indicated that the jurisdictional agencies more often should consider fire planning in the

land management planning process. On the other hand, many participants talked about the need for staff from protection agencies to better understand land management goals, because historically divorcing the protection agencies from land management has led to the prioritization of suppression over fuel management in the fire program. An interviewee described efforts to integrate land and fire management by agency leadership but acknowledged that this will depend on a shift in social dynamics, including "personalities, and perspectives, and culture," indicating the perceived complexity of achieving needed changes in governance.

Discussion

Our results show that the Alaska fire governance system is generally adaptive, but actors nonetheless see a need for changes in management in response to climate change. The current system is defined by laws and institutions from above, actor norms, and its unique interagency structure and statewide management option planning. Participants identified expected challenges under climate change and alternatives to current practices, including strategies for both adaptation and mitigation. To meet these challenges, actors must leverage advantageous aspects of the governance system and utilize opportunities to address governance barriers.

Adaptive governance in Alaska fire management

Reflecting on the facets of adaptive governance yields insights about the system's ability to respond to climate change via collective action, collective learning, and long-term social memory. Although the system is fundamentally a bureaucratic hierarchy controlled by state and federal law and resources, it incorporates elements of networked governance and self-organization for collective action at both statewide and more local scales (Morrison et al. 2017).

Connections span types of actors, from land managers to fire managers, and governing levels, from state and federal lawmakers to agencies to the public, such that interactions occur in nested networks. For example, vertical coordination occurs between the local Kenai All Lands/All Hands group and the statewide Alaska Wildland Fire Coordinating Group (AWFCG), and horizontal coordination occurs within both networks. Each of these groups reflects some degree of self-organization across actors. Through connections with resources external to this system, the Alaska Fire Science Consortium (AFSC) acts as a bridging organization to facilitate the flow of information between research and management (Crona and Parker 2012). Biannual meetings of representatives from all involved state and federal agencies, tribes, and science partners allow for reflection, information sharing, and collective learning. Meetings, research, and fire season statistics, often documented and disseminated by AWFCG or AFSC and internalized by experienced managers, can build long-term social memory among actors. Effective coordination and information dissemination help actors to set cohesive priorities, understand new challenges such as climate change, and support innovative management approaches. These aspects of the system's internal social dynamic encourage a collaborative environment that sustains adaptation (DeCaro et al. 2017*a*).

The multi-level networked structure in Alaska's fire governance system is a result of interrelated contextual parameters and institutional design. Alaska's large, bounded spatial extent and low population density have led to its unique organizational structure, in which the separate protection and jurisdictional agencies must coordinate despite their compartmentalized responsibilities. The mismatch in spatial scale between the protection and jurisdictional agencies necessitates the formation of multi-scaled institutions (Folke et al. 2007). The agencies have responded with formal institutions, like the Alaska Interagency Wildland Fire Management Plan

(AIWFMP) and the Master Agreement, and other norms, including consistent phone communication and face-to-face meetings that allow for necessary coordination. In support of multi-level governance, top-down policies have effectively decentralized decision-making authority to governance networks like the Kenai All Lands/All Hands group and AWFCG. At the same time, the agencies maintain the structure necessary for the legitimate, centralized control and capacity to manage large landscapes as public lands for multiple uses (Craig et al. 2017). The agencies have found creative ways to balance the need for networking and coordination with administrative specialization, which has become an imperative in public administration (Kettl 2005).

Despite a multi-level network designed to address spatial challenges in Alaska's vast landscape, the governance system has not overcome some spatial and temporal scale mismatches common in fire management (Ager et al. 2015). Spatial scale mismatches occur among prioritization decisions, such as the need to protect local values against the statewide review of management strategies during biannual interagency meetings. For example, the protection of remote private properties is a value in the system and is codified in top-down law and policy, but the protection of small plots of land does not match the statewide scale of resource mobilization or the landscape scale of many boreal and tundra fires. A persistent temporal scaling challenge is budgeting for suppression capacity in federal and state legislatures that often respond to fire funding needs reactively and annually, whereas sustained resource investments could extend the purview of choices about prioritization and fuel management. These spatial and temporal scale mismatches create conflicting priorities between local values, top-down law and budgeting, and fire management policy, placing agency fire managers in a challenging executive position.

