DISSERTATION

CLIMATE CHANGE ADAPTATION ON PUBLIC LANDS: POLICY, VULNERABILITY ASSESSMENTS, AND RESILIENCE IN THE U.S. FOREST SERVICE

Submitted by

Thomas Timberlake

Department of Forest and Rangeland Stewardship

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Doctoral Committee:

Advisor: Courtney Schultz

Tony Cheng
María Fernández-Giménez
Robert Duffy

ABSTRACT

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How will forests change in the future and what can land managers do in response? As climate change impacts public lands in the United States, natural resource managers must grapple with this question to ensure that these lands and the ecosystems that they support continue to provide what human communities have come to expect from them. In the forests of the western United States, climate change has begun to and will continue to exacerbate the impacts of naturally occurring disturbances, including fires, insect outbreaks, and flooding. In order to respond to these impacts, managers need access to scientific information that helps them understand what to expect. Yet, in government agencies, adaptation is not only a technical issue but also involves a policy side. However, academic studies of adaptation have largely not explored the policy dimensions of adaptation, and a next step for research on the topic involves examining how actors make and implement policies related to adaptation.

My dissertation addresses this need with a focus on the U.S. Forest Service, a federal agency in charge of 193 million acres of public lands. The Forest Service's adaptation strategy emphasizes the development of climate change vulnerability assessments to provide managers with targeted scientific information and management for resilience, a concept that generally describes a system's ability to absorb and recover from the impacts of disturbances. My research examines how practitioners take these somewhat ambiguous ideas and put them into practice given the Forest Service's policies, bureaucratic characteristics, and social-ecological contexts.

The agency has had adaptation policies in place for around a decade; however, these policies have not replaced other requirements and little is known about how managers are addressing adaptation objectives in the complex institutional landscape that shapes contemporary national forest management.

Using qualitative research methods, I examine adaptation in the U.S. Forest Service through three papers (Chapters 2-4). In Chapter 2, I examine how land managers operationalize resilience in planning processes through case study research of planning on the Kaibab National Forest in Arizona. In addressing this objective, this chapter considers how managers pursue new priorities like resilience, ecological restoration, and climate change adaptation, despite operating in a policy framework defined by institutions from previous eras. For the Kaibab National Forest, addressing these priorities involved restoring the ecological process of fire to forests in the area, in response to a history of fire exclusion. However, managers faced institutional challenges in navigating changes in planning regulations, institutions for fire management, and balancing discretion with accountability.

Chapter 3 discusses the production of vulnerability assessments, which are targeted science products that summarize potential impacts of climate change on ecological resources found in a particular area. Specifically, it reports on document analysis of 44 vulnerability assessments in the U.S. Forest Service, and highlights how partnerships between research scientists and land managers are central to the development of most vulnerability assessments. As the practice has developed, vulnerability assessments are increasingly covering larger spatial extents and addressing the vulnerability of more types of resources, thus incorporating the input from a range of scientific disciplines. However, there exist opportunities for better integration across these disciplines. The practice of vulnerability assessment represents an early step for the

U.S. Forest Service in adaptation, and this practice has proven to be successful insofar as scientists and their agency partners have developed vulnerability assessments that cover nearly the entire National Forest System. However, as we discuss in this paper, more work is needed to support the application of vulnerability assessments in decision-making.

Chapter 4 examines how bureaucratic characteristics of the U.S. Forest Service shape its contemporary adaptation approaches. This addresses a need in the literature to examine how administrative agencies in government bureaucracies pursue adaptation, and how bureaucratic traits affect the implementation of policies in general. I conducted interviews with 55 land managers and scientists about climate change considerations in decision-making. This chapter highlights how vulnerability assessments offer a promising new routine to support climate change adaptation and how managers are beginning to use information from these efforts. However, to date, adaptation efforts are primarily occurring through existing policy processes and management paradigms. Specifically, the contemporary regulations guiding land management planning processes require a consideration of climate change, and interview participants view planning processes as key opportunities for considering climate change. Contemporary management paradigms focus on the restoration of resilient ecosystems, and managers view many of the ongoing management activities occurring under this paradigm as conducive to adaptation. Ultimately, this approach to adaptation reflects bureaucratic characteristics of the Forest Service that make it challenging for managers to implement activities dedicated primarily to climate change adaptation, including the agency's structure, budgeting and performance targets, and complex set of multiple goals. Nonetheless, the existing, incremental innovations that have occurred to date suggest starting points for the development of more robust adaptation practices for the Forest Service.

Collectively, these chapters demonstrate the importance of taking seriously policy, institutions, and bureaucracies in the study of adaptation. In the conclusion, I discuss common themes across the chapters and opportunities for future research. As all three chapters highlight, forest plan revisions are an important routine for the U.S. Forest Service in terms of adaptation and there exist opportunities for additional research that examines how these processes are addressing adaptation across different contexts. In addition, the findings across these chapters highlight the complexity of adaptation; successful adaptation ultimately requires a combination of supportive policies, useful scientific information, and adept actors able to navigate these dimensions and figure out how broad guiding concepts apply in specific contexts. A next step for research would be to develop a conceptual model that organizes these different dimensions and provides a basis for future research, and I present a preliminary structure for this conceptual model in the conclusion. Ultimately, this study demonstrates the value of studying adaptation in the specific context of the Forest Service, given the agency's history, current challenges, and future prospects in managing ecosystems for a range of social values.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Increasing temperatures and more variable precipitation patterns associated with climate change threaten ecosystems, human societies, and the benefits that ecosystems provide societies. Even with intensive efforts to mitigate greenhouse gas emissions, societies will need to make significant changes in order to adapt to the impacts brought on by climate change. For governments and their constituent agencies, this means developing and implementing adaptation policies. However, academic research has largely ignored the policy dimensions of adaptation (Javeline, 2014; Swart et al., 2014). Accordingly, a frontier for research involves examining how governmental agencies put adaptation policies into practice through decision-making processes shaped by existing institutions (Biesbroek et al., 2014, 2018b; Sieber et al., 2018). These processes require ground-level actors to use relevant scientific information and work out adaptation approaches suitable for the contexts in which they work, while continuing to comply with existing expectations (Füssel, 2007).

For government agencies that steward ecosystems and natural resources, adaptation involves preparing for a future where the occurrence of ecological change is certain but the magnitude, timing, and location of these impacts of climate change are uncertain (West et al., 2009). In the United States, one such agency, the U.S. Forest Service (USFS), has begun to develop adaptation approaches for the management of its 193 million acres (78 million hectares) of public forest and grasslands. The agency's statutory mandate for multiple use management requires it to concurrently provide for a range of uses of forests, including recreation, water for downstream users, grazing, timber production, and wildlife habitat. The statutes establishing the

agency's mission, predate awareness of climate change adaptation; however, in order to carry out its mission, the agency will need to implement adaptation for a range of ecological components and associated social benefits and in a range of social-ecological contexts (Joyce et al., 2009a). The current need for adaptation comes at a time when the agency is contending with the ecological legacies of past management decisions, as is apparent in the threat posed by wildland fires (Stephens et al., 2016). Furthermore, the agency's contemporary institutional landscape reflects the legacies of routines and commitments established in previous eras, which potentially present challenges to climate change adaptation (Benson and Garmestani, 2011a; Klyza and Sousa, 2008; Maier and Abrams, 2018).

The USFS has established a strategy for adaptation, through internal policies and guidance, that emphasizes the development of vulnerability assessments that provide scientific information to support adaptation in management decisions, and managing for resilience, which generally describes a system's ability to absorb disturbances and adapt to change (U.S. Forest Service, 2008, 2011a). However, managers face challenges in operationalizing resilience and using information from vulnerability assessments in actual decision-making (Bone et al., 2016; Wellstead et al., 2013). This endeavor of translating vague concepts and complex information from science into policy action reflects a broader challenge that government agencies, including the USFS face (Biesbroek et al., 2018b; Winkel, 2014). Furthermore, few examples of successful adaptation projects in U.S. federal land management exist in the literature (Bierbaum et al., 2013). Studies of adaptation in this context have focused primarily on managers' perceptions of the topic, and there is a need to examine how adaptation factors into real-world decision-making processes driven by the complex policies guiding the USFS. These processes reflect foundational statues like the National Environmental Policy Act of 1970 and the National Forest Management

Act of 1976, as well as associated institutions that guide how managers meet specific requirements of these statutes and other expectations that have emerged throughout the agency's history (Archie et al., 2012; Hagerman, 2016; Jantarasami et al., 2010). Accordingly, in this dissertation, I examine the USFS's adaptation practices with an emphasis on resilience and vulnerability assessments, and an eye towards how these efforts interact with the policy requirements, institutions, and processes that guide decision-making in the agency.

By focusing on these topics, my work makes contributions to two domains of literature. First, my dissertation demonstrates how institutions shape adaptation in a bureaucratic agency. This account thus addresses a growing need in the study of adaptation, which has largely ignored how public policy and administration shape adaptation. The studies that have occurred on the policy dynamics of adaptation have focused on other locations, and little work of this sort focused on the United States. In addition to advancing knowledge of adaptation policy, this dissertation informs what we know about the governance of public lands in the United States, a topic of interest in the academic literature and one that has generated considerable public interest in recent years. The USFS is about a decade into climate change adaptation, and the trajectory of climate change indicates that adaptation will remain an element of the agency's mission well into the future. My dissertation captures the early status of this endeavor, and thus highlights key themes and questions that will underpin future research into this topic. Accordingly, this account of adaptation contributes to the knowledge on how USFS as an agency has updated or resisted changes in its management paradigms in response to changes in ecological conditions and social preferences over its history (e.g., Hirt, 1994; Kaufman, 1960; Langston, 1995; Winkel, 2014).

1.2 Overview of literature

Adaptation in the U.S. federal government requires ground-level managers to put into practice concepts like resilience and vulnerability in specific contexts, through processes shaped by governance institutions and available scientific information. However, few studies to date have integrated these considerations, and there is a general lack of empirical work on adaptation in government bureaucracies (Biesbroek et al., 2015, 2018b; Eisenack et al., 2015). Given the cross-cutting nature of adaptation, studying adaptation requires the integration of ideas from different disciplines, including theories on resilience and vulnerability, knowledge management, and public policy. Furthermore, adaptation practices are still developing, and research into adaptation supports continued advancements in practice. In this introductory literature review, I provide an overview of how climate change affects forested ecosystems and the benefits that they provide societies, conceptual approaches to adaptation, knowledge management, and the turn to policy and governance in studies of adaptation. Each empirical chapter includes a literature review that provides specific theoretical and topical context for that chapter's content.

1.2.1 Impacts of climate change

Climate change has begun to and will continue to have significant adverse impacts on forested ecosystems in the United States and on the benefits that human communities derive from forests (Vose et al., 2012). These impacts are numerous and complex, often compounding one another and leading to unexpected outcomes. This section provides an overview of impacts that forest managers face; comprehensive accounts of these impacts are available in various publications, including the vulnerability assessments that are one of the focal subjects of this dissertation (e.g., Halofsky et al., 2018b, 2018a).

Climate change will drive shifts in the distributions and assemblages of plant communities, leading to the potential for novel ecosystem types in particular locations (Millar et al., 2007; Vose et al., 2012). Similarly, wildlife species may experience shifts in their suitable habitat (Friggens et al., 2013). Freshwater fish species are particularly vulnerable to increases in stream temperatures (Isaak et al., 2015). Climate change is exacerbating drought conditions, contributing to high levels of tree mortality (Williams et al., 2013). In addition to direct mortality impacts, stress from droughts will make trees more susceptible to other disturbances (Millar and Stephenson, 2015). Climate change is also contributing to more severe and larger fires (Millar and Stephenson, 2015; Westerling et al., 2016). Similarly, climate change contributes to more frequent insect outbreaks, which can lead to widespread tree mortality (Bentz et al., 2010). Changes in precipitation patterns resulting from climate change will also lead to increased flooding and associated impacts on ecosystems and infrastructure (Strauch et al., 2015). The severity and timing of these impacts will vary considerably across different ecosystem types and geographic locations (Vose et al., 2012).

The impacts of climate change stand to harm the ability of forests to provide the ecosystem services on which human communities rely (Millar and Stephenson, 2015). By Congressional mandate, national forests are managed for multiple uses, including recreation, timber, water, grazing, and wildlife and fish habitat; all of these uses stand to experience impacts from climate change (Joyce et al., 2009a). The fact that around half of water in the West originates as precipitation falling on national forests underscores the importance of these lands in supporting societal wellbeing in communities near and far from these lands, and climate change impacts on snowpack and precipitation patterns will harm the provisioning of water (U.S. Department of Agriculture Forest Service, 2012). The impacts of climate change thus interact

with socioeconomic determinants of community vulnerability, and adaptation in forest management has both ecological and social benefits (Murphy et al., 2015).

These impacts are well-established in the literature; however, little is known about the extent to which these impacts are salient to practitioners, and how managers are changing their management practices in response to these impacts. Thus, in this dissertation, I consider how managers interpret potential impacts of climate change in making management decisions.

1.2.2 Conceptual approaches to adaptation: resilience and vulnerability

The USFS uses management approaches for adaptation that focus on reducing the vulnerability of key resources, while increasing the resilience of landscapes and ecosystems (U.S. Forest Service, 2011a). The theoretical developments of these two concepts, vulnerability and resilience, reflect contributions from a range of disciplines in the social and biophysical sciences, as well as integrated inquiries on social-ecological systems. Recent review papers on both vulnerability and resilience have weighed their value and laid out common criticisms of both concepts (Ford et al., 2018; Moser et al., 2019). Scholars have highlighted similar challenges in the operationalization of both resilience and vulnerability, including ambiguity in their meaning and challenges with linking the concepts to actual decision-making (Ford et al., 2018; Moser et al., 2019; Olsson et al., 2015). Furthermore, the relationship between the concepts remains unclear (Gallopín, 2006). Nonetheless, as the USFS's adaptation approach indicates, vulnerability and resilience are central to contemporary adaptation policies, and papers have also highlighted considerable empirical and practical value of these concepts (Ford et al., 2018; Moser et al., 2019). Examining these concepts in a particular policy sector thus offers an opportunity to examine the operationalization of these concepts, their benefits for practice in this

context, and their drawbacks. The remainder of this section provides brief overviews of the concepts and key discussions in the literature.

Resilience

The current prominence of resilience in academic work, social discourse, policies, and management practices reflects the development of the concept over time through multidisciplinary research and thinking (Davidson et al., 2016; Moser et al., 2019). For ecosystems, resilience's roots reflect the work of C.S. Holling who introduced the concept to ecological theory, emphasizing domains of attraction, flexibility in management in response to irreducible uncertainty, heterogeneity, and persistence of key ecosystem features (Holling, 1973). Over time, the meaning and reach of the concept has expanded and resilience now serves as an organizing discipline for research (Carpenter et al., 2001; Gunderson, 2000). Uses of resilience often incorporate social dimensions, and describe qualities exhibited by individuals and communities, in addition to ecosystems (Brown, 2014; Cote and Nightingale, 2012; Lyon, 2014). However, criticisms of the applicability of resilience to social dynamics have emerged. Some social scientists are skeptical of resilience's relevance to explaining phenomena in social science disciplines, since the fundamental dynamics of social systems differ from the ecological dynamics that underpin the study of resilience and resilience's emphasis on maintaining certain system states may conflict with a desire for social progress (Brown, 2014; Cote and Nightingale, 2012; Olsson et al., 2015).

Scholars tend to classify uses of resilience into different types (Davidson et al., 2016; Moser et al., 2019). Bone and coauthors (2016) focus on three types of resilience in analyzing uses of the concept by the USFS. Engineering resilience describes "how fast a system can

recover to this state of equilibrium following disturbance," and uses of this definition emphasize efficiency and linear dynamics (Bone et al., 2016, p. 432). The second type of resilience, ecological or social resilience depending on the type of system of interest, describes "the ability of an ecological system or social system to withstand disturbance while still maintaining necessary functions" (Bone et al., 2016, p. 432). A focus on ecological resilience recognizes the complex, non-linear dynamics of ecosystems and how they may have multiple different stable states, thus contrasting with engineering resilience's emphasis on the efficiency of ecosystems' linear recovery following disturbances. Third, social-ecological resilience "deals with the capacity of an integrated social-ecological system to adapt to disturbance" (Bone et al., 2016, p. 432). Social-ecological resilience also describes a system's ability to reorganize, adapt, and transform (Bone et al., 2016; Davidson et al., 2016). However, these definitions tend to employ verbs that prove challenging to objectively and reliably measure, and operationalizing these different types of resilience in practice can prove challenging.

Land management for resilience is predicated on an understanding of system dynamics that recognizes uncertainty, interactions at different scales, and non-linearity (Walker et al., 2004). This manifests in forest management activities that enhance the diversity of species and structural stages at different spatial scalar extents, and emphasize ecological processes (Seidl et al., 2016; Swanston and Janowiak, 2016). Across these applications of resilience, understanding disturbance regimes and how they may change as a result of climate change is important in order to understand what a system should be resilient to, and disturbances offer opportunities for changes in management strategies (Seidl et al., 2016). The relationship between climate change adaptation and resilience warrants further exploration, because resilience has become synonymous with adaptation yet its historical focus on the maintaining a particular identity of an

ecosystem appears to conflict with the potential for fundamentally novel ecological and climatic conditions (Fisichelli et al., 2015; Rissman et al., 2018). While resilience is a dominant concept for adaptation, ecologists have also suggested managing for resistance and transitions in ecosystems (Millar et al., 2007; Peterson et al., 2011).

The literature suggests that planning for resilience requires collaboration between stakeholders, managers, and scientists through adaptive and cyclical processes, though there has been limited empirical inquiry into these processes (Resilience Alliance, 2010; Swanston and Janowiak, 2016; Wurtzebach and Schultz, 2016). A focal point for future research on this subject involves understanding how these governance processes affect the implementation of resilience as a policy and management goal, and the role of institutions in mediating the operationalization of resilience (Biesbroek et al., 2017; Cosens et al., 2014). Federal land management offers a useful context to study these dimensions of resilience, given the emphasis on the concept in policies, legal requirements for public involvement in land management decision-making, and the range of ecological and social settings in which the USFS operates.

Vulnerability

Vulnerability assessments provide targeted scientific information on the potential impacts of climate change in a particular location, and offer scientific grounding for adaptation actions (U.S. Forest Service, 2011b). Similar to resilience, a variety of fields, including engineering and psychology, use the term vulnerability; however, in the context of social-ecological systems, it refers to "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger, 2006, p. 268). Three central elements of vulnerability include exposure, sensitivity, and adaptive capacity

(Adger, 2006). Exposure describes "the degree of stress on a system." Sensitivity refers to "the degree to which a resource will be affected by that stress." Sometimes, exposure and sensitivity are collectively described as "potential impact." Adaptive capacity describes "the ability of a resource to accommodate or cope with potential climate change impacts with minimal disruption" (Swanston and Janowiak, 2016, p. 10). However, adaptive capacity, in particular, has proved challenging to conceptualize, especially in relation to resilience (Gallopín, 2006).

A recent review summarizes criticisms and uncertainties that the literature has identified with regards to vulnerability research. Similar to resilience, vulnerability can have meanings that vary across disciplines and contexts. As a result, there are concerns that vulnerability research lacks interdisciplinary collaboration, especially between social science and climate researchers (Ford et al., 2018). Additional challenges identified include a lack of use of vulnerability research in actual decision-making (Ford et al., 2018; Wellstead et al., 2016, 2013). These challenges reflect the field's interdisciplinary roots and subsequent application across a range of settings, and a next step for the subject is examining the practice in specific contexts. This dissertation achieves this need by examining the practice of vulnerability assessment in the USFS.