Pathways to improved scale fitting for budgeting and suppression planning require utilization of collaborative networks and bridging organizations at every level of the governance system. The agencies have engaged in continuous adaptation through existing structures, institutions, and cultural practices to achieve the transformative governance change predicated by climate change (Termeer et al. 2017). The flow of scientific information and practical experience across the system via networks and bridging organizations such as AFSC can close gaps between land and fire managers and the agencies and lawmakers, and is critical to continuous adaptation (Fischer and Jasny 2017).

Broader implications for research and management

The application of adaptive governance to Alaska's fire governance system demonstrates a tension between the generalizability of governance principles and the need for empirical studies specific to individual systems. Lessons drawn from Alaska's experience may help inform broader issues in fire management and adaptive governance. In a rapidly changing Arctic landscape, Alaska is a particularly valuable place to understand governance adaptation (Brunner and Lynch 2010; Chapin et al. 2014). The pace of change and its direct effects on social and ecological systems present a distinct opportunity for researchers to observe the effects of governance change over time, which may prove relevant to fire management worldwide as the climate changes (Moritz et al. 2012; Stephens et al. 2013). For example, Alaska's management options map and approach to fuel management may inform approaches that state and federal agencies in the conterminous United States have increasingly considered (Steelman and Burke 2007; Schoennagel et al. 2017). More broadly, experiences in Alaska may be useful in

understanding the challenges and opportunities of adaptive governance in systems facing an array of natural hazards (Djalante et al. 2011).

At the same time, the diversity of contextual influences on Alaska's fire governance system highlights the need for place-specific empirical analyses of governance needs in a changing climate (Lynch and Brunner 2007). Historical, geographic, and social context have defined the nature of the governance system. The historical separation of the protection and jurisdictional agencies has required that actors create strong interagency communication structures. In addition, the geographic centralization of the agencies and AFSC in the population centers of Anchorage and Fairbanks has facilitated communication between fire managers and researchers. On the other hand, this centralization often hinders communication and coordination with groups removed from those areas, such as remote communities, lawmakers in Juneau and Washington, D.C., and federal agencies focused primarily on the needs of the conterminous United States. Finally, Alaskans may have local cultural practices that have shaped the development of the state's unique fire governance system. These factors indicate that adaptive governance in Alaska must be viewed through a contextually specific lens. The interplay between local context and institutional design presents a challenge for the empirical application of adaptive governance principles. Future research across cases of governance change may have the opportunity to disentangle incidental and designed adaptation in environmental governance systems.

CHAPTER 5: CONCLUSION

In this thesis, I explored challenges and possibilities for climate change adaptation in wildland fire governance and management in Alaska. I found that, in general, the fire management community in Alaska recognizes the challenges associated with climate change and a need for adaptation in management approaches. The fire management system currently features mechanisms that support its capacity to adapt to climate change. For example, interagency meetings allow actors in the system to regularly review operations, planning, policy, and recent science. In addition, organizations such as the Alaska Wildland Fire Coordinating Group and the Alaska Fire Science Consortium have successfully supported adaptation by bridging gaps among decision makers within the interagency network. Despite these existing adaptive structures and institutions, fire managers anticipate challenges to their management capacity. Several values face growing risk due to increasing fire activity across the landscape, and the fire management community may need to engage in formal decision-making processes to reevaluate management priorities and policy. Managers identified the need to improve land and fire management communication during planning and operations. Managers also see a need for community organization and collaboration to augment fuel management capacity and reduce risk in the wildland-urban interface. In general, climate change is causing a reevaluation of priorities, policy, and structures in the fire management community. Climate change has created both a complex challenge and an opportunity to enhance the adaptability of the system.

In the preceding chapters, I discussed the importance of understanding adaptations in management and governance in the context of rapid climatic change at high northern latitudes. As Alaska's agencies face critical failures in their capacity to protect values, their initial challenges and successes may be able to inform fire management policy elsewhere in the United

States and the world. My research adds valuable empirical data to the literature on climate change adaptation in fire management. I also discussed the uniqueness of Alaska's geography, culture, and management system, and the specific relevance of this research to fire managers in Alaska. My interviews constituted part of a mutual knowledge-building process with the specific goal of developing an understanding of the intersection between climate change and fire management. Because of this, my research will be directly useful to actors in the system as they move forward with decisions that affect communities and ecosystems in Alaska.

This thesis opens an opportunity for future research to delve more deeply into adaptation in specific aspects of the fire management system. While much of the decision making that controls the broad direction of priorities and policy occurs at a statewide scale, necessitating a broad view of networks and institutions, much of the actualization of shifts in management approaches will occur at smaller scales with shifts in manager and firefighter culture and the creation of local collaborative groups. My research demonstrated the multilevel nature of management adaptation, but future research should explore the smaller-scale processes of collaboration and change in management approaches in the unique context of Alaska, where isolated communities face monumental capacity challenges in risk reduction. Furthering the use of the iterative knowledge-building process, future researchers may also be able to help extend the adaptive mindset from the fire management community to the public and policymakers. Realizing the potential adaptations that I have identified in this thesis will require a strong effort for understanding and action at every level of the governance network. But fundamentally, the results from this study should engender optimism at the recognition of common challenges and a desire to search for solutions across Alaska's fire management community.

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APPENDIX A: PILOT QUESTIONNAIRE AND INTERVIEW METHODS

Questionnaire Sampling

To recruit participants for the online pilot questionnaire, I used an Alaska Fire Science Consortium (AFSC) contact list of 84 individuals from a wide-ranging set of fire management, research, and private forestry organizations. I contacted participants using an Institutional Review Board-approved recruitment letter, sent via a single email in early-February 2017 through the online survey software SurveyMonkey. The recruitment email included a summary of the broader project's research objective and links to the online Alaska Frame-Based Ecosystem Code (ALFRESCO) vegetation and fire regime climate change modeling tool created by Paul Duffy (Co-Principal Investigator on the research team) and a recorded webinar introducing that online tool. The email also invited participants to participate in a planned post-questionnaire conference call about the usefulness of and needs for the online tool. The email then linked to the questionnaire on the SurveyMonkey website, which began with an Institutional Review Board-approved consent form that ensured participant confidentiality. We received 20 total responses to the questionnaire.

Questionnaire Data Collection

The purpose of the questionnaire was to gather pilot information on fire management challenges in Alaska and initial response from the fire management community to the online climate change modeling tool. We used this data to develop our interview protocol and gather ideas for improving the online tool, but we did not formally analyze questionnaire responses. The questionnaire consisted of seven total questions, as follows:

1. What is your current position and what is your role in Alaska fire management?
2. What current challenges are you and the broader fire management community facing in Alaska fire management? We are interested in capacity, policy, jurisdictional, financial, or ecological challenges, among other challenges we might not have considered. If there are too many to mention, consider listing your top three or four.
3. To what extent have you explored the ALFRESCO website? How much have you used it, and for what purposes?
4. What new information do the ALFRESCO fire regime projections give you, if anything?
5. Are there ways you'd like to see the information packaged or presented (e.g. time frames, jurisdictional scale, etc.)?
6. Does seeing these model outputs change your perspective on future fire management approaches and needs? In other words, does this information make you think about the problem in a new way?
7. Is there anything else you would like to tell us at this time?

Interview Sampling

To recruit interviewees, I primarily used a list of attendees at the AFSC 2017 Spring Alaska Fire Science Workshop, which occurred in conjunction with the 2017 Interagency Spring Fire Management Officer Meeting. AFSC provided me with this list of attendees, as an inclusive sample of those involved in decision making in the Alaska fire management system. At the Fire Science Workshop, Paul Duffy, who was presenting research as part of the Workshop, notified attendees that I would be contacting them to request interviews regarding the project. Using this list, I entered each name into an Excel spreadsheet, then added the names of our questionnaire

respondents that did not already appear in the list. I then added the names of those who had attended our post-questionnaire conference call that did not already appear in the list.