1.2.3 The development and application of knowledge through partnerships

As the use of vulnerability assessments in the USFS indicates, scientific knowledge offers a starting point for determining adaptation approaches. In the USFS, scientists and managers have formed partnerships for the coproduction of vulnerability assessments to support adaptation (J. E. Halofsky et al., 2018a; Littell et al., 2012). Studying these efforts aligns with recommendations in the literature on the use of scientific knowledge in environmental

management, which suggest focusing on interactions between scientists and practitioners, mechanisms for the development and communication of information, and the institutions that shape knowledge development (Cash et al., 2003). The literature has also promoted coproduction of science, where scientists and practitioners work together, in informing adaptation (Beier et al., 2017; Dilling et al., 2015; Dilling and Lemos, 2011; Kirchhoff et al., 2015, 2013; Sarewitz and Pielke, 2007). The literature suggests three criteria, salience, legitimacy, and credibility, as important qualities of knowledge that will inform action (Cash et al., 2003). Salience indicates that knowledge exhibits "relevance…to the needs of decision makers" (Cash et al., 2003). Legitimacy describes knowledge processes that are "respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in [their] treatment of opposing views and interests" (Cash et al., 2003, p. 8086). Credibility refers to the "scientific adequacy of the technical evidence and arguments" (Cash et al., 2003, p. 8086). Achieving these criteria may prove challenging in adaptation, as the complexity and uncertainty associated with climate change can make it challenging for scientists to provide conclusive projections for the future that managers also find useful (Füssel, 2007).

Working together requires scientists and managers to manage differences in rules, values, and priorities through boundary work (Cash et al., 2003; Gieryn, 1999; Wesselink, 2009). Science-management partnerships, central to adaptation in the USFS, are examples of boundary organizations, which "[facilitate] the interaction between science producers and users and stabilizes the science-policy interface" and offer opportunities to navigate the differences between these groups (Kirchhoff et al., 2013, p. 394). These interactions often focus on specific products, objects, and concepts (Cash et al., 2003; Star and Griesemer, 1989). Boundary objects refer to "efforts or outputs" of boundary work (Cash et al., 2003, p. 8089), which are "both

plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star and Griesemer, 1989, p. 393). The status of vulnerability and resilience as boundary objects present opportunities and challenges for adaptation (Adger, 2006; Brand and Jax, 2007).

While the improved delivery of scientific knowledge is necessary for successful adaptation, what can get lost in a focus on scientific knowledge is the fact that adaptation is ultimately a social process, guided by governance structures, institutions, and actors (Adger et al., 2009). Contemporary US forest governance is highly networked, meaning that agency managers must work closely with stakeholders (Maier and Abrams, 2018). Accordingly, it is important to consider how these relationships shape the development and use of scientific information for adaptation, and, as some suggest, opportunities may exist to better involve stakeholders in science-management partnerships (Ascher et al., 2010; Golladay et al., 2016). This dissertation thus advances understandings of knowledge development and use by examining how knowledge produced through boundary work fits into real-world decision-making processes.

1.2.4 Policy and the study of adaptation

This dissertation examines how the USFS, a federal agency with a policy history that dates back more than a century, addresses adaptation. Adaptation is a policy priority implemented through governance processes influenced by existing institutions and governance relationships. Across disciplines, there is a noted lack of research on adaptation as compared to climate change mitigation (Pielke et al., 2007; Swart et al., 2014). Political scientists, in particular, have largely ignored climate change adaptation, though recent efforts have sought to

change this (Javeline, 2014). Accordingly, understanding how governance processes and existing policies shape adaptation is a frontier in the literature (Biesbroek et al., 2015). Similarly, there is a growing interest in how public bureaucracies are addressing adaptation (Biesbroek et al., 2018b).

The turn to policy in adaptation studies comes in response to an emphasis in early studies on tracking adaptation progress by diagnosing technical, social, and political barriers to adaptation (Moser and Ekstrom, 2010). Several initial studies of adaptation in land management used this approach, highlighting how managers perceived a lack of adequately tailored scientific information, certain policy requirements, and aspects of the agency's structure as barriers to adaptation (e.g., Archie, 2013; Archie et al., 2014, 2012; Jantarasami et al., 2010; Laatsch and Ma, 2015). However, scholars have criticized this approach focused on barriers for oversimplifying the complex processes that guide how governments make and implement policies (Biesbroek et al., 2017, 2015, 2014; Wellstead and Howlett, 2013). As an alternative, scholars suggest focusing on the structure of networks of state and non-state policy actors, real-world policy processes that unfold over time, and interactions between policy actors and institutions (Biesbroek et al., 2015, 2017, 2018b; Wellstead et al., 2013, 2016). Institutions describe informal or formal requirements, commitments, or expectations that shape individual and collective activities in policy spheres (Crawford and Ostrom, 1995; Heikkila and Cairney, 2018; Moseley and Charnley, 2014; North, 1991). In studying adaptation as a policy priority, it is also important to recognize that adaptation is often incorporated into existing policy processes, rather than addressed on its own (Runhaar et al., 2018).

By studying adaptation as a policy priority, my dissertation stands to contribute to the growing body of literature focused on the contemporary dynamics of federal forest policy and

governance. Paradigms guiding federal forest management have evolved over time as a result of episodic crises focused on the legacies of overharvesting of timber and fire suppression, as well as broader sociopolitical forces (Maier and Abrams, 2018; Winkel, 2014). These past paradigm shifts affect how the agency pursues contemporary priorities like climate change adaptation.

Understanding decisions in the agency requires understanding how managers interact with external actors, how institutions shape land managers' actions, and how managers change or create new institutions to take on emergent challenges (Moseley and Charnley, 2014). The USFS currently operates as a networked agency reliant on external actors for the capacity and legitimacy needed to address contemporary forest management challenges (Abrams et al., 2017; Maier and Abrams, 2018). This appears to contrast with the agency's past, when it was able to remain largely insulated from most external influences and built a system for efficiently meeting its objectives (Fleischman, 2017; Kaufman, 1960). However, institutions, including legal requirements and informal expectations, from the agency's past continue to show up in contemporary decision-making (Maier and Abrams, 2018).

In response to the legacies of past management practices, contemporary managers are focused on the restoration of ecological processes, including fire, which requires them to plan across broader spatial extents and over longer timeframes than were previously common in the agency (Schultz et al., 2018). As management paradigms will undoubtedly need to evolve to accommodate adaptation, an important next step for the literature involves considering how these contemporary paradigms and the remnants of past institutions shape how managers address adaptation. My dissertation contributes to this need specific to the study of the USFS and also addresses the broader interest in adaptation as a policy priority implemented through governance processes that is apparent in the global literature on adaptation.

1.2.5 Overarching research objectives

I draw on these domains of literature to structure my investigation of climate change adaptation in the USFS. Specifically, I guide my dissertation research with the following overall aims:

1. Examine how land managers operationalize resilience in planning processes in light of scientific information, public expectations, and governance factors.
2. Investigate the practice of climate change vulnerability assessment in the USFS.
3. Explore how adaptation planning integrates with existing approaches to decision-making in specific contexts.

The three empirical chapters each focus on one of these research objectives by addressing research questions that align with the objective.

1.3 Overview of research methods and positionality

This section provides a general introduction to the qualitative methods used in this dissertation. Each empirical chapter includes its own methods section. The research objectives of my dissertation focus on governance processes. Qualitative methods are useful for understanding these decision-making processes, because they allow the researcher to understand how different episodes and factors interact with one another to produce particular outcomes (Charnley et al., 2017; Yin, 2016). Furthermore, qualitative methods support the in-depth examination and discussion of contextual factors (Charnley et al., 2017; Geertz, 1973). These methods also offer opportunities to capture differences in perceptions amongst governance actors, as well as the existence of a range of pathways leading to a particular outcome (Charnley et al., 2017).

For all three chapters, I used a combination of qualitative research interviews and document analysis for data collection. Interviews capture key actors' accounts and perceptions of focal processes and offer opportunities for follow-up questions and further probing by the interviewer (Yin, 2016). Documents offer perspective on policy statements, rationale for policy decisions, and scientific information that are involved in climate change adaptation. Furthermore, documents are often readily accessible, thus allowing for efficient research into a topic (Bowen, 2009; Siegner et al., 2018). In policymaking contexts, documents often contain explicit policy requirements with which actors comply (Cairney et al., 2019).

I used coding to analyze these data. Coding involves assigning descriptive phrases or words to excerpts of text. Codes are "a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data", and correspond to concepts suggested in the literature, as well as topics that become apparent in the research process (Saldaña, 2016, p. 4). To make sense of coded data, I wrote memos, which are written accounts capturing the researcher's though process in moving from codes to the presentation of the analysis. Memos allowed me to explore individual coded themes, group or contrast different themes, and search for the underlying phenomena apparent in the data (Lofland et al., 1995).

These memos served as the basis for writing up the findings from my research. In reporting results, I emphasized using thick descriptive narratives that incorporate quotations from interview participants when possible (Geertz, 1973). In addition, when relevant, I presented conflicting ideas shared amongst participants. Collectively, these efforts supported the validity of my work and ensure that the reader can determine whether the specific findings of my work are transferable to other contexts (Charnley et al., 2017). In addition, to ensure the validity and

trustworthiness of my findings, I triangulated findings across sources (Bowen, 2005; Yin, 2016). Furthermore, I guided my research with the underlying goal of my findings being useful to the people that participated in the research (Cho and Trent, 2006).

In qualitative research, it is important that the researcher acknowledges how their research principles and theoretical assumptions shape their inquiries (Moon and Blackman, 2014). Researchers bring their own motivations, responsibilities, and assumptions, and the researcher's position vis-à-vis research participants can affect the research process, what questions are asked, and what information gets shared (Cheng and Randall-Parker, 2017). Here, I discuss my positionality as a researcher, addressing the philosophy underpinning my research and my motivations. In their paper describing social science research to natural scientists, Moon and Blackman (2014) propose ontology, epistemology, and philosophical orientation as three fundamental elements of research. Ontology describes "the nature of reality," and differences in ontologies of researchers correspond with differences in views on whether there exists a single true reality versus multiple realities. Epistemology describes knowledge and how researchers know what they know. A key distinction in epistemology lies between the view that knowledge can be certain and objectively-derived and the view that knowledge is subjective and reflects the individual knowledge-seeker's perceptions and understandings of reality (Charnley et al., 2017, p. 81; Moon and Blackman, 2014). Moon and Blackman (2014) use the term philosophical orientation to describe this third element of research, which describes a researcher's purpose in engaging in empirical inquiry, which reflects their values, motivations, and assumptions (Moon and Blackman, 2014). This third element of research closely resembles the idea of axiology, which refers to a researcher's "goals underlying a particular approach to science" (Patterson and Williams, 1998, p. 289).

I see my own ontology as evolving; however, this dissertation largely reflects a structural realist ontology, whereby knowledge development works towards a single reality but the tools for getting there—the definitions, research techniques, and methodological approaches—are ever-evolving (Moon and Blackman, 2014). In engaging with this ontology, I find that it is important to recognize the limitations of our existing forms of knowledge generation, and, so, while a true reality may exist somewhere out there, we may never have the ability to entirely capture this reality. I find that this perspective is useful for the study of a topic like climate change adaptation, where understandings of key concepts are evolving, and, in many ways, the change and uncertainty associated with climate change make understanding what constitutes successful adaptation a moving target. Given this ontology, my epistemology essentially spans the line between objectivism and constructivism. For some topics, I see it as entirely possible to derive an objective truth that is empirically valid, verifiable, and generalizable. However, for other topics, I see a disconnect between our ability to understand these topics and the complexity of these topics. This latter situation suggests an epistemology of constructionism, which accepts that different individuals will construct different conceptions of truth especially with regards to complex and uncertain phenomena (Moon and Blackman, 2014). In terms of my axiology, I guide my overall research philosophy with the idea of pragmatism, meaning that the goal of my research is to produce knowledge that has value in its practical application (Moon and Blackman, 2014; Patterson and Williams, 1998). I was drawn to my topic of study given the societal need to take on climate change, and the opportunity through research to support adaptation efforts.

An additional element of positionality involves the relationship between me as a researcher, research participants, and the broader structural elements of adaptation research and practice. As an academic researcher, I had the time and incentives to take a big picture view of

the topic, and I recognize that many of the research participants with whom I spoke operated under more stringent constraints. In particular, as federal employees, interview participants had to work through challenges presented by national politics regarding their presumed ability to openly discuss climate change, as well as an extended government shutdown in the winter of 2019. I appreciate participants' willingness to candidly speak with me despite these challenges. Academic researchers often have a certain level of luxury to push big picture thinking on topics like climate change adaptation; however, practitioners often have important perspectives on these topics despite challenges that they may face in terms of accessing the academic conversations about these topics. Accordingly, I view qualitative research involving interviews with practitioners as an important opportunity for incorporating practitioners' perspectives into the academic discourse, and I sought to do that throughout the work associated with this dissertation.

1.4 Prior work, research funding, and outline of empirical chapters

1.4.1 Prior work and research funding

My dissertation research builds on my previous work on the topic. In my first year at CSU, I conducted research interviews with USFS managers in the Rocky Mountain Region (Region 2) about salient impacts of climate change, policies and concepts for responding to climate change, and scientific information supporting climate change adaptation. We published an article summarizing this research in *Climatic Change* in 2017 (Timberlake and Schultz, 2017). This research offered me an opportunity to learn about how managers understand climate change adaptation and highlighted themes that have become central to my dissertation work. I also worked with Professor Schultz, Dr. Linda Joyce with the USFS Rocky Mountain Research Station (RMRS), and the Intermountain Region of the National Forest System to organize a

workshop to examine key concepts in forest planning, including natural range of variation, ecological integrity, and climate change. We wrote a Research Note published through RMRS, summarizing the workshop process and offering resources for managers working with these concepts (Timberlake et al., 2018). Through this work, I gained an understanding of how land managers make decisions and the practical opportunities associated with the study of adaptation. I have also written a chapter on federal forest policy in the United States, which will be published in an environmental policy textbook. Writing this chapter gave me the opportunity to explore the development of the policy sector from the establishment of national forest reserves around the turn of the 20th century through the present-day.

Two projects provided funding support for my dissertation research. Led by Dr. Jesse Abrams, we received funding from the Joint Fire Science Program (JFSP) as part of a call for proposals on social-ecological resilience. This project[1] provides funding support for Chapter 2, titled "Navigating challenges in operationalizing resilience: a case study of forest planning on the Kaibab National Forest." Prior to engaging in this case study research, I helped to write a working paper summarizing policy mandates and resources related to resilience and federal land management (Timberlake et al., 2017). This work provided me with background in the theory, ambiguities, and promise associated with resilience. In addition to leading the field research and writing for the case study on the Kaibab National Forest that is included in this dissertation, I participated in field research for another case study focused on resilience in forest planning on the Francis Marion National Forest in South Carolina. I also contributed to our analysis of uses of resilience in Environmental Impact Statements conducted by the USFS, and I will help to

[1] The JFSP grant number for this project is 16-3-01-10.

develop a survey instrument used to examine managers' perceptions of the concept of resilience. We will publish additional papers that address these other tasks.

Based on our early work on climate change adaptation in the USFS, Professor Schultz and I received funding from the USFS's Office of Sustainability and Climate to examine climate change vulnerability assessments; this funding supports Chapters 2 and 3 of this dissertation. The overall goal of the work is to understand how managers consider climate change, including information provided through vulnerability assessments. The objective of the first phase of this project was to characterize the range of content, approaches, and findings of USFS vulnerability assessments. The objective of the second phase of this project was to evaluate the connection between vulnerability assessments, adaptation planning, and management action. As part of this project, we are developing a survey to identify characteristics of national forests and their social-ecological contexts that support robust considerations of climate change, which we will write about in additional publications beyond what is included in this dissertation.

My work across these projects and through my dissertation has yielded additional opportunities to contribute to other work. I worked on a paper led by Professor Schultz examining the implications and potential solutions to scalar mismatches in federal forest management, which was recently published in *Ecology and Society* (Schultz et al., 2019). Based on my work on the resilience working paper mentioned above, I was invited by the European Forest Institute to attend a workshop and contribute to a collaborative paper focused on supporting the operationalization of resilience by forest managers.

1.4.2 Summary of empirical research chapters

I present the empirical work of this dissertation in three chapters. I have written each of these chapter as a stand-alone manuscript for submission to a peer-reviewed journal. Below are summaries of these chapters.

Chapter 2: Navigating challenges in operationalizing resilience: a case study of forest planning on the Kaibab National Forest

Co-authors (in order): Courtney A. Schultz, Alexander Evans, Jesse B. Abrams

This chapter presents case study research on the Kaibab National Forest and its recently completed land management planning process. This work is part of the project funded by the JFSP. Drawing on qualitative research involving interviews and document analysis, this paper examines how forest managers working for the Kaibab National Forest in northern Arizona and their partners operationalized resilience in forest planning, as well as challenges came up in this process. This paper draws on theoretical literature on the concept of resilience and how institutions shape policy implementation. It addresses a need in the literature on resilience by examining how practitioners make sense of the ambiguous concept in a specific context, while also meeting longstanding institutional expectations. For the Kaibab, managing for resilience aligns with an ongoing emphasis in the region on restoring forests adapted to frequent fires, which addresses the legacy of past management practices and helps to adapt forests for climate change. Our research contributes to the literature on natural resource policy by demonstrating how the USFS's complex and layered institutions shape contemporary planning processes aimed towards preparing for the future. Furthermore, we outline how challenges associated with operationalizing resilience interact with key themes in contemporary forest governance,

including the networked nature of the USFS and challenges associated with balancing discretion and accountability.

Chapter 3: The practice of climate change vulnerability assessment in U.S. national forest management

Co-author: Courtney A. Schultz

This chapter, which we intend to submit to the journal *Forests*, presents results from a document analysis conducted as part of the project funded by the USFS Office of Sustainability and Climate. The paper presents a summary of the current status of climate change vulnerability assessment practice in the agency based on a review of 44 vulnerability assessments conducted by or for the USFS. Its research questions focus on four key topics of interest: the participants, partnerships, and processes used to develop vulnerability assessments, scopes of assessments, definitions and analysis of vulnerability, and support for application in decision-making. In addition to their relevance to the USFS's adaptation practices, these questions address prominent challenges in the literature on vulnerability research. Accordingly, this paper demonstrates how vulnerability researchers and their partners address key challenges in a particular context. On a practical level, it provides a useful guide to potential decisions that researchers would face in developing vulnerability assessment for forest and natural resource managers, and offers an overview for practitioners about the potential value of vulnerability assessments in supporting management activities, especially in the context of land management planning.

Chapter 4: Vulnerability and resilience in a bureaucratic agency: climate change adaptation in the U.S. Forest Service

Co-author: Courtney Schultz

This chapter, which we intend to submit to *Regional Environmental Change*, draws on qualitative research, including interviews and document analysis, conducted for the second phase of the project funded by the USFS Office of Sustainability and Climate. The overall objective of this phase was to examine how managers are using information from vulnerability assessments in decision-making and, more generally, how climate change is factoring into decision-making. This aim allows us to address a frontier in the literature on adaptation policy: how do bureaucracies address climate change adaptation given their traditional missions, institutions, and routines? For this chapter, we conducted research interviews with over 50 different individuals knowledgeable about climate change adaptation in three regions in the national forest system. Our findings capture how managers are incorporating climate change through existing policy processes, such as land management planning and project planning processes guided by the National Environmental Policy Act. We found limited evidence of climate change motivating new types of management activities or decision-making routines; rather, in most cases, climate change provided additional rationale for management activities that would likely occur absent consideration of the subject. We explore how various features of the USFS's administrative history and practices contribute to this status of adaptation practice. Even so, some instances where managers were pioneering new practices to address climate change exist, and these instances offer an opportunity to ascertain how adaptation may progress in the future in the USFS.