The recruitment list included individuals from each agency and Alaska Native organization that was an active member of the Alaska Wildland Fire Coordinating Group, excepting the Alaska Department of Environmental Conservation, plus the protection agencies and some additional stakeholder organizations. These organizations include (with some specifics omitted to maintain participant confidentiality):

- Alaska Department of Fish and Game;
- Alaska Department of Natural Resources Division of Forestry;
- Alaska Native organizations;
- Borough emergency services departments;
- U.S. Department of Agriculture Forest Service;
- U.S. Department of Defense military bases, fire operations sections;
- U.S. Department of the Interior Bureau of Indian Affairs;
- U.S. Department of the Interior Bureau of Land Management;
- U.S. Department of the Interior Bureau of Land Management Alaska Fire Service;
- U.S. Department of the Interior Fish and Wildlife Service; and
- U.S. Department of the Interior National Park Service.

Within these agencies, we recruited individuals in the following positions: fire management officers, planners, and operations supervisors; fire prevention officers; fuel management specialists; agency researchers, including fire ecologists, biologists, and GIS specialists; foresters; agency administrators and line officers; agency directors; and stakeholders.

Initial contact for recruitment occurred in seven waves, prioritized in sets of 10 individuals. To begin, Paul Duffy reviewed the list to prioritize names to contact. He removed names associated with universities and research organizations to limit the sample to agency personnel and stakeholders. He then marked nineteen high priority names; these were primarily people whom he had directly interacted with at the Fire Science Workshop and who expressed significant interest in participating in interviews. These nineteen generally represented management or director positions in a variety of agencies. I contacted 10 of these individuals during the first wave of recruiting, then the remaining nine during the second wave. For the third wave, I chose 10 names based on recommendations from prior interviewees. The recommendations often overlapped with those that Paul Duffy had marked as high priority. Interviewees generally recommended individuals from within their own agency, but interviewees in high management positions also recommended contacts in other agencies. For the fourth wave, I chose those remaining eight names that I recognized from the questionnaire respondents and the post-questionnaire conference call, plus two additional recommended names. I prioritized prior participants because I assumed that because they had already participated in our research, they might be willing to participate again. For the final three waves, I chose 10-11 names at random from within each agency for which uncontacted names remained or using further recommendations. I sent out one final recruitment email to contact an additional recommendation from a later interviewee. I recruited 71 total individuals with the intent of conducting approximately 40 interviews, at which point we anticipated that we would have reached information saturation (Patton 2015). We stopped recruiting interviewees after we had received confirmation of intent to interview from 38 individuals, though some additional

interviews occurred after this point, due to late responses to recruitment. In total, we conducted 41 interviews between early-May and mid-September of 2017.

The recruitment process involved several steps, conducted primarily via email. I sent waves of emails once per one to two weeks between late-April and late-June of 2017. I used an Institutional Review Board-approved recruitment letter in the body of each email. The letter explained the purpose of the interviews and the consent process, ensuring recruits of the confidentiality of their responses should they choose to participate. I attached to this email a one-page project timeline and a suppression scenario as an example of adaptation in management approaches. The body of the email also contained links to the online version of the ALFRESCO vegetation and fire regime modeling tool and the recorded webinar introducing that online modeling tool. I carbon copied Paul Duffy and Courtney Schultz (Principal Investigator on the research team) on each initial email. In the case of no response within one and two weeks, I sent a reminder email, and then a second reminder email. After no response to the second reminder email, I did not pursue further contact, given the high likelihood that we would reach at least 40 interviews based on the size of our sampling pool and initial rates of participation.

Interview Data Collection and Interview Protocol

I conducted interviews remotely via telephone. Interviews typically lasted about one hour, but varied from 30-90 minutes in length. Courtney Schultz co-conducted 12 interviews, and Paul Duffy co-conducted one interview with me. The purpose of the interviews was to explore how actors in the fire management system perceived current fire management priorities, challenges, needed adaptations in policy and management approaches, and science needs. We used interview results to develop an understanding of possible future climate change adaptation

in fire governance and fire management in Alaska. We conducted interviews in a semi-structured format, meaning we asked open-ended questions and let the interview proceed conversationally, responding to interview responses with further, unplanned questions. This format allowed interviewees to fully develop thoughts and topics and provide information to us somewhat organically while remaining within the scope of our broad research objectives (Yin 2016). We used the following questions as a loose protocol for each interview (we did not always ask every question, or read questions verbatim, but rather adapted to the individual circumstances of each interview):

1. What is your current position and involvement in Alaska fire management?
2. **Understanding of current management**
    - What are the current priorities for fire management in Alaska? For your organization specifically?
    - What are current management approaches that you (or your organization) use in your job (to meet your agency's priorities)? In what ways are current approaches effective? Not effective?
    - What are the primary challenges faced today in Alaska fire management?
    - How have you seen costs and resource needs change in recent years? What has driven these changes?
3. **Understanding of future management options**
    - How do you think management approaches (for example, the ones you mentioned) will need to change in the future?
    - Do you anticipate changes to funding or other resource needs in the future?

- We will be modeling the effects for fire and vegetation for different future management scenarios and would like to know what scenarios you think we should consider. We shared with you a possible future fire management scenario. Can you tell us what you think of it? Are there others you think we should consider?
- What would be necessary to make these management approaches possible?
- What do you think are some barriers to achieving the necessary changes?

4. Policy pathways

- Do you see any challenges in the current interagency cooperative system for fire suppression? (Cue to discuss billing/cost-sharing system if they do not mention it.)
- Do current policies support fire management goals?
- Do you have any recommendations for changing interagency policy or planning (the things you mentioned or jurisdictional boundaries, cost sharing, or land management goals)?
- Are there changes in policy or management goals your agency might need to undertake?

5. Science delivery

- Have you looked at the new fire regime projections tool on the SNAP website?
- Have the projections been useful or given you new information?
- Is the website useful (intuitive, understandable)?
- What do you think are the primary science needs of managers? What science would they like to see?

6. **Closing**

    - Is there anything else you would like to discuss or that I should have asked about?
    - Whom else should I be talking to?
    - Would you be willing to take a follow-up call from us if we have further specific questions when we are building management scenarios into the model?

Interview Analysis and Codebook

I used coding and memoing methods derived from grounded theory to analyze interview data (Corbin and Strauss 2015). I began coding interviews after having completed Interview #14. I sent audio recordings to the online transcription service Rev.com. I then closely edited each transcript in a Microsoft Word document. I uploaded each Word document to the online qualitative data analysis program Dedoose. I developed a list of codes in Dedoose, under which I could then organize data. I initially created a list of seven codes, based on themes that I identified after writing post-interview summary memos for each interview. I identified themes related to my research objectives and ideas derived from several bodies of literature related to climate change adaptation, learning, and knowledge systems in natural resource governance and management (Braun and Clarke 2006). I coded Interview #1, then added five additional codes based on what I had found in that interview. I coded several interviews using this original list of 12 codes, then discussed this initial analysis with Courtney Schultz. We developed a revised list of 13 mutually exclusive codes, which I used in all subsequent phases of analysis. These codes, with a brief description, are:

- *Alaska Native Claims Settlement Act/Native allotments/Native Corporations*: I used this code to describe excerpts about: the structure of or challenges involving the Alaska

Native Claims Settlement Act (ANCSA), especially regarding the "significant profit" clause about the forfeiture of free fire suppression from the federal government if any landowners use ANCSA land to generate profit; the protection of Native allotments; and fire management by ANCSA Native Corporations or Alaska Native nonprofits, including collaboration with the federal and state agencies, fielding of suppression resources such as Emergency Firefighter crews, and the development of fire management plans.