1.4 Conclusions

This dissertation examines the topic of climate change adaptation in the USFS, a federal manager of public lands across the country, with a focus on the topics of vulnerability assessments and resilience. I guide my work with the intent of contributing to the practical knowledge of adaptation in this particular context, and to contribute to the scholarly knowledge on public lands governance and adaptation policy. Collectively, the literatures on adaptation, resilience, and the development and application of scientific information have lacked engagement with specific decision-making processes and the policies that guide them. My dissertation advances these literatures by addressing this need.

As outlined above, the three empirical chapters follow in order. The final chapter presents conclusions, summarizing the overall messages apparent across the study. In addition, this final chapter discusses topics for future work in the field as a whole and for my own research.

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CHAPTER 2: NAVIGATING CHALLENGES IN OPERATIONALIZING RESILIENCE: A CASE STUDY OF FOREST PLANNING ON THE KAIBAB NATIONAL FOREST[2]

2.1 Introduction

In order to achieve their missions, land management agencies must restore natural disturbance processes in ecosystems to maintain ecological integrity, and doing so has become especially important in the face of inevitable but unpredictable impacts of climate change (Archie et al., 2012; Millar et al., 2007; Wurtzebach and Schultz, 2016). The concept of resilience, which generally describes a system's ability to absorb disturbances and reorganize to maintain its identity in the face of change, has emerged as a promising paradigm to guide natural resource management in response to climate change (Folke, 2006; Holling, 1973). Resilience often means different things in different contexts (Bone et al., 2016; Carpenter et al., 2001). This ambiguity leaves ground-level managers with the challenge of operationalizing resilience in specific social-ecological settings (Walker and Salt, 2012). However, there has been little research on this topic, and studies of the operationalization of resilience stand to make practical and theoretical contributions to natural resource management.

The U.S. Forest Service (USFS), which manages approximately 193 million acres (78 million hectares) of public lands, is conducting land management planning through approaches that emphasize resilience as a response to climate change and its impacts on ecological disturbances (Laatsch and Ma, 2015; Timberlake and Schultz, 2017). In line with statutory requirements, the agency's management units (i.e., national forests) periodically develop management plans that outline how they intend to meet various goals, including to manage for

[2] The authors for this chapter are as follows, in order: Thomas J. Timberlake, Courtney A. Schultz, Alexander Evans, Jesse B. Abrams.

ecological integrity in the face of changing conditions and provide for multiple uses of national forest lands (16 USC §528 and 36 CFR §219 et seq.). Forest planning processes are the primary venue in which the agency is addressing climate change adaptation, and the forest plans that result from these processes guide management for periods of more than a decade following their completion. Thus, these policy processes offer useful opportunities to study the operationalization of resilience given policy, institutional, and contextual influences. In this paper, we use a case study of land management planning on the Kaibab National Forest in Arizona, USA (hereafter, "KNF") to address the following questions: 1) How do managers operationalize resilience in forest planning? 2) What challenges complicate operationalizing resilience in forest planning?

2.2 Literature review

2.2.1 Resilience in concept and in practice

Resilience guides both theoretical and practical frameworks in environmental governance (Bone et al., 2016). Early writings on resilience focused on how ecosystems maintain particular states in light of disturbances (Gunderson, 2000; Holling, 1973). This type of resilience, referred to as ecological resilience, is defined as "the ability of an ecological system…to withstand disturbance while still maintaining necessary functions" (Bone et al., 2016, p. 432). Subsequent scholarship has expanded the reach of the concept to incorporate linkages between ecosystems and social systems; the term social-ecological resilience describes a social-ecological system's ability to absorb disturbances, independently reorganize, learn, and adapt (Davidson et al., 2016; Folke, 2006; Folke et al., 2002). Resilience thinking emphasizes taking a dynamic view of social-ecological systems, and embracing uncertainty, change, non-linearity, and cross-scalar

relationships (Walker and Salt, 2012). Applied to forest management, resilience thinking suggests that managers should emphasize functional ecological processes, enhance structural and species diversity, and pursue collaborative and experimental approaches (Seidl et al., 2016).

Critiques of resilience highlight the concept's lack of relevance to social sciences and its ambiguity. While resilience thinking potentially offers a theoretical lens for research on social-ecological systems, this application of ecological dynamics to study human and political elements can be problematic in light of the potential conflict between resilience's emphasis on maintaining a particular state of the world and the demand for social progress (Biesbroek et al., 2017; Cote and Nightingale, 2012; Davidson, 2010; Olsson et al., 2015). Numerous definitions of the different forms of resilience exist (Davidson et al., 2016; Timberlake et al., 2017). The expansive and changing scope of resilience makes its application in practice ambiguous, meaning that it is "subject to multiple differing interpretations" (Rainey and Jung, 2014, p. 83). The ambiguity of resilience has led to the concern that management for resilience does not adequately protect biodiversity (Newton, 2016). In addition, questions have emerged as to whether resilience is "old wine in new bottles," meaning that resilience may not be a substantive departure from past management paradigms (Bone et al., 2016, p. 437). Furthermore, while environmental policy has embraced resilience as foundational for climate change adaptation, concerns exist that the concept does not adequately allow for the ecological transitions that may prove necessary as a result of climate change (Bone et al., 2016; Fisichelli et al., 2015; Laatsch and Ma, 2015; Millar et al., 2007; Rissman et al., 2018).

Despite calls for conceptual clarity in the literature, several policies have codified the concept in contemporary land management and natural resource managers are using it across a range of contexts. Its ambiguity may allow it to operate as a boundary concept relevant across a

range of different settings (Brand and Jax, 2007; Meerow and Newell, 2016; Timberlake et al., 2017; Timberlake and Schultz, 2017). Nonetheless, operationalizing resilience in specific contexts presents managers and external partners with a challenging task, further complicated by uncertainty associated with climate change. Because resilience can be interpreted flexibly and must be operationalized locally, a frontier in the literature lies in understanding how actors translate resilience mandates included in agency-wide policies into plans in particular social, political, and ecological contexts.

2.2.2 Factors affecting the operationalization of resilience in federal land management

Here, we discuss factors that influence the operationalization of resilience and climate change adaptation in U.S. federal land management. The implementation of federal land management policies in the United States occurs through complex processes influenced by different categories of factors: institutions, the dynamics of the management unit, and socio-environmental context (Moseley and Charnley, 2014; Rainey and Jung, 2014). Institutions are formal or informal rules and expectations that shape individual and collective activities (Abers and Keck, 2013; Heikkila and Cairney, 2018; North, 1991). Within the USFS, institutions operate at multiple levels, including agency-wide policies, incentive structures, and norms for specific management units (Abrams et al., 2015; Moseley and Charnley, 2014). A diversity of procedural and prescriptive policies with roots in different political eras shape contemporary management decisions (Jantarasami et al., 2010; Klyza and Sousa, 2008). As an agency, the USFS is subject to national-level laws, policies, and budgetary processes, yet lower-level managers retain substantial autonomy to set management direction through formal plans and subsequent decisions within the scope of those plans (Laatsch and Ma, 2015; Moseley and

Charnley, 2014; Rainey and Jung, 2014). Due to declines in agency capacity and the "veto power" held by outside actors, the USFS often works closely with external stakeholders to achieve its mission (Maier and Abrams, 2018; Abrams et al. 2017). Out of these interactions come opportunities to engage in "institutional work" (Lawrence et al., 2009); this term describes activities where actors reshape, combine, or create new institutions (Berk and Galvan, 2009; Beunen et al., 2017; Beunen and Patterson, 2017). Institutional work can provide a useful mechanism for implementing resilience, given the concept's emphasis on self-organization in light of change and the need to balance stability and flexibility in putting resilience into practice (Beunen et al., 2017; Beunen and Patterson, 2017).

While the USFS has embraced resilience in strategies for addressing contemporary challenges associated with wildland fire and climate change, little is known about how the agency operationalizes the concept and how these processes interact with the influences discussed above (Bone et al., 2016; Timberlake et al., 2017). Our paper addresses this gap by examining how one national forest operationalized resilience in its institutional, social, and ecological context.

2.3 Policy developments for forest planning and resilience

The National Forest Management Act of 1976 (NFMA) requires management units to periodically develop land management plans that detail how the USFS will implement its multiple-use mandate and meet substantive legal standards to protect ecological conditions (Rasband et al., 2009). Following the passage of the NFMA, the USFS convened a committee of scientists, per requirements in the law, to inform the development of regulations guiding the implementation of the NFMA, commonly referred to as "the planning rule" and found at 36 CFR

219 et seq. In 1982, the agency promulgated a first set of regulations, which guided the initial development of land management plans for the various national forests across the nation under the NFMA. Following shocks to forest management in the 1990s, President Clinton's administration promulgated the 2000 planning rule, which emphasized ecological sustainability, in an attempt to replace the 1982 rule (Davis, 2008; Wilkinson, 1997). In response to concerns about this emphasis and the cumbersome planning processes laid out in the rule, the Bush administration put the 2000 planning rule on hold and tried in 2005 and 2008 to put forth new regulations that would require equal considerations of ecological, economic, and social sustainability in planning and ease compliance with the National Environmental Policy Act (NEPA) for planning processes. However, courts determined that the 2005 and 2008 rules did not comply with NEPA and the Endangered Species Act, and these rules did not take effect (Schultz et al., 2013). As a result, the USFS continued to operate under the 1982 planning rule through the 2000s, as allowed by transitional language in the 2000 planning rule.

In 2012, under the Obama administration, the USFS successfully promulgated a new planning rule, which emphasized collaboration, ecological integrity, and climate change, among other contemporary concepts. The 2012 rule included a transitional provision that allowed national forests that had already begun planning processes under the 1982 rule to complete their plans under that rule (Schultz et al., 2013). Under both the 1982 and 2012 rules, forest planning entails a multi-year process through which land managers use various sources of information, including public input and relevant science, to develop forest plans, which set the management trajectory for 10-15 years; specific management actions or projects are then implemented in line with the forest plan (Ryan et al., 2018; Wilkinson, 1997). Regulations allow for members of the

public to appeal forest plan decisions on the grounds of perceived procedural or substantive violations (Teich et al., 2004).

The KNF completed its first land management plan in 1988 following the 1982 regulations. It then began developing a revised forest plan in the mid-2000s, finishing in 2014. The planning process legally complied with the 1982 regulations, but incorporated ideas from the 2012 regulations. The KNF and other national forests in Arizona and New Mexico make up the Southwestern Region of the National Forest System. National forest units are situated within a hierarchical structure across nine different regions; Regional Offices guide activities within their regional jurisdiction and report to leadership working out of the Washington D.C. Office, which directs agency-wide practices, including through the development of planning regulations.

Policies addressing other aspects of forest management interact with planning processes. The USFS's approaches to wildland fire, climate change adaptation, and ecological restoration emphasize resilience. Agency guidance outlines a strategy for climate change adaptation that highlights restoring and maintaining ecological resilience and reducing vulnerability to climate change (U.S. Forest Service, 2011a). Similarly, the National Cohesive Wildland Fire Management Strategy, which guides fire management for the Department of Agriculture, which includes the USFS, and the Department of Interior, identifies "resilient landscapes" as one of its three goals (Cohesive Strategy Oversight Committee, 2014). In 2009, the U.S. Congress established the Collaborative Forest Landscape Restoration Program (P.L. 11-111; 16 USC §7303); the Four Forests Restoration Initiative (4FRI) is a project funded under the Program and includes land on the KNF. The 4FRI emphasizes resilience as a goal (Coconino and Kaibab National Forests, 2015); however, planning for the 4FRI has occurred separately from the KNF's forest planning process (Schultz et al., 2012).

2.4 Methods

Our paper addresses two questions: 1) How do managers operationalize resilience in forest planning? 2) What challenges complicate operationalizing resilience in forest planning? To address these questions, we use a case study approach, drawing on qualitative key informant interviews and document analysis, that allows us to examine a governance process in a specific context (Sieber et al., 2018; Yin, 2014). The KNF offers a useful case for exploring these questions, as it recently completed land management planning, and faces particularly acute challenges associated with the impacts of climate change and wildland fire (Fulé, 2008; Williams et al., 2010). Using a semi-structured interview approach, we conducted interviews with 23 individuals in-person and by telephone in Fall of 2017. Interview participants included members of the planning team, other staff on the KNF, USFS regional office employees, and people external to the agency affiliated with universities and non-governmental organizations. Our interview protocol addressed a series of predefined themes, but we also pursued additional topics that emerged during these conversations (Yin, 2016). During our field research, we also attended a public meeting involving the KNF and visited locations on the KNF and in surrounding areas. We used planning documents and suggestions by interview participants to purposively sample participants knowledgeable about the planning process, including KNF staff, regional USFS staff, and stakeholders from academic institutions and non-governmental organizations. In accordance with a protocol approved by our universities' Institutional Review Boards, we recorded and transcribed the interviews. We used documents, including planning documents and news articles, to provide context for the study and confirm findings in interviews; in addition, planning documents commit the KNF to particular management actions and thus provide valuable insight on the trajectory of forest management in the region (Siegner et al., 2018).

To analyze these data, we coded transcripts and documents (Saldaña, 2016). A code is "a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldaña, 2016, p. 4). We used an iterative process for coding, where we initially coded for general themes, including predefined themes based on the literature and themes that we identified during the initial coding process. We then looked for consistencies and conflicts across different coded text excerpts within a theme, and split some themes into more specific sub-themes. We developed memos building on this coding to summarize conclusions, highlight findings, and support the research process (Yin, 2016). In the interest of producing credible qualitative social science research, we triangulated conclusions across multiple interview subjects and data sources, but also strived to report different perspectives on issues (Charnley et al., 2017). In this article, we provide representative quotations for our findings and attribute these quotations to specific interview participants.[3]

2.5 Results

2.5.1 Operationalizing resilience in the Kaibab National Forest's plan

We began by examining how the forest plan, a key policy document guiding management, addresses resilience. The plan defines resilience as the "capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedback" (U.S. Forest Service, 2014a, p. 6). This definition cites the Forest Service Manual (FSM), which provides direction on how national forests implement policy requirements; it also replicates the definition of resilience provided in a

[3] The prefix to the numbered identifier indicates the interview participant's affiliation. A "*NF"* identifies individuals working for the Kaibab National Forest. A "*R*" refers to individuals working at the regional office. An "*Ext*" refers to individuals not affiliated with the Forest Service.

prominent paper on the concept (Walker et al., 2004). The goals of the plan include restoring ecosystem structure and historic frequent fire regimes, which will "improve forest resiliency in the face of climate change" (U.S. Forest Service, 2014a, p. 12). For several forest types, the plan sets desired conditions that indicate that the "composition, structure, and function of vegetative conditions are resilient to the frequency, extent, and severity of disturbances and to climate variability" (U.S. Forest Service, 2014a, p. 23). An appendix to the plan explains why managing for resilience will prepare the forest for the impacts of climate change.

We asked interview participants about how they understood resilience. Several interviewees referred to the plan definition, and others expanded on the definition, noting that resilience also involves learning how "to adapt to changes" [*NF_1*] and "inevitable" [*NF_7*] stressors. Similarly, several participants viewed resilience as a process: "Resilient doesn't mean we just hit desired conditions [and] we're done" [*NF_1*]. Many interview participants believed that disagreements over the meaning of resilience should not hinder getting started on ecological restoration, because the forest was seen as "way past the tipping point with our last 100 years of management" [*Ext_3*], representing an "ecosystem that's been pushed way out of the norm" [*Ext_1*]. Furthermore, participants suggested that the uncertainty of future conditions makes identifying a specific future desired state of the forest exceedingly difficult.

Echoing the forest plan, interview participants discussed how resilience applies to a range of ecological resource goals, including promoting groves of quaking aspen (*Populus tremuloides*), protecting natural waters including springs and wetlands, restoring grasslands, and restoring fire to Ponderosa pine (*Pinus ponderosa*) forests. Fire was by far the most important disturbance agent considered in the plan and by interviewees. The plan and interview participants highlighted that, for forested ecosystems, including Ponderosa pine and dry mixed conifer

forests, a resilient forest would be one where frequent low-severity fires occur, but high-severity fires burning in the canopy are largely absent. The occurrence of several prominent fires in the region, such as the Rodeo-Chediski Fire that burned in Arizona in 2002, convinced interviewees and the broader public of the need for ecological restoration, defined in the plan as the "process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (U.S. Forest Service, 2014a, p. 313). Restoration activities included mechanical thinning and timber harvests to create larger gaps between trees and more complex forest structures, and the reintroduction of fire to forests that historically would have had frequent fires but had experienced the exclusion of fire in the 20th Century. Participants noted that the overall goal of these restoration activities is to create forests resilient to fire and climate change.

In addition to resilience in the context of forests and fires, several participants noted that the hundreds of springs in the forest provide water, thus playing a key role in the ecology of the area, and are negatively impacted by climate change. Participants mentioned managing for resilience of springs as a response to these impacts. Participants noted social values associated with springs, including their "tremendous religious value to a lot of the native people" [*NF_3*]. The KNF's forest plan identifies seven Native American tribes that have "aboriginal territories and traditional ties to the land now administered by the Kaibab NF," including the Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, Yavapai-Prescott Indian Tribe, and Pueblo of Zuni (U.S. Forest Service, 2014a, p. 67).

2.5.2 Challenges shaping the operationalization of resilience

In considering themes that contributed to the operationalization of resilience, we identified several challenges that shaped this effort in the KNF's planning process. We discuss

ambiguity in policy direction, challenges in managing for the ecological process of fire, managerial discretion, and partnerships. We also consider ways in which managers navigated through these challenges. In presenting them, we recognize that many of these hurdles are not exclusively caused by the need to manage for resilience and would affect other aspects of federal forest management absent a mandate to consider resilience. However, here, we discuss how these challenges apply in the context of operationalizing resilience.

2.5.2.1 Ambiguity in policy direction

Ambiguity in policy direction manifested in the KNF's forest planning process in the form of turnover, layering, and conflicts between different policies that apply to forest management. The KNF officially began its plan revision in 2009, and, so, the process happened following several attempts to promulgate new planning regulations in the 2000s. The final plan, published in 2014, officially follows the 1982 regulations as allowed by a provision in the 2012 regulations; however, the KNF's planning staff emphasized scientific concepts "in the vein of the latest thinking" [*R_1*] as one participant put it, including resilience, and a plan structure that reflects the 2012 regulations and contemporary knowledge. Outlining this dynamic, another participant said, with some exaggeration, "we operated under five different planning rules" [*NF_2*]. Some participants expressed frustration with the 1982 regulations and other "antiquated rules" [*NF_7*] that led to prioritizing deadlines and accordance with regulatory requirements, such as a timber suitability spatial analysis, which some participants suggested came at the expense of more innovative land management approaches to restoring fire-adapted ecosystems.

This ambiguity in policy priorities placed the burden on unit-level managers to develop a coherent plan, according to most interviewees. Interview participants, internal and external to the

USFS alike, complimented the planning team, attributing the KNF's success to, in the words of one participant, "a very lucky confluence of very smart people being allowed to do work fast enough that they could get it done before they had to transfer to move up" [*Ext_5*]. According to an outside partner, the planning team expertly "cross-walked" different policy requirements, thus preventing the process from being "controversial and bogged-down" [*Ext_1*]. Similarly, one external partner classified the KNF as "probably the most progressive forest in terms of thinking about resilience, and climate change, and how we do restoration treatment" [*Ext_3*]. What factors made the KNF, in the words of one interviewee, "the little forest that could" [*NF_9*]? According to interviewees, the success reflects "savvy" [*Ext_5*] leadership able to navigate the political dimensions of planning while allowing the planning staff space to develop the plan and collaborate with partners. In addition, the forest's ecological features and proximity to the Grand Canyon make it, according to one participant, "a special part of the National Forest System" [*Ext_1*], and contribute to the retention of a high-caliber management unit staff.