- *Capacity*: I used this code to describe excerpts about challenges related to capacity, resources, or funding, or the structure of the budget request or resource sharing system.
- *Changes in the fire regime*: I used this code to describe excerpts about observed effects of climate change on fire severities, fire extent, fire seasons, fire frequencies, forest ecology, and the amount of fuels on the landscape.
- *External communication/culture/collaboration*: I used this code to describe excerpts about jurisdictional and protection agency communications with the public, communities, or institutions outside of the central fire management decision-making structures in the Alaska Wildland Fire Coordinating Group and Alaska Interagency Wildland Fire Management Plan. More specifically, this code describes excerpts about public culture regarding fire management, including engaging in preparedness actions such as defensible space, and collaborative arrangements between the agencies and communities to complete fire management activities, including in planning and the Kenai Peninsula All Lands/All Hands collaborative group.
- *Fuel management*: I used this code to describe excerpts about uses of and challenges implementing fuel management in Alaska.

- *Governance and policy ideas and needs*: I used this code to describe excerpts about suggestions that interviewees had for improving the fire management system and general governance challenges and needs that did not fit under the "External communication," "Internal communication," or "Political communication" codes. This code describes suggestions or very general observations about the fire management system, including calls for change or anticipation of major change.
- *Internal communication/culture/policy*: I used this code to describe excerpts about challenges with and the structure of internal governance, meaning communication among the Alaska Wildland Fire Coordinating Group and Alaska Interagency Wildland Fire Management Plan organizations, their culture, and statewide fire management policy in general.
- *Management options*: I used this code to describe excerpts about challenges, benefits, and needed changes related to the management options map in the Alaska Interagency Wildland Fire Management Plan.
- *Political communication*: I used this code to describe excerpts about communication between actors in the fire management system and actors in the legislatures that govern the fire management system, including elected representatives and agency leadership in the State of Alaska and the U.S. federal government.
- *Science needs*: I used this code to describe excerpts about general science needs among interviewees, especially in relation to manager interactions with researchers via the Alaska Fire Science Consortium.
- *Suppression tactics*: I used this code to describe excerpts about suppression tactics or changes in suppression tactics in Alaska.

- *Valued resources and management priorities*: I used this code to describe excerpts about valued resources and management priorities that inform decision making and control the development of fire management policy in Alaska. These include operational efficiency and the protection or maintenance of human property, timber, ecosystem carbon sinks, wildlife habitat, or natural ecological processes.
- *Website uses and ideas*: I used this code to describe excerpts about interviewees' responses to the ALFRESCO website and thoughts about its usefulness to them or to others in the fire management system.

During the data collection and coding process, I periodically wrote general summary memos to collect ideas and further develop analysis. After conducting 25 interviews I wrote a memo regarding interview excerpts about the online ALFRESCO modeling tool. After conducting 35 interviews, I wrote a general analysis of all interview data that we had collected thus far. After conducting 38 interviews, I began to organize all excerpts into Microsoft Word documents by code, leaving out a few (one to five) excerpts per code that I did not foresee providing any relevant information to the analysis. I then summarized individual excerpts within each document. At the top of the documents, I wrote memos on themes and ideas appearing across excerpts within codes. Further analysis occurred during outlining and writing processes for this thesis, as I further organized excerpts based on frameworks of variables pertinent to understanding fire management or governance.

GLOSSARY

Agency administrator: A managing officer with statutory responsibility for fire management in an agency. The agency administrator exercises decision-making authority regarding fire management priorities, resource use, and interagency agreements. Agency administrators for jurisdictional agencies hold these responsibilities for individual land management units (AICC 2017).

Alaska Fire Science Consortium (AFSC): A regional branch of the Joint Fire Science Program Fire Science Exchange Network serving the Alaska, with the explicit goal of linking fire management practitioners to fire science researchers for the development of applicable knowledge.

Alaska Frame-Based Ecosystem Code (ALFRESCO): A frame-based, spatially explicit model of fire ignition probabilities, fire spread, and vegetation recruitment at a landscape scale in the circumpolar boreal and arctic region. The frame-based model projects changes in vegetation over time as a series of states within independent frames; each frame operates as an independent sub-model that simulates stochastic growth, mortality, recruitment, and disturbance processes that may cause a shift to a different frame (Rupp et al. 2000).

Alaska Interagency Wildland Fire Management Plan (AIWFMP): An interagency fire management plan overseen by the Alaska Wildland Fire Coordinating Group to provide operational direction for the policy and authorities laid out in the Master Agreement. The AIWFMP defines policy, priorities, the initial attack management options, and the jurisdictional and protection agencies (AWFCG 2018).

Alaska Master Cooperative Wildland Fire Management and Stafford Act Agreement (Master Agreement): An agreement between the U.S. Department of the Interior, U.S. Department of Agriculture, and State of Alaska jurisdictional agencies to improve efficiency in fire management through resource sharing. The Master Agreement authorizes the transfer of fire management responsibilities from the jurisdictional agencies to the protection agencies and outlines cost sharing and interagency billing procedures (USDOI BIA et al. 2016).

Alaska National Interest Lands Conservation Act of 1980 (ANILCA): A federal law providing for the protection of over 157 million acres of land in federally managed conservation units. ANILCA additionally directs federal land management agencies to prioritize the protection of subsistence use opportunities on federal land for Alaskan citizens living in rural areas (16 USC 3101 et seq.).

Alaska Native: A member of any of several groups of indigenous peoples of Alaska.

Alaska Native Claims Settlement Act of 1971 (ANCSA): A federal law settling Alaska Native land claims. ANCSA established thirteen Alaska Native regional corporations and several hundred local Alaska Native village corporations and allowed these corporations to select 44 million acres of federal land for transfer under fee simple private ownership (43 USC 1601 et

seq.). ANCSA guarantees free fire suppression from the federal government to all Native Corporation lands so long as those lands do not generate "substantial revenues" (43 USC 1620(e)).

Alaska Wildland Fire Coordinating Group (AWFCG): An interagency group of representatives from U.S. Department of the Interior, U.S. Department of Agriculture, State of Alaska, and Alaska Native land management agencies and organizations, which oversees the Alaska Interagency Wildland Fire Management Plan and coordinates and provides direction for interagency fire management policy and operations (USDOI BIA et al. 2016).

ANCSA Native Corporations: One of 13 regional or several hundred local private corporations created under the Alaska Native Claims Settlement Act of 1971 (43 USC 1601 et seq.).

Climate change adaptation: The result of an action intended to ameliorate an anticipated negative effect of climate change (IPCC 2014).

Coding: A qualitative method derived from grounded theory to analyze excerpts of raw data by organizing them at a conceptual level (Corbin and Strauss 2015).

Defensible space: An area around a valued resource, usually a private structure, in which action has been taken to reduce fire risk to that valued resource, usually through the modification of the fuel profile.

Emergency Firefighter (EFF): A group of employees without dedicated agency positions hired as Type 2 Incident Management Team to supplement regular fire management staff during wildland fire emergencies (DOF and AFS 2016).

Fire governance: The conditions for collective decision making and action regarding the management of wildland fire (Folke et al. 2005). Components of the governance system include the actors, organizational structures, and institutions, including laws, policies, rules, regulations, and norms, that determine outcomes in this collective decision making (Chaffin et al. 2014).

Fire management: Decision making and actions concerning the set of activities that modifies the characteristics or effects of a wildland fire, including, but not limited to, suppression, fuel management, planning, post-fire rehabilitation, training, fire prevention, public affairs, and any related administrative activities (USDOI BIA et al. 2016).

Fire management officer: An employee within a jurisdictional or protection agency with responsibility for planning and implementing fire management for a specific agency unit.

Fire regime: The characteristic frequency, severity, intensity, extent, and seasonality of wildland fire occurrence over a given spatial and temporal domain.

Fire risk: A characterization of the probability of negative impacts to a valued resource by wildland fire.

Fuel management: Any action intended to alter the fuel profile of a given area, primarily using mechanical means or the intentional application of low severity fire to reduce the amount of undesirable, highly flammable fuels.

Initial attack: Suppression action taken as soon as a fire is detected to prevent fire spread.