2.5.2.2 Fire management

The KNF's approach to operationalizing resilience involved scaling up prescribed fire activities, which consist of managers intentionally setting fires to achieve resource objectives, such as reducing fuel loads or restoring wildlife habitat. In 2017, the KNF carried out prescribed fire activities on 15,000 acres (6,000 hectares), around 65 percent higher than the forest's ten-year average; this trend of increasing burning activities compared to the decennial average had also occurred in 2015 and 2016 (Kaibab National Forest, 2018). As several participants noted, the potential for negative health and aesthetic impacts of smoke from prescribed burning required the agency to consider the social dynamics of managing fire. As one participant said,

"smoke impacts [will always be] one of the major issues" [*NF_1*] associated with prescribed burning. Participants mentioned how smoke from prescribed burning could have impacts on various socially-valued endpoints, including "once-in-a-lifetime" [*NF_1*] visits to the Grand Canyon, college football games in Flagstaff, sought-after elk hunting on the Tusayan District of the KNF, visibility on interstate highways, and the health status of vulnerable populations. Still, participants noted that they have found ways to navigate these challenges, including justifying to the public the need for prescribed burning.

In addition to prescribed burning, according to participants, the KNF "is on the leading edge of managing fires" [*NF_6*]. Managed fires describe fires naturally ignited by lightning that managers do not attempt to immediately suppress and allow to burn in a controlled manner to achieve management objectives. Participants noted that certain institutions make the tactic difficult in practice. Several participants described how this dynamic played out in the past by bringing up the Warm Fire, which burned on the North Kaibab Ranger District in 2006. According to participants and documents describing this fire, the agency sought to manage the Warm Fire for resource benefits through an approach that policies at the time described as "wildland fire use;" however, the fire got out of control, burning nearly 60,000 acres (24,000 hectares; Kaibab National Forest, 2007; McMaster et al., 2010). One participant noted that policies at the time required that, once a fire manager decided to suppress a fire, they must continue to pursue full suppression of the fire and could not transition back to managing a fire for resource benefits (USDA Forest Service and U.S. Department of the Interior, 2004). According to the participant, this seemingly inflexible rule made fire managers hesitant to begin to suppress the Warm Fire, even as weather conditions became unfavorable for management of the fire. Interview participants noted that policies of this sort may have locked in managers'

decisions about whether to suppress or allow a fire to burn, and made it challenging to respond to day-to-day differences in weather. The Warm Fire had lasting impacts in terms of willingness to manage wildfires to achieve resource objectives (McMaster et al., 2010).

Several participants mentioned the Boundary Fire, which burned nearly 18,000 acres (7,300 hectares) following a lightning strike in the summer of 2017, as a recent example of a managed fire. The fire burned on the border between the KNF and Coconino National Forests, including areas located within the Kendrick Mountain Wilderness. The fire overlapped the footprints of past fires, including the Pumpkin Fire of 2000, and the footprints of some of these past fires provided fire lines that constrained the spread of the Boundary Fire (Lynch and Evans, 2018). Participants noted that the KNF's new forest plan provided justification for the agency to manage the fire instead of immediately suppressing it. Some participants viewed the fire event as an overall success in accomplishing restoration objectives; however, others noted several downsides associated with the managed fire, including soil erosion, the fact that some staff were upset by the decision, and the cost of the fire. Interview participants noted that, in response to frustrations among staff, forest leadership used an "after-action review" to learn about this event, concluding that the KNF should enhance collaboration between different resource areas, including fire and fuels, timber, and watersheds. The forest plan recognizes the need for learning about managed fires; with regards to frequent fire mixed conifer forests, the plan notes that: "The ability to manage naturally ignited wildfires to achieve resource benefits has been very limited, and much remains to be learned" (U.S. Forest Service, 2014a, p. 24). Collectively, these discussions from participants about fire management show institutional challenges that affect the restoration of fire-adapted ecosystems, as well as ways that managers have worked through these challenges.

2.5.2.3 Discretion and partnerships

Interview participants suggested that planning for resilience on the KNF may require increased flexibility to enable responsive management approaches. For example, some participants viewed the new forest plan as allowing "a lot more discretion in implementing projects on the ground to respond to changing circumstances" [*NF_6*]. Participants noted that this contrasts with the previous plan's more prescriptive approach, particularly in relation to protecting wildlife habitat. One participant noted how conservation efforts for the Mexican spotted owl (*Strix occidentalis lucida*), listed as threatened under the Endangered Species Act, and the northern goshawk (*Accipiter gentilis*) resulted in amendments to the earlier plan, which the participant described as "clunky" and "very detail-oriented" [*NF_8*]. This emphasis on discretion, especially with regards to wildlife, spurred some friction between the USFS and outside groups, because, as one participant put it, "wildlife is always a key issue that triggers a lot of buttons for a lot people in various ways" [*NF*_5]. A USFS interview participant described the flexibility of the plan: "we eliminated…a good amount of the standards and guidelines, and made the revised plan much more programmatic, [as], I think, it was always intended to be" [*NF_11*]. However, an external stakeholder lamented these changes, saying: "Well, the forest plans as of late have been remarkably vague…and really permit a lot of flexibility for the forest to change direction if they see fit" [*Ext*_8]. Similarly, while they recognized the need for restoration, some external partners that we interviewed suggested that the agency should prioritize the use of fire in restoration activities and questioned the use of timber harvesting as an ecologically sound practice.

A recent ecological restoration project on Bill Williams Mountain, just south of the KNF headquarters, illustrates the implications of these features of the plan. Project objectives included

"reintroducing fire as a natural part of the ecosystem" and "improving tree vigor and stand resiliency" (Kaibab National Forest, 2015, p. 3). Under the 1988 plan, implementing the project would have required site-specific amendments to the forest plan to remove standards and guidelines limiting management activities near Mexican spotted owl habitat. However, upon completion of the revised plan in 2014, these amendments were no longer necessary to implement the project as designed.

Concerns about this approach manifested when several environmental advocacy groups filed an administrative appeal to the USFS's Washington Office regarding the 2014 plan based on concerns about its consideration of climate change. The appeal argued that the plan violated several federal laws by not including "the reasonable 'no regrets' alternative proposed by Appellants," which would involve "creation of a forest plan specifically modeled to address climate change with a maximum of ecological caution" for key species (Center for Biological Diversity, 2014, pp. 3–4). The decision on the appeal determined that the planning process adequately considered climate change, and that the appellants did not provide adequately specific details on the proposed "no regrets" alternative (U.S. Forest Service, 2014b). Several interview participants noted that the appeal did not present a substantial challenge to finalizing the plan.

Several participants discussed how partnerships with external actors helped the KNF ensure accountability in light of increased discretion in the new plan. The plan revision process compelled the agency to, as one participant put it, "[talk] to a lot more people than we normally did" [*NF_11*], including stakeholder groups, politicians, and academic researchers. A participant credited the ability of a member of the planning team to build a network of stakeholders: "Somebody who can build those relationships…that's really key" [*NF_6*]. Participants highlighted how external partners were particularly helpful in terms of developing applied

scientific information, which provided scientific grounding for the plan's overall management direction. In some cases, this sort of external analytic capacity explicitly supported efforts to manage for resilience. For example, as the forest plan notes, the Kaibab Forest Health Focus, a collaborative endeavor led by faculty at Northern Arizona University, helped the KNF prioritize specific locations for restoration activities on the North Kaibab Ranger District with the overall goal of making the forest resilient to climate change and fire (Sisk et al., 2009; U.S. Forest Service, 2014a, p. 20). In 2018, the KNF began developing the Kaibab Plateau Ecological Restoration Project to implement recommendations from the Kaibab Forest Health Focus over an area of 500,000 acres (200,000 hectares).

In other instances, partnerships provided scientific information that did not directly apply to resilience, but helped the KNF identify and justify intended management activities. Several participants pointed to collaboration with researchers affiliated with the Ecological Restoration Institute (ERI) at Northern Arizona University, a congressionally established applied research entity, and The Nature Conservancy, a non-governmental organization, as sources of scientific information on wildlife and knowledge of planning concepts required under the 2012 planning rule. In addition, the Grand Canyon Trust, a non-governmental organization, developed a climate change vulnerability assessment for grazing allotments on the North Kaibab Ranger District, for which the Trust had acquired grazing permits.

The KNF also emphasized partnerships with Native American tribes whose traditional lands are located within the national forest boundaries in support of its plan development and management for resilience. Several participants highlighted collaboration with resource management staff and youth from the Hopi Tribe to design and implement restoration of the Elk Spring on the North Kaibab Ranger District; the KNF had not previously used this type of

collaborative approach. The KNF includes lands traditionally used by the Hopi and six other Native American tribes. Participants also mentioned how the springs restored in this manner would be more resilient to climate change.

2.6 Discussion

We examined how forest managers in a specific social-ecological context view and put into practice the concept of resilience given existing policies, the history of forest management in the region, and their understandings of resilience. For the KNF and its partners, resilience describes a condition of Ponderosa pine and mixed conifer forests with frequent, low severity fires and an avoidance of stand-replacing fires that spread through the crowns of trees. This vision of resilience aligns with a prominent management paradigm in the region focused on restoring frequent fire forests. Reactions to catastrophic fire events in the recent past and a concern about current and future impacts of climate change catalyzed the emergence of this paradigm, and were topics discussed by interview participants (Allen et al., 2002; Fulé, 2008).

The KNF uses a definition of resilience from an agency-wide policy, originally derived from scholarly literature (Walker et al., 2004). Other research has criticized a similar definition of resilience provided in the Forest Service Manual, noting its ambiguity and potential conflicts with definitions of restoration that emphasize the recovery of ecosystems to historical conditions (Bone et al., 2016). However, these critiques of resilience do not appear to be particularly relevant in the specific setting examined in this case study. As a result of a history of fire exclusion and unchecked timber harvests, the status of forests in the region, described as "way past the tipping point," demonstrated to managers and most external partners a clear need for restoration activities. These restoration activities intend to make forests resilient and support climate change adaptation, by moving forest structures towards historical reference conditions

and restoring frequent fires to these forests (Hanberry et al., 2015). Accordingly, in this context, the pressing and apparent management need cuts through the ambiguity of resilience and alleviates potential conflict between restoration and resilience. However, for other forest types, especially those with stand-replacing fire regimes, such as lodgepole pine (*Pinus contorta*), this approach to resilience, focused on restoring fire, would not be useful, and it could be that the ambiguity associated with resilience would present a more pronounced challenge than it did for the KNF (J. S. Halofsky et al., 2018).

The case highlights the inherent ambiguity in contemporary forest policy that has resulted from turnover in regulations guiding planning, layering of priorities from different eras, and outright tradeoffs between different policy expectations associated with the agency's multiple-use mandate (Klyza and Sousa, 2008; Rainey and Jung, 2014). While the forest officially completed its plan under the 1982 planning rule, the concurrence of the KNF's planning process with the development of the 2012 planning rule compelled the planning team to incorporate contemporary paradigms, including resilience and restoration, along with other traditional institutions from the 1982 rule and other policies (Benson and Garmestani, 2011b; Maier and Abrams, 2018). The planning team had to "crosswalk," or evaluate against one another, numerous institutional requirements, in order to ensure legal compliance, but, also, to identify a coherent path forward for management that would be acceptable to stakeholders. While resilience tasks managers with grappling with an ambiguous concept, ambiguity in policy goals is a natural feature of working in a government agency, especially one with multiple goals, a long history of policy layering, and management responsibilities across a wide range of ecosystem types and social settings (Rainey and Jung, 2014). Accordingly, managers likely already have some of the skills necessary to evaluate, eliminate, and create institutions in order

to address ambiguity (Beunen et al., 2017). Given the limited potential for legislative efforts to bring clarity to this ambiguity in policy direction, ground-level managers will need to continue to use these skills to devise appropriate responses to environmental change in the future (Abrams et al., 2018; Klyza and Sousa, 2008).

The KNF's approach to resilience emphasizes the ecological process of fire, and comes in response to a century of management decisions that were predicated on the assumption that humans could and should exclude fire from forests in the region (Allen et al., 2002; Fulé, 2008; Seidl et al., 2016). The practice of excluding fire occurred throughout the country for most of the 20th century and originally dates back to the early 1900s, when the newly established USFS began to suppress all fires as quickly as possible in response to the particularly devasting fire season of 1910, a mission to protect timber values, and a desire to justify its existence in the face of political challenges (Davis, 2006). The legacy of fire exclusion is apparent in ecological conditions, particularly in forests that would historically have experienced frequent fires, and in prevailing management institutions (Stephens et al., 2016).

In the present day, the agency has moved away from fire exclusion and managers on the KNF and elsewhere are enhancing their use of fire to restore resilient forests in line with agency policies. However, managing fires is inherently challenging given their unpredictability and the need to make effective and timely decisions. In addition, for prescribed burning, managers must get buy-in from the community, given the perceived risk associated with these activities and potential nuisance that smoke from these fires presents. Discussions presented in our study about prescribed fire and responses to past managed fire events highlight how, in contexts where operationalizing resilience requires restoring frequent fire regimes, managers likely must overcome institutional challenges that stem from the legacy of fire exclusion, and a tension

between discretion and inflexibility. There may be opportunities to overcomes these institutional challenges through local and context-specific institutional work, in addition to the broader scale policy changes that have largely been the focus of the literature on fire (Beunen et al., 2017; Schoennagel et al., 2017; Stephens et al., 2016).

The planning team developed a forest plan viewed as increasing discretion available to managers, by limiting the use of standards and guidelines, which had been central components in the previous KNF plan. Efforts to expand and contract managerial discretion have been a central administrative strategies in the Forest Service's history (Cheever, 1997). The 2012 planning rule's wildlife provisions demonstrate a recent turn towards discretion, characterized by reduced regulatory requirements for standards to protect wildlife in plans (Schultz et al., 2013). In this case, managers interpreted discretion as useful for resilience, given the concept's expectation that systems can reorganize to track changing conditions (Walker et al., 2004). However, this potentially results in a lack of formal mechanisms to ensure accountability. This interplay between increased discretion under a resilience paradigm and the protection of individual species highlights a debate that has spurred mixed opinions in the literature. One perspective argues that managing for resilience to fire should be a priority, which would then support high-valued specific resources, such as wildlife habitat (Stephens et al., 2016). Another questions the extent to which managing for resilience supports biodiversity (Newton, 2016). Furthermore, the ambiguity associated with resilience can lead to accusations that the concept could be used to "greenwash" commercial timber harvests (Laatsch and Ma, 2015; Timberlake and Schultz, 2017). As our interviews indicate, stakeholders are often quite skeptical of management projects that involve any level of commercial timber harvest, which likely reflects the history of conflict resulting from the agency's prioritization of timber harvests at the expense of wildlife and other

environmental objectives. Thus, for the USFS with its mission and history, implementing resilience requires managers to not only determine what the concept means in a specific context but also to figure out how to implement management activities that yield contribute to resilience and are perceived as legitimate by stakeholders (Bone et al., 2016; Maier and Abrams, 2018).

This debate over discretion and accountability in the context of resilience directs attention to the KNF's relationship with external stakeholders. Our case confirms that external stakeholders sometimes act as veto players through actions like appealing the forest plan, but also operate as key sources of capacity to develop scientific information targeted to the particular management context of the KNF (Abrams et al., 2017; Maier and Abrams, 2018). These scientific products included restoration strategies, informal advice, monitoring approaches, and information on climate change. Some products directly supported management for resilience, while others helped the planning team navigate ambiguity in policy direction and identify courses of action with their discretionary space that would be legitimate given stakeholders' preferences and the agency's mission. This highlights how collaboration as a source of capacity and legitimacy, a theme identified in the literature on forest governance, applies to the operationalization of resilience, an emerging imperative in federal forest management (Abrams et al., 2017; Seidl et al., 2016).

Given the networked nature of the contemporary USFS, the implementation of policy goals, including creating and maintaining resilient forests, occurs through the combined efforts of ground-level managers and their external partners (Abrams et al., 2017; Maier and Abrams, 2018). Our case suggests that the management staff on the KNF did a strong job of building partnerships with some stakeholders, and it is worth considering what features of the unit and its context have supported its success on this front. For the KNF, the development and nurturing of

these partnerships reflect both the forest staff's ability, a regional emphasis on collaborative restoration, and high interest in and capacity for supporting forest restoration found in organizations in the region. Its retention of staff for extended periods of time allowed these individuals to develop lasting relationships with external partners and provided relative consistency in personnel throughout the planning process. This characteristic of the KNF runs counter to a persistent challenge in the USFS, where frequent transfers in location and associated high levels of staff turnover hinder sustained external partnerships and multi-year planning processes (Davenport et al., 2007; Stern and Predmore, 2012). The KNF's proximity to Flagstaff provides access to partners associated with Northern Arizona University, federal research entities, and NGOs focused on federal land management; amongst these partners, there is a strong interest in the topic of forest restoration. However, the KNF does not directly border the city and, as a result, some interview participants suggested that it enjoyed some insulation from scrutiny that the neighboring Coconino National Forest faced given its location surrounding Flagstaff. Accordingly, management units located in different social contexts, where past decisions have spurred contention, may face persistent challenges in garnering support from stakeholders who often have opportunities to delay or block management action; this would complicate efforts by these units to enhance their discretion in line with the resilience paradigm (Maier and Abrams, 2018). In addition, managers in other contexts may not have similar opportunities associated with high capacity non-governmental organizations and a nearby university with a focus on natural resource management. In these other contexts, managers may find more prescriptive direction more appealing.

2.7 Conclusions

We examined how ground-level managers operationalize resilience within a structured planning process that still leaves room for local negotiation and institutional work. On the KNF, the policy goal of resilience aligned with the need to restore fire to these forests, and an ongoing emphasis on forest restoration in the region provided ready guideposts for operationalizing the concept. Still, several challenges shaped the planning process and its consideration of resilience, including ambiguity in policy direction, fire management, and the drawbacks of increased managerial discretion. Yet, managers and their partners found ways to work through these challenges, especially by updating the institutions that guide their actions, suggesting the importance of the interactions between ground-level managers and higher-level institutions. While these challenges and their solutions affect the operationalization of resilience, they also reflect broader themes in federal forest policy, including the turnover in NFMA planning regulations in the 2000s, the legacy of fire exclusion in the Southwest, and the longstanding competition between values oriented towards commodity production and environmental protection embedded in the USFS's mission and history.

Adding to the literature on U.S. forest policy, our study demonstrates how the addition of resilience to the USFS's layered set of conceptual policy goals played out in a planning process in a specific context. The setting for our study is a Southwestern national forest that contains ecosystems that have experienced substantial impacts from past fire exclusion and that are expected to bear the brunt of the impacts of climate change on forests. Given the growing use of resilience in government policies, an opportunity for the study of resilience involves examining how government agencies implement resilience as a policy goal in specific contexts, as we have done here. This work would benefit from the integration of perspectives from the literature on

resilience thinking with contributions from the study of public policy, especially on how ground-level practitioners make sense of ambiguous goals.

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CHAPTER 3: THE PRACTICE OF CLIMATE CHANGE VULNERABILITY ASSESSMENT IN U.S. NATIONAL FOREST MANAGEMENT[4]

3.1 Introduction

In order to support climate change adaptation planning, forest managers need access to targeted scientific information in order to devise appropriate management actions, identify priority resources and locations for intervention, and inform decision-making (J. E. Halofsky et al., 2018e, 2018a). Climate change vulnerability assessments offer a tool for natural resource managers to address these needs. Here, we use "vulnerability assessments" to describe the processes and resulting documents that identify potential impacts of climate change to forests and associated resources in particular locations (Füssel and Klein, 2006; Peterson et al., 2011). International and national policies for responding to climate change highlight vulnerability assessments as central elements to adaptation. Yet, various questions remain regarding the extent to which contemporary vulnerability assessment practices achieve their goals, and how principles for vulnerability research, a field that incorporates insights from a range of locations and research disciplines, apply to particular operational contexts (Ford et al., 2018).