Jurisdictional agency: Any of the federal or state agencies or ANCSA Native Corporations that manage land in Alaska. The jurisdictional agencies identify valued resources and initial attack priorities for land in Alaska (USDOI BIA et al. 2016).

Known Sites Database: An interagency database to specify locations, descriptions, management responsibility, and operational direction for valued resources on the landscape (AWFCG 2018).

Management option: One of four designations of priority for initial attack, including, in order from highest priority to areas where the jurisdictional agency intends to allow fires to burn: "critical," "full," "modified," and "limited." Jurisdictional agencies must designate all land as one of these four management options under the Alaska Interagency Wildland Fire Management Plan (AWFCG 2018).

Memoing: A qualitative method derived from grounded theory to record analytic thinking throughout the data analysis process. A memo generally consists of any written collection of thoughts, and memos can have several specific purposes, including, but not limited to, description, summarization, synthesis, and generation of ideas (Corbin and Strauss 2015).

National Cohesive Wildland Fire Management Strategy (Cohesive Strategy): A three-phase federal strategy and action plan for fire management on U.S. federal lands, originating in the Federal Land Assistance, Management, and Enhancement Act of 2009 (FLAME Act). The Cohesive Strategy fosters collaboration between federal agencies and state, tribal, and private partners, and provides for competitive federal grant assistance for fire risk reduction, fuel management, and post-fire recovery to communities and other local governments (USDA and USDOI 2014).

Native allotments: Parcels of up to 160 acres of non-mineral land selected by Alaska Native individuals under the Alaska Native Allotment Act of 1906 for fee simple private ownership. The Alaska Native Claims Settlement Act of 1971 repealed the Allotment Act (43 USC 1617(a)). For the purposes of fire protection, the Master Agreement treats Native allotments as Bureau of Indian Affairs (BIA) trust land; the BIA is responsible for fire suppression on all Alaska Native trust land (USDOI BIA et al. 2016).

Point protection: A type of suppression action taken to prevent the spread of fire into the boundaries of small areas on the landscape, rather than directly attacking a fire to prevent any spread.

Protection agency: One of three agencies in Alaska responsible for suppression and fuel management in a designated area. Protection agencies are responsible for fire management

across jurisdictional boundaries at the direction of the jurisdictional agencies (USDOI BIA et al. 2016).

Suppression: An action taken to prevent the spread of fire or alter the direction of spread of a fire, including point protection (USDOI BIA et al. 2016).

Valued resource: An object or location designated for protection from wildland fire, including, but not limited to, structures, infrastructure, natural resources, recreational sites, and cultural sites.

Wildland Fire Decision Support System (WFDSS): An interagency computer application to document fire management objectives and actions for fire incidents. WFDSS supports decision making for the management of individual fires (USDOI BIA et al. 2016).

Wildland-urban interface: An area where human developments are located adjacent to or within undeveloped land that is subject to some degree of fire risk.

LIST OF ABBREVIATIONS

ADF&G – Alaska Department of Fish and Game

AFS – U.S. Department of the Interior Bureau of Land Management Alaska Fire Service

AFSC – Alaska Fire Science Consortium

AICC – Alaska Interagency Coordination Center

AIWFMP – Alaska Interagency Wildland Fire Management Plan

ALFRESCO – Alaska Frame-Based Ecosystem Code

ANCSA – Alaska Native Claims Settlement Act

ANILCA – Alaska National Interest Lands Conservation Act

AWFCG – Alaska Wildland Fire Coordinating Group

BIA – U.S. Department of the Interior Bureau of Indian Affairs

BLM – U.S. Department of the Interior Bureau of Land Management

CSU – Colorado State University

DOF – Alaska Department of Natural Resources Division of Forestry

EFF – Emergency Firefighter

FWS – U.S. Department of the Interior Fish and Wildlife Service

GIS – Geographic Information System

JFSP – Joint Fire Science Program

SNAP – Scenarios Network for Alaska + Arctic Planning

USDOD – U.S. Department of Defense

USDOI – U.S. Department of the Interior

USFS – U.S. Department of Agriculture Forest Service

WFDSS – Wildland Fire Decision Support System