In the U.S. Forest Service, a federal land management agency in charge of 78 million hectares (193 million acres) of forest and grasslands located throughout the United States, scientists and mangers are working together to coproduce vulnerability assessments, a central element of the agency's adaptation strategy (J. E. Halofsky et al., 2018a; Littell et al., 2012; U.S. Forest Service, 2011a). Over the past decade, agency staff and partner scientists have devoted considerable energy to completing a collection of vulnerability assessments that now cover

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nearly the entire system of national forests. Studying the agency's practice thus can identify lessons for other land management and forestry agencies. In this paper, we summarize the state of the practice with the intent of understanding early forays into climate change adaptation and informing studies on the future development and application of vulnerability assessments.

3.1.1 An overview of climate change adaptation policy and practice in the U.S. Forest Service

Here, we provide context on the U.S. Forest Service's climate change adaptation strategy to illustrate the role of vulnerability assessments. A series of Executive Orders from the Obama presidential administration established climate change adaptation and mitigation as policy priorities across the federal government; federal agencies, including the U.S. Forest Service developed strategic policies in response (Halofsky et al., 2016; Timberlake and Schultz, 2017). The Forest Service established the Climate Change Performance Scorecard in 2010, which required national forests and other management units to self-assess their progress in addressing climate change. It described objectives for each management unit with regards to climate change, and units scored themselves based on ten "yes/no" questions. One question asked: "Does the Unit actively engage with scientists and scientific organizations to improve its ability to respond to climate change?" Another question asked: "Has the Unit engaged in developing relevant information about the vulnerability of key resources, such as human communities and ecosystem elements, to the impacts of climate change?" This policy thus directed management units to engage in science-management partnerships and develop vulnerability assessments (U.S. Forest Service, 2011b). In line with the scorecard, Forest Service research scientists developed frameworks for adaptation that emphasize vulnerability assessments (Peterson et al., 2011;

Swanston and Janowiak, 2016). Some initial vulnerability assessment processes had also begun prior to the establishment of the scorecard (Littell et al., 2012).

Vulnerability assessments inform land management planning on national forests, a process where interdisciplinary teams determine the trajectory of management activities for periods upwards of a decade. The 2012 planning rule (36 CFR §219 et seq.), which outlines land management planning requirements in line with the National Forest Management Act of 1976, dictates that plans "maintain or restore the ecological integrity of terrestrial and aquatic ecosystems and watersheds," while considering climate change as a system stressor (36 C.F.R. §219.8). The rule lays out a three-phase planning approach, including assessment, plan development, and monitoring; stressors, like climate change, must be addressed during all three phases. It also requires forest plans to use "best-available scientific information" to inform the development of plans (36 C.F.R. §219.3). While one alternative proposed during the analysis leading to the 2012 planning rule would have required vulnerability assessments as a step in the planning process, the final planning rule does not provide specific legal requirements for vulnerability assessments (USDA Forest Service, 2012). Nonetheless, in line with the general requirements to consider climate change in planning, one intention of vulnerability assessments has been to support the plan revision processes conducted under this rule (Peterson et al., 2011).

3.1.2 The broader state of practice for climate change vulnerability assessment

A variety of fields, including engineering and psychology, use the concept of vulnerability. However, scholars have established approaches specific to examining potential impacts of climate change on ecosystems, other biophysical topics, and social-ecological systems (Adger, 2006; Turner II et al., 2003). In this context, vulnerability includes three components:

exposure, sensitivity, and adaptive capacity, and recommendations from the Intergovernmental Panel on Climate Change suggest analyzing vulnerability across these three components (IPCC 2007). Exposure describes "the degree of stress on a system." Sensitivity refers to "the degree to which a resource will be affected by that stress." Adaptive capacity describes "the ability of a resource to accommodate or cope with potential climate change impacts with minimal disruption" (Swanston and Janowiak, 2016, p. 23). As the field of climate change vulnerability research has grown, scholars have identified several points of contention about the field that inform our research questions (Ford et al., 2018). We discuss several of these points in the remainder of this section.

Scientists, trained in analyzing the impacts of climate change, often take the lead in producing vulnerability assessments; however, scholars also advocate for the involvement of stakeholders in vulnerability research (Mastrandrea et al., 2010; Turner II et al., 2003). Without involving stakeholders, vulnerability researchers run the risk of problematically classifying populations and locations as vulnerable without interrogating what causes this vulnerability (Ford et al., 2018). Furthermore, adaptation activities happen through social processes that reflect stakeholders' preferences and existing policies (Adger, 2006). To overcome this challenge, vulnerability assessments can integrate top-down scientific methods with bottom-up involvement of stakeholders, including environmental managers and their constituents (Mastrandrea et al., 2010; McNeeley et al., 2017). Previous research described how a lack of appropriate information limits U.S. federal land managers' ability to adapt to climate change and suggested that improved networks between managers and scientists could alleviate this challenge (Archie et al., 2014; Laatsch and Ma, 2016). Partnerships between scientists and managers have emerged as a central element of the U.S. Forest Service's response to climate change (J. E. Halofsky et al., 2018a;

Littell et al., 2012). Accordingly, in our analysis, we considered the actors involved and processes used to develop vulnerability assessments.

A variety of social and biophysical disciplines have contributed scientific knowledge to the development of vulnerability assessment practices (Füssel and Klein, 2006). Vulnerability assessment offers a common framework for examining climate change impacts to a range of different endpoints, including human communities, ecosystems, or their combination, social-ecological systems (Adger, 2006; Peterson et al., 2011; Swanston and Janowiak, 2016). However, the assessment of vulnerability for different endpoints requires different disciplinary methodologies, which may vary in their sophistication. Vulnerability research has faced challenges in terms of integrating contributions from different disciplines, especially in terms of balancing the relative contributions of social and biophysical factors in determining vulnerability (Ford et al., 2018). By law, the U.S. Forest Service manages for a range of uses of national forest land and ecosystem services, thus requiring the agency to implement adaptation across several different natural resource management disciplines (Joyce et al., 2009a). Accordingly, we considered the different types of resources considered in the agency's vulnerability assessments in order to understand how vulnerability assessment processes address different scientific disciplines.

The reach of climate change across different scales requires assessments to engage with the impacts of climate change across different spatial extents (Adger, 2006; Cash et al., 2006). However, scale issues have proved difficult to address in vulnerability assessments (Ford et al., 2018). Past studies have demonstrated that a lack of scientific information produced at an useful spatial scale represents a common challenge for natural resource managers, but downscaling projected climate change impacts to resolutions useful to managers is also challenging and

introduces uncertainty (Archie et al., 2012; Wiens and Bachelet, 2010). These types of scalar mismatches are particularly applicable in forest management (Fischer, 2018a; Schultz et al., 2019). In addition to considering the scope of assessments in terms of the types of social and ecological endpoints and resources covered, we also considered scope in terms of the spatial scale levels addressed in vulnerability assessments.

Vulnerability can have a vague meaning with different definitions used across different contexts, and multiple approaches to conceptualizing vulnerability exist (Ford et al., 2018). Approaches to determining vulnerability may involve expert elicitation processes and group deliberation, synthesis of peer-reviewed literature, climate change projections and modelling, geospatial analyses, or detailed case studies (Füssel and Klein, 2006; Mastrandrea et al., 2010; Peterson et al., 2011; Swanston and Janowiak, 2016). These methods present conclusions about vulnerability in different ways, with some comparing the relative vulnerabilities of different species, others identifying watersheds that are especially vulnerability, and still others presenting narrative summaries of how climate change may affect a particular resource. All of these types of approaches are in use in the Forest Service, and it was necessary to consider this variety in order to get a sense of the current state of practice (Peterson et al., 2011; Swanston and Janowiak, 2016).

Scholars and practitioners often criticize vulnerability research for a lack of application in actual decision-making processes (Ford et al., 2018; Wellstead et al., 2013). According to some authors, overcoming these criticisms requires a more robust recognition of governance and policy dynamics in the development of assessments (Wellstead et al., 2016, 2013). Others argue for the inclusion of stakeholders and decision-makers in the development of assessments, as these actors can provide insight on the policy constraints and opportunities for climate change

adaptation that they face (Enquist et al., 2017; Littell et al., 2012; Mastrandrea et al., 2010). Ideally, vulnerability assessments provide support for managers making decisions about an inherently uncertain future (Millar et al., 2007). Improving the application of assessments in forest management decisions represents a current priority for the Forest Service (J. E. Halofsky et al., 2018a; Janowiak et al., 2014b; Littell et al., 2012). Accordingly, we considered ways in which assessments sought to support decision-making, including through discussions of uncertainty.

3.1.3 Summary

The overall goal of our inquiry was to ascertain the current state of vulnerability assessment practice in the Forest Service. Our specific research questions are as follows and are based on the literature and early stages of our research (described in the next section): 1) Who participates in the development of vulnerability assessments and what processes do they use? 2) What are the scopes of vulnerability assessments? 3) How do assessments define and analyze vulnerability? 4) How do assessments support application in decision-making? We believe that this information is useful to practitioners implementing vulnerability assessments and to forest and land managers developing other vulnerability assessments. Our work also contributes to the growing body of literature examining challenges in vulnerability research (e.g., Ford et al., 2018).

3.2 Methods

The goal of our research was to examine several key questions in vulnerability research in the context of vulnerability assessment practices in the U.S. Forest Service. We worked

closely with the Forest Service's Office of Sustainability, which oversees adaptation in the agency and funded this work, to identify topics of interest and inform our approach. We retained control over the design of our research and how we present our findings. Our primary research method for this paper was a qualitative analysis of vulnerability assessment documents, a process that we designed based on a series of key informant interviews.

We began our research by conducting interviews with 11 scientists, who had worked on vulnerability assessments, in order to get a sense of what to look for in our document analysis. In semi-structured interviews, we asked scientists a series of questions about the processes that they used to develop assessments and topics that we should consider in our analysis of existing assessments; we also discussed other topics that emerged during our interviews (Leech, 2002; Yin, 2016). In line with a protocol approved by our university's Institutional Review Board, we recorded and transcribed these interviews. We then coded the transcripts of the interviews; coding refers to a process of assigning short, descriptive phases to blocks of text in order to identify themes (Saldaña, 2016). The intent of this analysis was to identify general themes and specific areas of inquiry for our document analysis. We settled on four themes that were commonly discussed by participants and that reflect themes in the literature: processes and partnerships used; scale and resources covered by documents; approaches to defining and assessing vulnerability; and application of assessments. These themes align with our research questions and the literature on vulnerability research indicates that these topics warrant further research.

Based on the interviews and other background research, we developed a document coding guide to analyze vulnerability assessment documents, and solicited feedback on the guide from interview participants. This guide included criteria for documents organized across the

themes described above (see Appendix B for interview guide). For example, within the theme of scale and resources, we recorded quantitative and qualitative information about the spatial area covered by assessments, as well as the general categories and specific species of resources addressed in the assessments. We used a spreadsheet to collect information for these criteria. For each vulnerability assessment, we began by skimming the document to get a general sense of its scope and structure; then, we conducted a targeted read of the document focused on specific points of interest. For certain questions, we used specific keyword searches to identify pertinent information; for example, searching for the term "define" and its derivatives (e.g., "definition") helped to efficiently identify definitions of vulnerability and other key terms. In addition, for other questions, we focused on specific sections of documents; for example, we first looked at vulnerability assessment introductions to understand participation in the vulnerability assessment process. This focus on documents is useful since these products can influence policy decisions (Siegner et al., 2018). We then composed analytic memos to summarize findings across our different research themes (Saldaña, 2016). In order to ensure the validity of our findings, we sought to triangulate our findings across sources (Charnley et al., 2017; Yin, 2016). In addition to reporting findings here, we are using this initial document analysis to inform case study research investigating the implementation of vulnerability assessments. We identified vulnerability assessments starting with a list provided by the Forest Service and did additional searches to identify additional assessments. We aimed to sample all assessments published during this period that intended to inform national forest management.

3.3 Results

In total, we reviewed 44 vulnerability assessments developed between 2010 and 2018 (see Appendix B for more details). These assessments cover national forests located across all nine regions of the National Forest System. These assessments include vulnerability determinations for forest types, key plant and wildlife species associated with forests, ecologically important endpoints like disturbance regimes and stream temperatures, hydrology, human uses, and ecosystem services. As discussed above, our analysis proceeds along four primary questions (see section 3.1.3), which reflect key themes in the literature on vulnerability research.

3.3.1 Participation, partnerships, and processes

In general, assessment processes involved several key steps, including convening a partnership of managers and scientists, assessing the current status of the system, projecting future climatic conditions, discussing future vulnerabilities, and identifying potential management responses (J. E. Halofsky et al., 2018a). Several common approaches existed, which tended to vary in use across the National Forest System regions. Table B.1 characterizes different approaches across regions of the National Forest System for vulnerability assessment and Table B.2 provides more details on processes used, including those described below. Two approaches were most common. First, the Adaptation Partners group developed assessments for several groups of forests in the Pacific Northwest (Region 6 of the National Forest System) and conducted regional-scale assessments for the Northern (Region 1) and Intermountain (Region 4) Regions (e.g., Halofsky et al., 2018e). Their approach involved scientists working with their disciplinary counterparts in management to research and write chapters focused on a range of

different resources. Second, using the Climate Change Response Framework (CCRF) developed by the Northern Institute of Applied Climate Science, scientists and managers have developed a series of bioregional assessments in the Midwest and Northeast (Region 9) (Swanston and Janowiak, 2016). While these CCRF assessments cover national forests, they are intended for a broader audience of forest managers working for a range of forest management jurisdictions. In addition to these two approaches developed and executed by Forest Service scientists, another commonly used approach involved applying a series of criteria (generally seven different metrics), which were originally developed by the Manomet Center, a conservation organization, and the Northeast Association of Fish and Wildlife Agencies, to assess vulnerability (Manomet Center for Conservation Sciences and National Wildlife Federation, 2013). This approach has been used to assess vulnerability in California, the Rocky Mountain Region, and for several national forests in the Intermountain Region (e.g., Kershner, 2014; Rice et al., 2018, 2017). Other assessments relied on general literature review and synthesis methods. A few assessments used methodologies specific to unique types of endpoints, including watersheds and socioeconomic endpoints (e.g., Hand et al., 2018; Lolo National Forest, 2016). Collectively, the processes used for vulnerability assessment reflect a range of methodological approaches, and demonstrate discretion available to managers in different regions and management units to determine an appropriate approach.

Most assessments reflected input from science-management partnerships who collaborated to identify target resources, interpret climate change projections and data, and make determinations about the vulnerability of resources. However, a few assessment processes used input only from scientists. While assessment publications did not consistently report numbers of participants, many of the assessments that used deliberative processes to determine vulnerability

brought together between 20 and 30 participants. At the high-end, the regional assessments for the Northern and Intermountain Regions each reached over 250 individuals through engagement methods like workshops. Scientists involved in these partnerships generally worked for the U.S. Forest Service Research and Development branch; some scientists worked for non-governmental conservation organizations and universities. Managers involved in most assessments worked for the Forest Service, including at the regional level or on national forests. Some of these managers had previous graduate-level scientific training and shared authorship responsibilities of assessment chapters with scientists. CCRF assessments also involved managers working for state, local, and tribal government management agencies, consultants and managers for private land, and conservation organizations.

3.3.2 Scope of assessments: spatial scale and target resources

We use the term "scope of assessments" to describe the spatial scale and target resources or endpoints addressed in assessments. The spatial scales used for assessments range from around 28,000 acres (11,000 hectares) for the El Yunque National Forest to 30 million acres (12 million hectares) of NFS lands covered by the Intermountain regional assessment. Several of the CCRF assessments cover bioregions of up to approximately 50 million acres (20 million hectares) across multiple different ownerships. Many of the assessments focus on extents between 2-10 million acres (0.8-4 million hectares) across one or several national forests. Collectively, the assessments considered in this assessment cover nearly the entire National Forest System; Table B.1 provides additional information on coverage across the National Forest System. Some units are covered by multiple different assessments, including a regional assessment as well as an assessment specific to that unit. Regional assessments often subdivide

their areas into sub-regions and also report results for individual management units. Most assessments summarize vulnerability and present spatial data for the target geographic area of the assessment, though some also include accounts of trends and vulnerabilities for broader geographic regions.

Assessments cover target resources or endpoints that reflect the different uses, resources, and management priorities included in the Forest Service's mission. Most commonly, assessments addressed the vulnerability of ecosystem, forest, or vegetation types; however, assessments conceptualized this type of endpoint in different ways. For example, the CCRF assessment for New England and New York assessed vulnerability for eight different forest systems, such as central hardwood-pine, with salience to local management organizations. The IAP assessment organized vulnerability determinations across forest vegetation types, such as montane pine forest, which reflect classifications used by the Intermountain Region of the NFS in planning and management. Assessments also covered non-forest ecosystem types, including aquatic ecosystems, non-forest and rangeland vegetation, and special habitat types, such as late-successional forest. For many assessments, input from managers in science-management partnerships helped to determine the ecosystem types and delineations of focus.

Other common endpoints included individual fish, wildlife, and plant species; recreational activities; ecosystem services and human uses other than recreation; watersheds, hydrology, and associated values; and, infrastructure. Some assessments incorporated climate change impacts on disturbance processes, such as fire, into determinations of vulnerability of vegetation types (see, for example, the Blue Mountains Adaptation Partnership, which incorporated disturbances as a textbox within a chapter on vegetation; Halofsky and Peterson 2017), whereas others provided separate chapters that assess the vulnerability of disturbance

regimes (see, for example, the Intermountain Adaptation Partnership; Halofsky, Peterson, et al. 2018). Some assessments linked biophysical vulnerabilities to impacts on human communities. The IAP, for example, examined this linkage in terms of the vulnerability of different ecosystem services, including water systems. An assessment for the Southwestern Region analyzed social-economic vulnerability in terms of the potential for vegetation change as a metric for exposure, economic ties between communities and national forestlands to describe sensitivity, and indicators of social adaptive capacity (Hand et al., 2018).

3.3.3 Defining and assessing vulnerability

We examined how assessments define and conceptualize vulnerability, finding that these approaches generally reflected guidance from agency scientists and the Intergovernmental Panel on Climate Change. Assessments commonly used the following definition for vulnerability from the Intergovernmental Panel on Climate Change: "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2007, p. 6). Most assessments discussed vulnerability in terms of its components of exposure, sensitivity, and adaptive capacity. Exposure and sensitivity were often combined into the single metric of potential impact. One scientist reflected on this approach and challenges associated with assessing adaptive capacity: "Often, the vulnerability assessments [follow] the 2007 IPCC report…that broke vulnerability into those three aspects: exposure, sensitivity, and adaptive capacity…I think we've done a pretty good job on the first two, [but adaptive capacity] is harder to get at." This challenge manifested in how some assessments include management interventions, such as planting a particular species of tree, as an element of

adaptive capacity, while others focused only on factors intrinsic to that resource, such as a tree species' ability to regenerate, to describe adaptive capacity.

Assessments generally included projections of future temperature and precipitation under different climate change scenarios and researchers used these projections as inputs for the determination of vulnerability, which involved modeling, group deliberation, or expert judgments. Commonly projected climate endpoints in vulnerability assessments included: increases in mean annual temperature; percentage changes in precipitation; seasonal minimum, mean, and maximum temperature and precipitation; and, snowpack metrics, including snow-water equivalent and snowmelt dates. Our research indicated that projecting climate change involves a series of methodological decisions, which include identifying general circulation models (GCMs) to represent physical climate dynamics and selecting forecasts of greenhouse gas emissions scenarios, which project flows of emissions into the atmosphere. Assessments tended to report ensemble projections, which average across different GCMs, and ranges that correspond to low-end and high-end emissions projections, to capture inherent uncertainties about the future trajectory of climate change. Newer assessments used Representative Concentration Pathways from the latest iteration of the Coupled Model Intercomparison Project (CMIP5) to anticipate levels of greenhouse gases in the atmosphere; in addition, these assessments drew on summaries of GCMs provided by the CMIP5. Assessments generally reported on projected climate endpoints aggregated over two or three future time periods using 30-year time slices, which are considered large enough to account for annual variability. Many assessments included end-of-century projections, and some included the caveat that forest planning timeframes cover only the next 10-20 years, highlighting a disconnect between projection and planning time horizons. Some assessments supplemented projections of future

climate with summaries of historic climate for the 20th century, which offered readers the opportunity to examine past events and trends in the context of climate.

Projections supported determinations of vulnerability, which assessments presented as narrative descriptions, rankings, categorizations, and the identification of vulnerable spatial areas. Narrative summaries qualitatively described vulnerability across its subcomponents based on review of peer-reviewed literature and modeling results. Most assessments included maps and tables summarizing model results to supplement these narrative descriptions. Facilitated group deliberation processes offered venues for the determination of vulnerability ratings organized in categories (e.g., low-medium-high). In these processes, each participant rated vulnerability in terms of subcomponents (e.g., potential impact and adaptive capacity) or criteria (e.g., range shift capacity, dependence on a specific hydrologic regime). These scores were averaged to provide an overall determination. Watershed assessments used downscaled climate projections and hydrologic modelling outputs to develop exposure and sensitivity indices presented on a map for each watershed within a national forest. Many assessments provided accounts of the level of uncertainty associated with determinations of vulnerability. Presentations of uncertainty often differentiated between a lack of or limited availability of scientific information and conflicts in evidence as sources of uncertainty.

3.3.4 Support for application in decision-making

Our analysis revealed several ways in which vulnerability assessments intended to support application in management decision-making. First, many assessments were peer-reviewed before publication. Most of these assessments (29 of 44) were published by the Forest Service's research stations as General Technical Reports, through a process which involves peer

review. In addition, scientists have published papers in refereed journals summarizing vulnerability assessment processes to share the approach with the academic community (e.g., Brandt et al., 2017; Halofsky et al., 2018e, 2018a; Janowiak et al., 2014a). Some assessments were published without peer review as white papers released by either national forests or partner organizations. Vulnerability assessment publications included devices to support the use of assessments, including one-page summaries, summary tables, and textboxes. Maps of model outputs also supported managers in identifying specific areas that were especially vulnerable. In addition, assessment processes used ESRI Storymaps to provide underlying spatial data to managers. Interview participants noted that partnerships create collective ownership of the end-product, build trust of scientists amongst managers, and promote mutual education. One participant described the mutual learning that results from these arrangements: "I think that's been very informative for both sides, because the scientists have some things to learn as well."

In developing assessments, authors intended to support improved decision-making in land management. As assessment documents and interviews with scientists highlight, many assessments were developed specifically to support upcoming forest plan revisions in the focal regions (e.g., Jennings et al., 2014; Rice et al., 2012). Forest plan revisions are a key venue for setting management direction for periods of a decade or more. The assessments that we reviewed sought to support planning by providing information on the current and future status of social and ecological conditions that could inform the development of plan content and by identifying management strategy that have adaptation benefits. Vulnerability assessments also sought to inform the motivation, design, and analysis of management projects through processes dictated by the National Environmental Policy Act. However, some scientists noted that they have to avoid providing recommendations on specific policy decisions, particularly when land managers

working in jurisdictions other than the National Forest System may use the assessments. Accordingly, assessments tended to focus on "climate-smart" management principles that offer broad advice or processes for incorporating climate change into project planning without specific prescriptions. For example, many assessments emphasized that managers seek to restore and maintain resilient ecosystems.

A key element of assessments were workshops where authors used presentations of preliminary assessment results to elicit discussion about actions that managers could take in response to identified vulnerabilities. These adaptation actions were included in tables in the published vulnerability assessments, thus providing a resource for managers seeking to identify management responses to climate change. Many of these actions were things that managers were already doing absent considerations of climate change, and, so, application may come through recognizing how existing management approaches prove to be "climate-smart." Vulnerability assessment authors associated with the Adaptation Partners group have compiled adaptation activities identified through several different vulnerability assessment processes into the Climate Change Adaptation Library of the Western United States (http://adaptationpartners.org/library.php). This compendium of adaptation strategies provides a starting point for managers not initially involved in vulnerability assessments to learn about potential responses to climate vulnerabilities (J. E. Halofsky et al., 2018e).

3.4 Discussion

Vulnerability assessments offer a practical tool to support adaptation across a range of environmental management contexts. Given the diversity of contexts in which vulnerability research is employed, a useful next step for the field involves understanding how vulnerability

researchers in a specific context are carrying out vulnerability assessment. Here, we have analyzed the current state of practice of vulnerability assessment in the U.S. Forest Service. Our findings highlight specific opportunities to improve this practice in the context of forest and land management, as well as contributions to broader understandings of vulnerability research. The remainder of this section is organized in four subsections, each corresponding to one of our research questions. These sections summarize findings in terms of the literature and raise questions for adaptation practice and future research.

3.4.1 Science-management partnerships: similarities and variations

The literature suggests that the people involved in vulnerability assessment will shape analytic decisions in developing the assessment, as well its prospects in being applied (Ford et al., 2018; Mastrandrea et al., 2010). We found that most vulnerability assessments considered in our analysis used some form of science-management partnership, though processes for integrating the collective insights of participants varied. By design, these partnerships involve the intended end-user, the land manager, in the development of the product. This is an established theme in the literature and by agency policies (Littell et al., 2012; Mastrandrea et al., 2010; U.S. Forest Service, 2011b). However, our findings highlight some variations in the extent to which assessments involved managers in the process, with some processes involving relatively limited engagement of managers beyond workshops to identify priorities and present information. In other processes, scientists and managers shared responsibility for a range of different tasks, including determining relative vulnerabilities through group deliberation, authoring reports, and identifying potential adaptation activities that managers could implement.

While the Forest Service is already using science-management partnerships, several dimensions of these arrangements warrant further attention. First, it would be useful to consider the extent to which partnerships are involving managers working at local levels, such as Ranger Districts in the Forest Service, versus primarily involving regional or national forest level staff. These local level staff may be able to contribute local knowledge to the process, and would have opportunities to implement vulnerability assessments in local decision-making. However, managers working in these roles often have limited time and capacity to devote to these efforts, and, if managers perceive involvement in vulnerability assessments as a burden, then the effectiveness of these processes will be diminished. Second, while some vulnerability assessment processes considered in this study have involved non-governmental organizations and other external entities, it is worth considering where stakeholders external to the agency, such as recreationists, ranchers, and water utilities, fit in vulnerability assessment processes. These stakeholders are affected by the impacts of climate change on national forests, and may be able to actively support adaptation actions. Third, as time progresses following the publication of these vulnerability assessments, it would be worth monitoring the extent to which different partners remain engaged in the application of vulnerability assessments, especially in light of frequent changes in location by managers. Prolonged engagement of these partnerships provides managers with opportunities to ask questions and follow-up on new scientific discoveries when applying vulnerability assessments in decision-making. Finally, research should consider whether managers' involvement in these vulnerability assessment processes ultimately manifests in substantive changes in forest management decisions.

Even within the US Forest Service, a single federal agency, a range of vulnerability assessment processes are in use, with differences especially apparent across regions of the

National Forest System. This reflects the level of discretion available to decision-makers working at different jurisdictional levels of the agency to determine how best to meet general agency directives regarding climate change adaptation. Decisions made through this discretion may reflect managers' individual preferences, their interpretations of how best to achieve objectives, and their understandings of the differences in the ecological and social characteristics of the contexts in which they work. The lack of uniformity in vulnerability assessment practices may have implications for the extent to which managers apply information in subsequent decision-making processes, and more broadly for the robustness of climate change adaptation practices across different regions and management units.

3.4.2 The expanding scope of assessments

The literature has identified challenges in addressing issues of scale in vulnerability research (Fekete et al., 2010; Ford et al., 2018). Current scientific projection and modelling methods may be unable to credibly produce information at the spatial resolution that managers would find useful in decision-making (Cash et al., 2006, 2003; Ford et al., 2018). The spatial extents of vulnerability assessments covered in this study vary. While many of the earlier assessments covered single national forest units, several of the more recent assessments cover broader spatial extents, including entire NFS regions. A smaller scale assessment may prove more salient to local managers and can include more focused analysis tied to specific places familiar to managers, such as individual watersheds (Cash et al., 2003). However, larger scale assessments, like the regional IAP and NRAP assessments, allow for more efficient coverage of management units in terms of effort from scientists, and, by bringing together managers from different management units, broader scale assessments can facilitate learning among managers

about practices in other units and coordinated adaptation responses across contiguous units, a key need in addressing the cross-cutting impacts of climate change (Bierbaum et al., 2013). Future research should consider whether this type of learning between management units within the agency is occurring, and how aspects of the agency's hierarchical structure and opportunities for decentralized decision-making shape these learning processes (Heikkila and Gerlak, 2013).

A next step for the practice will be developing ways to combine the efficiency of regional assessments with salience to local land managers. We found that regional assessments are incorporating devices to support salience to local managers, including dividing regions into sub-regions, providing summaries of results for each management unit, and providing downscaled spatial data and maps when relevant. As the literature suggests, the network of science-management partnerships that has emerged as a result of vulnerability assessments could help to navigate the inherent scalar mismatches between land management, ecological processes, and the impacts of climate change (Fischer, 2018a; Schultz et al., 2019). However, there is a need for future research that examines how managers deal with these scalar challenges in real-world adaptation decision-making processes. Ultimately, this challenge specific to vulnerability assessments reflects a persistent institutional fit challenge in forest management, where the scale levels at which forest managers operate often differ from the levels at which ecological processes play out, and, in turn, the scale levels at which scientists draw conclusions.

Vulnerability research spans multiple social and biophysical scientific disciplines (Ford et al., 2018). For the Forest Service and other agencies mandated to manage for multiple objectives, it is useful for vulnerability assessments to cover multiple endpoints corresponding to these various objectives, which range from timber production to providing wildlife habitat (West et al., 2009). As our research shows, the regional-scale assessments for the Intermountain and Northern

Regions, especially, capture a wide range of endpoints of interest to managers, tree species, broad ecosystem types, unique ecosystems, wildlife species, fish habitat, physical resources associated with hydrology, and the links between social systems and ecosystems. By covering a larger spatial scope, these regional assessments may also provide opportunities to efficiently cover more types of resources. It remains to be seen whether methodologies and resulting information from these different disciplines range in their sophistication and whether managers working on specific resources are more likely to engage in the development and application of vulnerability assessments.

3.4.3 Toward integrated vulnerability determinations

Given the cross-cutting nature of climate change, integrative approaches to adaptation prove necessary, and vulnerability assessments can support these efforts by identifying opportunities to align adaptation efforts occurring in different resource areas and to merge social and ecological dimensions of forest vulnerability. Policy scholars argue for integrated efforts across different environmental sectors to take on climate change (Duffy and Cook, 2018; Tosun and Lang, 2017). However, the U.S. Forest Service's administrative structure separates budgets and staff by resource area, which can present a challenge to integrated management approaches (Schultz et al., 2017). As we note above, approaches to analyzing vulnerability used in the agency vary depending on the resource in question, as well as the management context of interest. Assessment documents tend to present vulnerability determinations in separate sections for different resources. In some cases, there has been some engagement across related disciplines (e.g., hydrologists working with fish biologists). A potential opportunity for improvement would involve dedicated efforts to support integration. Vulnerability assessments could incorporate

additional chapters that discuss how vulnerabilities of different resources relate to one another, and managers could consult spatial overlays of vulnerabilities of different resources to prioritize specific locations for adaptation interventions. The planning rule includes regulatory justification for these approaches, noting that plans should support "integrated resource management" (36 CFR§219.10) defined as "multiple use management that recognizes the interdependence of ecological resources and is based on the need for integrated consideration of ecological, social, and economic factors" (36 CFR §219.19). Adaptation efforts across a wide range of forest management contexts would benefit from a consideration of how climate change may affect a range of ecosystem components and benefits, as well as the relationship between these different components. For vulnerability research, a key question is determining how to merge insights from multiple disciplines in a way that proves useful to natural resource managers.

A lack of integration between social and ecological factors has presented a challenge to vulnerability research (Fischer, 2018a; Ford et al., 2018). To address the social-ecological linkages inherent in vulnerability, the literature suggests techniques including "bottom-up" qualitative case studies, top-down quantitative indicators, and participatory scenario processes (Fischer et al., 2013; McNeeley et al., 2017; Murphy et al., 2015). Furthermore, the concept of ecosystem services, by design, recognizes the benefits that ecosystems provide human communities (Peterson et al., 2011). Several of the assessments that we examined address these linkages, including through qualitative case studies (e.g., Neely et al., 2011), "top-down" indicators of socioeconomic vulnerability (e.g., Hand et al., 2018), and chapters addressing ecosystem services (e.g., Halofsky et al., 2018d). There exist opportunities to scale up this focus on social and ecological linkages in vulnerability assessments and adaptation practices, in line with requirements of the 2012 planning rule. In addition to emphasizing environmental

sustainability, the rule indicates that plans should contribute to "social and economic sustainability" (36 CFR §219.8). Similarly, ecosystem services are included in the planning rule (36 CFR 219.8 and 219.10). A focus on social-ecological linkages and key ecosystem services could offer a useful starting point for managers working out what adaptation actions to prioritize. Accordingly, there is a need for more robust methods to forecasting impacts of climate change on key ecosystem services that extend beyond the qualitative description of impacts to ecosystem services that are currently prominent in the vulnerability assessments that we reviewed.

3.4.4 Supporting application

A common criticism of vulnerability research is a lack of relevance to policy-driven decision-making (Ford et al., 2018; Wellstead and Howlett, 2013). Vulnerability assessments represent an interim output in the chain of scientific and policy outputs that occur as part of adaptation processes in forest governance. Accordingly, for assessments to serve their intended purpose, these documents will need to inform subsequent policy decisions, and these policy decisions will need to have ecological and social outcomes that result in forests that are better adapted to climate change. Here, we consider ways in which vulnerability assessments can link to specific decisions required by policy. For the Forest Service, plan revision processes represent an important opportunity for implementing adaptation based on vulnerability assessments (Timberlake and Schultz, 2017). Furthermore, the 2012 planning rule represents one of the most significant changes in several decades to the policy processes employed by the U.S. Forest Service, and the plans that national forests will produce under this rule will guide management activities for periods upwards of a decade (Schultz et al., 2013). Our findings demonstrate that many assessments were intentionally developed to support plan revision.

As we have discussed above, there exist opportunities to align vulnerability assessments with specific planning requirements, which would enhance their applicability in decision-making. For example, the planning rule requires that plans provide for ecosystem integrity, which is defined as "the quality or condition of an ecosystem when its dominant ecological characteristics…occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence" (36 CFR §219.19). Vulnerability assessments can provide useful information on what the "dominant ecological characteristics" of a system will be in the future, thus allowing for a comparison with the current conditions and the natural range of variation (Wurtzebach and Schultz, 2016). For wildlife, assessments offer useful information about whether particular species are likely to continue to occupy a given management unit, which can help forests identify "species of conservation concern," a required topic in the planning rule (36 CFR §219.9). A key product of vulnerability assessments are suggestions for adaptation activities, which could be incorporated into specific plan components, as several recent forest plans have done. However, it would be useful to investigate the ways in which managers reconcile this information on vulnerability with other expectations that they face in the context of planning. These include ensuring public participation, using best available scientific information, and providing for multiple uses (Ryan et al., 2018). Furthermore, an important pursuit for future research involves determining the extent to which policy decisions that incorporate information from vulnerability assessments result in improved adaptation prospects for forests.

Managing for future forests under climate change requires accepting the notions that prediction of the future is inherently uncertain, current knowledge of the impacts of climate change on forests is limited, and disagreements about how to respond exist (Dewulf and

Biesbroek, 2018; Messier et al., 2015; Millar et al., 2007). For managers, there are disincentives to acknowledge uncertainty in cases where they perceive conflicts with other legal requirements and planning norms (Schultz, 2008). Assessments in the Forest Service use a range of approaches to acknowledge and characterize uncertainty. Our analysis of assessments indicates that information included in these documents, as well as group deliberations aimed towards determining adaptive responses that occur during the assessment process, could help to reduce some types of uncertainty. However, more work is needed to understand how managers use vulnerability assessments to make decisions in light of irreducible uncertainty about the future.

3.5 Conclusions

The current status of vulnerability assessments in the U.S. Forest Service reflects an early success in the agency's adaptation efforts in that scientists and their partners have developed a collection of assessments that, as a whole, cover the National Forest System, as well as forests under other management jurisdictions. However, more work will prove necessary as managers begin to apply assessments in guiding their actions. In their paper summarizing the state of forest adaptation practices in the United States and Canada, Halofsky and coauthors (2018) write: "We are optimistic that climate change awareness, climate-informed management and planning, and implementation of adaptation in forest ecosystems will continue to evolve in Canada and the US" (J. E. Halofsky et al., 2018a, p. 95). A similar statement appears in the IAP assessment. Similar to these statements, the literature emphasizes optimism in response to vexing environmental challenges, arguing for a focus on "bright spots" (Cvitanovic and Hobday, 2018, p. 1) or "small wins" (Termeer and Dewulf, 2018, p. 1). Identifying and sharing successes, as well as approaching the challenge of adaptation with optimism, can help adapters navigate conflict,

collaborate, and innovate (Cvitanovic and Hobday, 2018; Termeer et al., 2016; Termeer and Dewulf, 2018). The networking opportunities and new knowledge that have resulted from vulnerability assessments represent a series of small wins, and broader scale change may result from these initial small wins if agency leadership share these successes widely, help units that are stuck and determine why they are stuck, and provide appropriate resources. This paper provides a starting point for these efforts. However, our focus on the vulnerability assessments themselves and our use of qualitative research methods leave open opportunities for future research that examines the application of vulnerability assessments in policy processes, as well as quantitative analysis of vulnerability assessments.

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CHAPTER 4: VULNERABILITY AND RESILIENCE IN A BUREAUCRATIC AGENCY: CLIMATE CHANGE ADAPTATION IN THE U.S. FOREST SERVICE [5]

4.1 Introduction

To adapt to climate change, government agencies must adjust their practices to prepare for a different and uncertain future (Biesbroek et al., 2018b). Civil servants working in bureaucracies may respond to this need by incorporating climate change adaptation into existing decision-making processes or they may break from tradition and develop new approaches (Biesbroek et al., 2018b; Runhaar et al., 2018). In all likelihood, adaptation will involve a combination of repurposing existing institutions, innovation, and incremental change. However, a lack of research into the policy and administrative dimensions of adaptation means that we know little about why governments pursue different adaptation strategies (Biesbroek et al., 2015; Javeline, 2014). While the term often takes a pejorative meaning, our use of bureaucracy is descriptive in nature, referring to an administrative system where non-elected professional civil servants implement policies (Olsen, 2006).

For government agencies in charge of managing public lands, adaptation proves necessary in order to ensure that these lands and ecosystems continue to provide key goods and services. The missions of these agencies focus on managing ecosystems and natural processes for societal benefits, and they have had to respond to ecological change in the past (Joyce et al., 2009b; Millar et al., 2007; West et al., 2009). One such agency, the U.S. Forest Service (USFS), manages 78 million hectares of forests and grasslands for a variety of goals. While statutory laws guiding forest management have not changed to accommodate climate change adaptation, the

[5] This chapter will be submitted the journal *Regional Environmental Change.* Courtney Schultz is a coauthor for this paper.

agency has put in place internal adaptation policies, guidance, and directives over the past decade. These institutions establish a strategy for adapting to climate change that emphasizes applied scientific research on forests' vulnerabilities to climate change and managing ecosystems for resilience (U.S. Forest Service, 2008). A key question in the study of bureaucracies and adaptation involves understanding the extent to which government agencies forge new routines to address adaptation versus repurposing existing routines, and why (Biesbroek et al., 2018b). This question is especially pertinent to the USFS, given the fact that the agency has undergone several infrequent but significant changes in its management paradigms and associated routines throughout its century-long history in response to ecological change, politics, and public preferences, but, despite these changes, managers continue to use administrative routines established under past paradigms (Maier and Abrams, 2018; Winkel, 2014). Accordingly, this paper examines the approaches to climate change adaptation that the USFS is using and how its bureaucratic characteristics and history shape these approaches.

4.2 Literature review

Our study contributes to the growing literature on adaptation and public policy and administration. In this section, we review this literature with a focus on how bureaucracies' traits shape adaptation to climate change. We also review literature on the USFS and discuss key traits of this particular bureaucratic organization.

4.2.1 Bureaucratic characteristics and adaptation routines

Once a "taboo" topic, adaptation[6] is now prominent in many disciplines' research programs, though political science has lagged behind (Javeline, 2014; Pielke et al., 2007; Swart et al., 2014). Recently, policy scholars have begun to study how nation states' bureaucracies and their constituent agencies address climate change adaptation as an emergent policy priority (Biesbroek et al., 2018b). Initial work comparing national bureaucracies suggests the importance of government-wide administrative traditions, including structures, institutionalized routines and practices, opportunities for innovation, and engagement with external factors, including non-state actors, science, and politics, as explanatory factors for adaptation (Biesbroek et al., 2018a, 2018b; Buuren et al., 2018). However, bureaucracies are not monolithic, and individual agencies within a national bureaucracy have their own respective organizational characteristics (Peters, 2015). Accordingly, a frontier for the literature is to understand how the characteristics of individual bureaus, departments, and agencies shape their efforts to adapt to climate change.

For bureaucratic organizations, there exists a tension between the tendency to rely on established and slow-to-change routines to carry out mandated tasks and the need for innovation associated with climate change adaptation (Biesbroek et al., 2018b; Termeer et al., 2016). We use the term routine to describe the sets of actions and behaviors that bureaucrats regularly carry out. Institutions, including formal policy requirements and informal norms and expectations, shape these routines. In some instances, bureaucrats may mainstream adaptation, which describes approaching adaptation through existing policy requirements and processes. Mainstreaming may prove necessary in situations where substantive top-down policy change has not occurred to accommodate adaptation (Runhaar et al., 2018). However, these incremental advances associated

[6] We use "adaptation" as shorthand to refer to "climate change adaptation" throughout this paper, unless otherwise noted.

with mainstreaming may prove limited in their ability to prepare organizations for the vast challenges associated with climate change (Fischer, 2019; Termeer et al., 2016). Scholars interested in forest management, who have written about this topic, make distinctions between incidental and intentional adaptation (Boag et al., 2018) and between coping and adapting (Fischer, 2019). Across these perspectives (summarized in Table 4.1), there exists a need for research that examines the extent to which adaptation happens through existing versus new routines and how bureaucratic traits of government agencies shape this dynamic.

Table 4.1 – Spectrum of adaptation approaches

Mainstreaming – adaptation through existing policies, practices, and processes	*Dedicated adaptation* - adaptation through new policies, practices, and processes	(Runhaar et al., 2018)
Incidental – adaptive actions pursued due to motivations other than climate change adaptation	*Intentional* – adaptive actions pursued with the intention of responding to or preparing for the impacts of climate change	(Boag et al., 2018)
Coping – actions addressing climate change that are primarily autonomous, reactive, and incremental	*Adapting* – actions addressing climate change that are planned, proactive, and transformational	(Fischer, 2019)
Incremental change – small adjustments to practices	*Transformative change* – in-depth changes occurring quickly and over broad scopes	(Kates et al., 2012; Termeer et al., 2016)
Climate-smart forest management describes both existing management practices and novel management practices that prepare for climate change		(Peterson et al., 2011)

4.2.2 Examining bureaucratic characteristics and adaptation in the USFS

As the literature on bureaucracies and climate change adaptation suggests, we focus on several categories of bureaucratic characteristics of the USFS, which include the agency's structure, the interplay between discretion and requirements for uniformity in the implementation of policies, institutionalized routines for making decisions and completing required tasks, and how the agency interacts with external influences (Biesbroek et al., 2018b, 2018a). In terms of

structure and discretion, public administration scholarship once held up the USFS as an example of how bureaucratic organizations function through hierarchy (Fleischman, 2017; Kaufman, 1960). The agency has a national office that sets overall policies, nine regional offices, and around 150 national forest units found across these regions. However, despite the agency's hierarchical structure, there now exists discretionary space for local managers to tailor decisions to social-ecological contexts and figure out which of the agency's multiple goals to prioritize, and different management units, even within the same region, may take considerably different approaches to carrying out administrative routines (Biber, 2009; Moseley and Charnley, 2014). In addition to the National Forest System (NFS), which encompasses these management units, the USFS has a research branch that employs scientists who study topics related to forest management. Funds appropriated through the federal government's budget, as well as targets set by Congress and executive branch leadership, are important in determining on-the-ground activities. However, outside of funds for managing wildland fires, the Forest Service's budget has significantly decreased over the past couple of decades, despite increasing management needs brought on by climate change and the legacies of past management decisions (Fleischman, 2017; Hagerman, 2016; Moseley and Charnley, 2014). For example, the agency's budget for managing national forests in 2015 had experienced a reduction of 32 percent compared to what it had been in 1995 (USDA Forest Service, 2015).

The agency has a set of institutionalized routines that guide its decision-making, which originate with statutes passed in the 1970s (Klyza and Sousa, 2008; Moseley and Charnley, 2014). The National Environmental Policy Act (NEPA), enacted in 1970, requires federal agencies to analyze the environmental impacts of their activities and to involve the public in these processes (Moseley and Charnley, 2014; Stern et al., 2010). Passed in 1976, the National

Forest Management Act requires managers to develop and periodically revise land management plans for national forests, which set management goals, zone allowable land uses, and set standards for management. Planning has proven difficult for the agency due to a lack of investment in the process and turnover in planning regulations in the 2000s, and many forests continue to operate under plans that are several decades old (Davis, 2008; Schultz et al., 2013; Wilkinson, 1997). Nonetheless, in 2012, the agency promulgated new planning regulations, which require consideration of climate change, and efforts are ongoing to revise many outdated land management plans across the country (Schultz et al., 2013; Timberlake and Schultz, 2017).

External factors, including public preferences, political influences, and science, influence bureaucracies' decisions pertaining to climate change adaptation (Biesbroek et al., 2018b; Moseley and Charnley, 2014). The present-day USFS is a networked agency, meaning that federal land managers work in collaboration with non-state entities, including industry and environmental NGOs, to accomplish management goals. These external actors determine the legitimacy of the agency's decisions and often offer external capacity not otherwise available to agency managers (Abrams et al., 2017; Maier and Abrams, 2018; Winkel, 2014). As past events demonstrate, local and national politics shape the policy priorities that the agency pursues (Fleischman, 2017). For example, President Clinton became involved in conflicts over timber harvesting and wildlife conservation, the development of planning regulations, and efforts to protect roadless areas in national forests from subsequent development; President Bush, who followed in 2001, sought to reverse some of these administrative initiatives (Davis, 2008; Nie, 2004; Winkel, 2014).

Throughout the USFS's history, science has played a complicated role in interacting with policy to inform management. In some instances, managers have relied on science to bolster their

chosen management approaches. In others, scientific discoveries have led to challenges to ongoing management activities. The agency has also solicited the help of scientists to chart paths through controversies (Winkel, 2014). For instance, one of the most substantive paradigm shifts for the USFS occurred in the late 1980s and early 1990s when scientific research highlighted the negative impacts of timber harvesting on the viability of Northern spotted owl (*Strix occidentalis caurina*) and other wildlife species found in national forests in the Pacific Northwest. Interpretations of this science indicated that the USFS was not fulfilling legal requirements in the NFMA and the Endangered Species Act of 1973 (Noon and Blakesley, 2006; Schultz et al., 2013). President Clinton then established teams of scientists to inform decisions about how to address this crisis, and scientists have remained involved in informing management in this context (Winkel, 2014). Given the complexity of responding to climate change, the agency's adaptation strategy also places science front-and-center in informing management action (J. E. Halofsky et al., 2018a). Scientists with the USFS have written publications providing overviews of key scientific concepts related to adaptation, including resilience and adaptive management (Millar et al., 2007; Peterson et al., 2011; Swanston and Janowiak, 2016).

Beginning in 2008, the USFS put forth a series of internal policies, guidance, and directives for climate change adaptation (U.S. Forest Service, 2008). This strategy centers on three principles: assessing the vulnerability of ecosystems to climate change, engaging in partnerships, and managing for resilience through ecological restoration and other activities (U.S. Forest Service, 2011a). These principles reflect a recognition that preparing for climate change requires scientific knowledge of how it will affect forested ecosystems, collaboration between government bureaucrats and external stakeholders and scientists, and management actions that respond to the impacts of climate change on disturbances such as fire (Hagerman, 2016;

Timberlake and Schultz, 2017). The 2012 planning regulations described above include requirements for planners to consider climate change as a system stressor and driver, and also emphasize planning principles that are conducive to climate change adaptation, such as monitoring (36 CFR 219.8). In addition to these policies specific to the agency, the Council on Environmental Quality in the Obama Administration produced guidance in 2016 for federal agencies for addressing climate change in NEPA analyses (Council on Environmental Quality, 2016). However, through an executive order, the Trump Administration repealed this guidance in the next year (White House Office of the Press Secretary, 2017).

4.2.3 Summary

These characteristics of the USFS as a bureaucratic organization inform our study of climate change adaptation in this agency. For the USFS, adaptation represents a natural priority given the agency's mandate to manage ecosystems for benefits to human communities and the impacts of climate change on forests. However, it is not codified in statute and may lack political support. Thus, the burden of adaptation falls to ground-level bureaucrats who must work out ways to address the priority through existing routines and practices, and to innovate when possible. Two research questions guide our research:

1) How is the USFS incorporating climate change into existing decision-making routines and activities and to what extent has the agency developed new routines for climate change adaptation?
2) How do bureaucratic traits of the USFS shape its considerations of climate change adaptation?

4.3 Methods

We used qualitative research, which combined research interviews and document analysis, to address these research questions. This approach is appropriate given our interest in climate change adaptation in policy processes and how managers understand this goal, as well as the relative paucity of existing research on this topic (Yin, 2016). Given the agency's hierarchical structure, we focused our research on three regions of the National Forest System in the western United States, where federally owned lands are concentrated (see Table 4.2 for details on the regions that are the focus of this research). The system of national forests is divided into nine geographic regions, and regional offices play key roles in interpreting national policy requirements and supporting implementation at ground levels (Moseley and Charnley, 2014). These three regions vary in social-ecological context, institutional history, and dominant uses. For example, the Pacific Northwest Region (Region 6) historically produced large amounts of timber; however, it was also the epicenter of conflicts in the 1990s over timber production and the protection of wildlife species and their habitat. Timber production is less of an emphasis in Region 2, the Rocky Mountain Region; however, managers in this area must contend with the challenges of high recreational use of national forests and the presence of many homes and communities located near to national forests. National forests in the Northern Region (Region 1) encompass key pieces of large ecosystems that generate considerable scientific and conservation interest and that offer habitat for iconic species like the grizzly bear (*Ursus arctos horribilis)*. In addition, the availability of vulnerability assessments, which provide scientific basis for adaptation, varies across these regions. In Region 6, the Adaptation Partners, a group of scientists, have led a series of sub-regional vulnerability assessments that consider the vulnerability of forested ecosystems and a range of other associated resources. In Region 1, the

same group conducted a single region-wide vulnerability assessment. In Region 2, there has been a regional vulnerability assessment that used a different approach and that only covers a selection of key ecosystem types.

We conducted semi-structured interviews with land managers working in regional offices and with national forests within the chosen regions, as well as scientists who have worked on vulnerability assessments. We used a purposive sampling approach that identified individuals working in specific roles that would require consideration of climate change, such as ecologists and forest planners, individuals involved in vulnerability assessment and other climate change processes, and suggestions from other interview participants (Yin, 2016). In total, we spoke with 55 individuals. This allowed us to reach saturation for key themes, meaning that we did not hear substantively new ideas in our final interviews (Yin, 2016). Qualitative interviews provide in-depth looks at how practitioners address challenges like climate change adaptation, including how they interact with scientific information (Posner and Cvitanovic, 2019). Our semi-structured interview approach addressed a series of topics included in an interview guide; however, we also asked follow-up questions and pursued lines of inquiry that came up in the course of our interviews. With the consent of participants, we recorded interviews or took detailed notes. Recorded interviews were then transcribed (Yin, 2016). The research was conducted in accordance with a protocol approved by our institution's Institutional Review Board.

We also collected documents to inform this study, including: vulnerability assessment publications and associated documents (e.g., workshop agendas and fact sheets); agency planning documents, such as land management plans and environmental impact analyses; administrative reporting on completed work and accomplishments; and peer-reviewed literature addressing vulnerability assessment processes. Documents capture official perspectives on a

particular issue and policy commitments in forest management (Siegner et al., 2018). We identified these documents based on suggestions from interview participants and reviews of websites. We read these documents in order to confirm findings from our interviews and ascertain additional details and background information on decision-making processes and contexts addressed in this study.

We analyzed data from interview transcripts by coding for themes, including pre-determined topics as well as ideas that determined in the process of conducting interviews and subsequent coding. These predefined topics generally corresponded to concepts from the literature summarized above. A code is "a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldaña, 2016, p. 4). We grouped codes into broader categories, and then collectively examined the text included under each code. We also considered relationships between different codes and contradictions apparent in the data (Antin et al., 2015; Attride-Stirling, 2001). As a next step, we wrote analytic memos to examine specific themes, including adaptation approaches and bureaucratic characteristics (Lofland et al., 1995). In the process of writing memos, we also consulted documents in order clarify findings from interview transcripts.

To ensure validity, we triangulated findings across multiple interview participants, and to use both interviews and documents to support findings. We use quotations to capture participants' own words; these text excerpts allow readers to make their own interpretations based on our data. These quotations along with contextual details also provide readers with information to assess the transferability of our findings to other contexts (Charnley et al., 2017). As researchers, we have maintained prolonged engagement with this topic through this study, earlier phases of this work, and other prior research on climate change adaptation in the USFS.

We have also sought to ensure the utility of our research to the participants in our research (Cho and Trent, 2006). Collectively, these efforts enhance the trustworthiness of our research.

Table 4.2–National Forest System regions considered in this study

Region	**Region name**	**States**	**National forests within this region mentioned in the text**	**CCVA coverage**
Region 1	Northern	Idaho, Montana, South Dakota, North Dakota	Custer-Gallatin National Forest	Northern Region Adaptation Partnership (NRAP) CCVA published in 2018
Region 2	Rocky Mountain	Colorado, Wyoming, Kansas, Nebraska, South Dakota	White River National Forest	Regional ecosystem CCVA published in 2018
Region 6	Pacific Northwest	Oregon, Washington	Mt. Baker-Snoqualmie National Forest	Series of sub-regional and multi-resource CCVAs conducted by Adaptation Partners between 2008 and present

4.4 Results

We first discuss routines and activities for adaptation in the USFS. We highlight the emergence of new routines and the incorporation of adaptation into existing routines. Then, we discuss how bureaucratic features of the agency shape these efforts, including the agency's structure and relationship with external factors.

4.4.1 Routines and management activities for adaptation in the USFS

Our research highlights how climate change adaptation in the USFS will require a series of linked processes, including the development of climate change vulnerability assessments, the

development of land management plans, and planning for management projects; however, the extent to which adaptation has been emphasized varies across these decision-making processes. Scientists and managers in the USFS have begun to institutionalize climate change vulnerability assessments (CCVA) as a new routine to support climate change adaptation. CCVAs refer to scientific publications and the corresponding processes that summarize potential impacts of climate change in specific locations. Led by scientists affiliated with the USFS's research branch and universities, the Adaptation Partners group began in 2008 to develop CCVAs for areas in the Pacific Northwest region (Region 6) of the National Forest System. The group also developed a regional assessment for Region 1, referred to as the Northern Rockies Adaptation Partnership (NRAP). These CCVA processes involve scientific modelling and literature synthesis, as well as workshops where scientists present initial findings and then lead discussions with managers about "strategies, tactics, and options" for adaptation (*19*). As participants pointed out, these collaborations required an acknowledgement of the policy and administrative constraints that shape managerial decision-making. Group discussions aimed to identify actions that managers were "empowered to do something about [given what they were] legally allowed to work on…without changing the law," as one participant described (*17*). Accordingly, these processes have resulted in learning among scientists about the policy frameworks and incentive structures under which managers operate. While our research highlighted the importance of CCVA processes as an initial step for adaptation in the USFS, it is important to note that these processes do not result in the implementation of actual adaptation actions.

We also considered how managers applied information from these CCVAs in making decisions, and found that managers were largely addressing climate change through management activities and processes that would happen even without a focus on climate change. This

suggests that, outside of CCVAs, entirely new routines for climate change adaptation have not been developed. Table 4.3 highlights some of the impacts of climate change that participants were concerned about. Many interview participants viewed climate change adaptation as an additional piece of rationale for their decisions. One participant said: "It's almost as though we're using [climate change] as further justification for what we're already planning on doing" (*20*). Another participant expressed a similar perspective: "One of the nice things about climate change is it doesn't seem…like there's anything right now [that] we have to do different than our normal stuff" (*24*). In line with these approaches, managers discussed how they were beginning to use CCVAs to validate that present-day management decisions would be good investments into the future. This emphasis on existing management activities to address climate change adaptation reflects scientific advice; one scientist stated: "We kind of emphasize to managers that about eighty percent of what they're doing is already climate-smart," citing management activities such as thinning, fuel treatments, and restoration of riparian areas (*34*).

Table 4.3–Climate change impacts identified by participants and in vulnerability assessments

Impact
Increases in the severity, frequency, and intensity of wildland fires
Impacts on specific species, such as whitebark pine (*Pinus albicaulis*), including through impacts to ecological disturbances
Erosion and road failures from storm events, including storms where rain melts snow
Adverse effects of increases in stream temperatures and sediment on fish and aquatic species
Failure of tree species to regenerate or establish following disturbances or timber harvests
Forests converting to shrublands and grasslands

Interview participants noted that contemporary land management activities were largely focused on the goal of ecological restoration. These participants noted that management actions implemented for restoration were largely consistent with actions that would support climate change adaptation. According to participants, addressing contemporary ecological stressors, such

as wildland fire, would prove "climate-smart," as increasing temperatures and changing precipitation regimes associated with climate change would exacerbate these stressors in the future. This rhetorical question from an interview participant illustrates this perspective: "Would the restoration approach be fundamentally different than the extra emphasis given it because of climate change?" (*10*). Several participants suggested that stressors in the present-day reflected the legacies of past management decisions. For example, one participant discussed how a history of grazing, fire suppression, and "high-grade logging"—harvesting the biggest trees and leaving the rest— in Montana created a need for restoration of forested ecosystems (*10*). Managers in all three regions also discussed the legacy of fire exclusion in Ponderosa pine (*Pinus ponderosa*) forests and other frequent-fire forest types, which has created a high risk for uncharacteristically large and severe fires. As a result, managers have focused on reintroducing fire to these ecosystems through prescribed fires and managing naturally-ignited wildfires, which they viewed as crucial to help these forests adapt to climate change. Managers working in wet areas in the Pacific Northwest were concerned about the legacy impacts of past timber harvests and forest roads constructed to enable these harvests. These managers noted that erosion of roads leads to sediment entering streams, which, in turn, harms aquatic species, and that roads may wash out entirely during severe storm events. Accordingly, in these areas, managers were working to get rid of many of these roads to lessen contemporary impacts to aquatic ecosystems, but also to prepare for a future when climate change would make these impacts more frequent and severe.

The concept of resilience guides the restoration activities described above and offers management direction for climate change adaptation. As one participant indicated, resilience as a concept is appealing, because it offers management direction in light of uncertainty: "Given uncertainties, perhaps the best strategy…is just supporting landscape resilience to all kinds of

stressors, be it climate change or insects and disease" (*28*). Resilience is often framed as an objective for ecological restoration, and, according to one participant, the Forest Service has "been doing a lot of actions over the past 10 years that are really focused restoration and resilience" (*24*). Participants noted that discussing resilience rather than adaptation proves useful in situations where explicitly discussing climate change could spur controversy. One participant described this in the context of NEPA planning: "Certainly when we do work that's related to forest restoration activities, the need for change [section of the NEPA document] won't explicitly say climate change, it will talk about building resilience in certain vegetative communities and protecting [human] communities in the wildland urban interface from fire" (*5*). However, participants also shared concerns about implementing resilience in practice: "We'll say, 'be resilient to climate', but it doesn't always go farther than that in terms of thinking about, what does that actually look like" (*5*). Another participant echoed this sentiment regarding resilience: "That's where the complexity comes in, and I think that might be worth looking at—how people interpret [resilience], and then how do we get [different managers and stakeholders] actually on the same page" (*14*).

Participants identified land management planning as a type of decision-making process that would be, in theory, conducive to considering climate change adaptation. The planning regulations promulgated in 2012, which guide contemporary land management planning under the NFMA, require that planning teams consider climate change as a driver and stressor of ecosystems when planning for ecological integrity and multiple uses (36 CFR 219.8). In line with this "loud and clear" requirement to address climate change, as one participant put it (*3*), many participants indicated that plan revision processes are a crucial opportunity for managers to implement adaptation strategies, as these processes involve a reformulation of management

objectives and consider "future climatic conditions over the next 20-80 years" (*31*). Furthermore, as one participant pointed out, planning is "a process by which you articulate what you want to do with full transparency [with stakeholders]" (*4*). However, planning, in practice, has proved challenging. Although the original intent was that national forests would periodically revise their plans every ten to fifteen years, many units continue to operate under plans that are two to three decades old. Several participants described frustrations with this dynamic and with delays in planning processes; as one participant indicated, "it has proven challenging to get to the "finish line" of "getting [a plan] signed" (*4*). According to the participant, "what really is a reality check hurdle for forests is [that] the Washington Office doesn't like [their plan], because…it's just insane [what the Washington Office's] interpretation of the planning rules and the direction [is]" (*4*). As one scientist pointed out, the emphasis on planning "creates a bit of a lag" in terms of applications of climate change vulnerability assessments, because, there is a perception amongst managers that "we don't have [policy requirements outside of planning] right now where we have to do this; we're going to put this off until we do or until somebody complains about it" (*34*). After all, as the participant pointed out, "that's no prejudice against climate change; people just aren't looking for extra work these days" (*34*).

In the Pacific Northwest, planning efforts are particularly complex because of the Northwest Forest Plan, a set of requirements that apply across many national forests in the region and that were developed in the 1990s chiefly by a team of scientists in response to a crisis surrounding the impacts of timber harvests on wildlife populations, including the Northern spotted owl (*Strix occidentalis caurina*). In this region, CCVAs had been scheduled with the intent that these processes would feed into forest plan revisions. However, according to participants, the Regional Office decided to develop a coordinated planning approach for the

national forests within the footprint of the Northwest Forest Plan. This decision delayed planning processes with adverse implications for the utility of CCVAs and staff buy-in for these processes. One participant described this: "If five or ten years from now, we are to go through a forest plan revision process, and we're looking at data from 2015 or previous, it's like, so are we just going to have to redo [the CCVA] again?" (*20*). Another participant remarked on a similar challenge: "My near term goal is to…remind folks…what the purpose of this [CCVA] document is,…[which is] to serve multiple levels of planning, [and to ensure] that it's not to be shelved until we start…forest plan revision" (*14*).

We interviewed several managers working on the Custer-Gallatin National Forest in Montana, which began forest plan revision in 2016 under the 2012 planning rule. This process offered a look at how an ongoing plan revision process was addressing climate change. The planning team used the NRAP CCVA in required analyses, and the NRAP provided, according to a participant, a "synthesis of the current state of the knowledge" (*11*). This saved the team from having to "go do all this research yourself" (*10*). As one participant described, "climate change has been folded in throughout the plan," meaning that it "is [implicitly] embedded in every plan component and every piece of analysis" (*11*). The plan includes only limited explicit discussion of climate change, but, as participants pointed out, the plan emphasized concepts that are viewed as conducive to adaptation. One participant noted that: "The whole focus of the plan is ecological integrity, which is basically defined as resilience, and climate change is one of the things that we are planning to be resilient to," and also that managing for a natural range of variation (NRV) of forest structure and composition would help forests adapt to climate change (*11*). According to interview participants, the planning team received help from external partners to understand the connection between these concepts and climate change adaptation. With

funding from a government center for climate change adaptation science, local university scientists partnered with the CGNF's planning team to conduct workshops and write a report to "validate" the plan's approach to climate change adaptation (*11*). This work involved using information from the NRAP and other sources to assess the vulnerability of different forest types found within the CGNF. As one participant described, these workshops allowed the planning team to ask: "does our plan make sense given the climate change future?" (*11*). The report from this effort provided scientific justification for the forest's intended management approach; specifically, it stated that "managing towards NRV is a reasonable approach for the CGNF given the current relatively natural state of the forest ecosystem and projected future change" (Hansen et al., 2018, p. 29).

Other existing policy processes where managers address climate change include strategic planning for individual resource programs, such as fisheries or recreation, and project-level NEPA planning. One participant described how vulnerability assessments inform strategic planning: "If someone was doing a strategic plan for all of the [recreation] facilities [on the forest], for instance, then, it was good information, or if you were going to do a strategic plan for where you might do fisheries and habitat improvement work on the forest, [then it would be useful]" (*11*). Participants also identified opportunities for considering climate change in landscape restoration strategies that integrate resource needs across different sectors and address large spatial extents. According to a participant, "we just need to be thinking about large landscapes [for our restoration projects], because that's where historic patch sizes have been, that's where our natural disturbance regimes are" (*22*). Several participants highlighted as an innovative example the landscape analysis approach developed by managers on the Mt. Baker-Snoqualmie National Forest (MBSNF) in Washington. This approach used a spatial analysis of

ecological and wildlife habitat conditions and the vulnerability of the forest's road system to climate change to prioritize specific locations for restoration treatments. The road system vulnerability metric reflected a combination of information produced for the North Cascadia Adaptation Partnership (NCAP) CCVA process and subsequent efforts to refine this information by external partners in line with the forest's development of a sustainable road management strategy (Mt. Baker-Snoqualmie National Forest, 2018; Raymond et al., 2014; Wooten, 2016). The first project in planning that used this strategy focused on the Snoquera area, which included the watersheds for the Green and White Rivers and was identified as a priority location by the analysis approach due to its high density of roads and their vulnerability to climate change. The project integrated vegetation management treatments, road decommissioning, and improvements to recreation infrastructures.

Over the past decade, NEPA analyses for projects in the USFS have begun to incorporate sections on climate change, which have increasingly discussed climate change vulnerabilities. For example, the Olympic National Forest completed NEPA analysis for the North Fork Calawah Vegetation Management project in 2017; the analysis cited the Olympic Adaptation Partnership vulnerability assessment to describe key vulnerabilities to climate change and highlight how the project contributes to adaptation strategies identified during this process. In some instances, concerns about climate change have led staff to make changes to projects to incorporate adaptive measures. For example, in 2018, the White River National Forest completed a NEPA process for the management of backpackers in the Maroon Bells-Snowmass Wilderness, a popular but overrun destination. The resulting plan allocated a limited number of permits, and managers said that they decided to implement the permitting system year-round, rather than only in the summer when visitation peaks, because they anticipated more people would use the area

during the "shoulder seasons" of spring and fall due to warmer temperatures and lower snowpack as a result of climate change.

4.4.2 Bureaucratic characteristics and climate change adaptation

We were also interested in understanding how traits of the USFS as a bureaucratic organization shaped its adaptation efforts. In the course of our interviews, we found out that this topic is also something that practitioners have also thought about. For example, one participant mentioned that taking a leadership role in a CCVA process required them to "learn a little bit more about the Forest Service as an organization…and how the different levels of the hierarchy…work together and how priorities are passed down and funding is passed down" (*20*). Participants portrayed the agency's bureaucracy as shaped by its multifunctional nature, hierarchical structure, and local discretionary decision-making. According to participants, managers must concurrently address multiple different goals, including some codified in statutes and others, like adaptation, that have emerged through more informal channels. One participant summed up inherent conflicts in the multiple use mission: "If you look at our forest plan, within five or six lines of each other, we're supposed to accommodate mining,…timber as a commodity, and we're also supposed to maintain and enhance viable populations [of wildlife]" (*37*). Another participant pointed out that this extends to a "strong dichotomy of public views," as well as "very heated, strong debates with our forest staff because the values are so different between our professionals on the forest" (*13*). The participant went on to note that climate change exacerbates these conflicts: "If I was an aquatics person and I read the piece [in the CCVA] about what the effects are of climate change on my aquatic resource, I would just stand even firmer…to basically say, 'You can't do anything because I need to get all the roads out of

here and protect my valley bottom areas from any kind of management action'" (*13*). In some cases, managers responded to the multi-functional nature of the agency by pursuing projects that "[look] more comprehensively at [the] landscape" and integrate multiple different resource goals (*9*). For example, participants mentioned incorporating what are described as "no regrets" actions, such as installing larger culverts to accommodate higher stream flows and enable the passage of aquatic species under roads, into restoration projects. Within this structure, staff frequently change locations to advance their careers, and participants noted that staff turnover means that individuals who participated in the development of a CCVA are often no longer working in that location when it comes time to apply the vulnerability assessment in management decisions, and, as a result, the assessment stays "on the shelf" (*34*).

A lack of capacity, including limitations in "staffing and funding" (*8*) and "time" (*2*), made it challenging for managers to prioritize adaptation. One participant described this dynamic by saying that "it's just not policy, it's really capacity" that hinders adaptation (*8*). According to another participant, "budgets have been going down for 25 years or more" due to a lack of increases in Congressional appropriations and a greater share of the agency's budgets going to fire suppression (*35*). Participants noted that this situation can lead to skepticism about devoting money to climate change; one participant described a line officer's reaction to the decision to invest in a vulnerability assessment: "'What? Why do you get money for [a CCVA] and not money for something that I want more?'" (5). Furthermore, several participants indicated that a lack of dedicated funding and associated performance measures for adaptation leaves little motivation to pursue dedicated adaptation projects. The following quotation illustrates this: "To do something for climate change, we would have to have funding for that and then we would say, 'Okay, what is it that we're doing that we could really focus on to meet the funding

objectives?'" (12). Other participants described a lack of funding specifically for "non-commercial restoration resilience actions," which are vegetation management projects that do not include commercial timber sales and were described by the participant as crucial for adaptation (13). Another individual connected this dynamic to performance targets focused only on treating lands to get rid of flammable vegetation and, most importantly, enhancing timber production: "We only have two [performance] targets in the Forest Service now: acres treated and CCF [or hundred cubic feet of timber] produced"[7] (*38*). This leaves managers interested in adaptation and from disciplines not focused on commodity production struggling to figure out how to stay "relevant in those [decision-making] processes that are really focused on vegetation management," according to one participant (*2*).

Our findings also highlight how relationships with external stakeholders shape climate change adaptation. As one participant put it, "the national forests that have these collaboratives built in as part of their operations are the ones who actually get to do stuff on the ground these days" (*34*). Managers often face both support and opposition in addressing climate change from stakeholders. One participant noted that public opinions on climate change exist on "two ends of the spectrum [from] 'you're not doing enough [to prepare for climate change]' [to] 'this isn't real, why are you considering [climate change]'" (*33*). Another participant illustrated this dynamic on the forest where they work: "The guy with the motorized interest thinks that climate change is a government conspiracy, and the lady across from him, she's ardently wringing her hands about the concept" (*9*). One participant noted that the response to this dichotomy tends to be to treat climate change as "politically charged"; in this context, "the astute operator avoids using the phrase [climate change]" (*34*). Another participant noted that they would be unlikely to

[7] "CCF produced" is a metric for volume of timber harvested.

cite climate change as "the reason why we want to do all of these actions" in a NEPA document, as they were "not sure if we'd have success with our public on that" (*13*).

Stakeholders may experience impacts to their livelihoods due to climate change, and thus may push for adaptation actions. For example, several participants cited the threat that climate change presents to ski resorts operating under special use permits on national forest land. On the White River National Forest in Colorado, participants recounted an influx of proposals to expand artificial snowmaking from various ski resorts following a winter that received low amounts of snowfall. Though these proposals did not explicitly mention climate change, managers anticipated a continued increase in these types of proposals in the future as a result of climate change. According to our interviews, external partners have also provided capacity to implement projects that would have adaptation benefits. For example, participants working in Colorado discussed investments from Denver Water, a city utility, in forest restoration and a recent ballot measure in Summit County, which has several resort communities surrounded by national forest land, to fund fuel reduction treatments in the wildland-urban interface (Adams, 2018; Summit County Government, 2018)

In the USFS, managers generally have discretionary space to craft context-specific approaches to achieve policy goals, and our interviews suggest that managers' individual motivations, perceptions of ecosystems' vulnerabilities to climate change, and responses to scientific uncertainty affect how they approach adaptation. For example, one participant noted perceptions amongst colleagues that wetter forest types, such as the forests of western hemlock (*Tsuga heterophylla*) and Douglas fir (*Pseudotsuga menziesii*) in the Pacific Northwest, would likely be "relatively buffered from the effects of climate change," describing these species as "almost ridiculous on the landscape because they have such broad ranges and can tolerate such a

wide range of conditions" (*20*). This idea was largely borne out by CCVAs conducted in this region. Another example highlighted how a different conclusion about tree species' vulnerability led to a similar preference for status quo management approaches. Reflecting on the NRAP vulnerability assessment's conclusions, one participant stated: "Basically all my tree species that I'm working with are high to moderate vulnerability," which makes it hard to prioritize specific species (*24*). The participant went on: "And then over time, like trees always do, they'll adapt" (*24*). Others noted that general uncertainty about the specific impacts of climate change in the contexts where they worked precluded implementing dedicated adaptation activities of climate change. In response to these perceptions and uncertainties, several interview participants noted that they were paying attention to whether forests were regenerating and reestablishing following disturbances and timber harvests, and, if they found evidence that they were not, they would consider implementing novel management approaches. Along these lines, some participants noted that they had begun to think about planting seeds from drier and hotter locations or species that do not currently occur in their management contexts in response to climate change; however, they indicated that additional scientific and policy guidance would be necessary before these forward-looking approaches would be implemented. These examples and other comments shared during interviews collectively suggest that, in addition to learning that a particular resource is vulnerable to climate change, managers also need to learn about feasible and effective responses to this vulnerability, in order to implement dedicated climate change adaptation activities.

4.5 Discussion

4.5.1 New and existing routines for adaptation

Our research questions and findings get at a fundamental question regarding the extent to which climate change adaptation can be accomplished through existing routines, institutions, and structures versus innovation resulting in new organizations, structures, and routines (Biesbroek et al., 2018b). This tension between routines and innovation reflects a need to balance stability and flexibility in adapting to environmental change (Beunen et al., 2017; DeCaro et al., 2017). This tension is especially relevant to the USFS, because the agency has a century-long history punctuated by rare but substantive changes to its management paradigms, and a complex institutional framework that incorporates routines from the past. Forest management as a context for adaptation also introduces an additional layer to this tension given the way that forested ecosystems continue to exhibit legacy impacts of past management practices (Fischer, 2018a).

In response to our first research question, our findings suggest that land managers in the USFS are primarily addressing climate change adaptation by mainstreaming it through existing decision-making routines and management practices. Several explanations for this exist. For one, there is congruence between management activities occurring as part of ongoing ecological restoration and what might prove necessary for adaptation; the literature suggests that the congruence of climate change adaptation with a sector's existing objectives is a driver of mainstreaming (Runhaar et al., 2018). While several internal agency policies promote adaptation as a goal for the agency, adaptation is one of many goals for the agency (Biber, 2009). And, as our research indicates, it is one that lacks underlying statutory policy direction, current political support, and incentive structures that would motivate managers to emphasize this goal over others. Given this situation, determining the extent to which adaptation gets prioritized in

decision-making ultimately falls to local practitioners, and, as the literature suggests, the activities of practitioners reflect a combination of their individual motivations and abilities, and their interactions with characteristics of the organizations in which they work (Biesbroek et al., 2018b; Moseley and Charnley, 2014; Runhaar et al., 2018).

CCVA processes represent a new routine developed by USFS scientists and managers with an express focus on climate change adaptation. Practitioners presumably benefit from access to scientific information to inform adaptation strategies, and bureaucracies often possess existing knowledge bases and the capacity to generate new knowledge in support of adaptation (Biesbroek et al., 2018b). For the USFS, having an internal research branch provides a foundation for targeted scientific research to support climate change adaptation. While top-down direction, including the agency's Climate Change Performance Scorecard, has motivated the development of CCVAs, these efforts are also largely the product of the commitment, leadership, and entrepreneurship of agency scientists (J. E. Halofsky et al., 2018a; Timberlake and Schultz, 2017). As our research indicates, scientists and managers see it important that scientists involved in these processes understand the legal, bureaucratic, and institutional constraints, incentives, and routines that guide decision-making. This understanding underpins scientists' efforts to translate and downscale complex scientific information into usable formats (Enquist et al., 2017).

Adaptation, by nature, and especially in federal land management agencies will occur through linked chains of routines rather than single stand-alone decision-making processes. This suggests a need to recognize the relationships between CCVAs, forest planning, strategic resource planning, and planning for management projects. CCVAs do not authorize management actions and are ultimately scientific publications, not management decisions. The intention of a CCVA is to inform subsequent decision-making processes, and, as our interviews indicate, forest

plan revision processes, in particular, are viewed as key venues for the application of CCVAs given the regulatory requirements to consider climate change in these processes. Still, these planning processes also do not authorize on-the-ground management activities, and project planning needs to occur prior to adaptation actions with material effects on forests occurring. This demonstrates the importance of coherently linking the various routines described here, including CCVAs, land management planning, programmatic allocation of resources, and project-level planning, in order to ensure that adaptation priorities are implemented through on-the-ground actions. Furthermore, our research highlights how the extent to which the timing of these processes lines up may shape their effectiveness (Sieber et al., 2018). Few forest plan revision processes have happened under the 2012 planning rule and on units that have had access to a fully complete comprehensive CCVA, and it is likely that, as more of these processes happen and units continue to work with the region-wide CCVAs published in 2018, there may be a host of additional examples of innovations with regards to climate change adaptation.

4.5.2 The influence of bureaucratic characteristics on adaptation in federal forest management

In line with our academic interest in how bureaucratic traits of the USFS shape its adaptation approaches, we found that practitioners were also interested in this topic. For these bureaucrats, pursuing climate change adaptation despite a lack of a clear top-down direction requires them to learn about how the structure, incentives, and discretion embedded in the USFS as a bureaucratic organization create and limit opportunities for this goal. Qualitative interviews as we have done here offer an opportunity to incorporate this learning into the broader academic discussion of the topic.

The USFS has a hierarchical structure but has also emphasized decentralized decision-making (Kaufman, 1960; Wurtzebach et al., 2019). Our research suggests that this creates a dynamic where decisions made at the national and regional levels provide a general framework for local adaptation activities and affect the timing of and resources available for climate change adaptation. However, managers working on national forests ultimately have discretion to determine the extent to which they want to pursue adaptation and how they might go about doing so (Cheng et al., 2015; Sabatier et al., 1995). A related trait of the USFS is the multifunctional nature of the agency, where, by legal mandate and by custom, the USFS must concurrently manage for multiple goals, which can sometimes prove incompatible (Biber, 2009). To address these multiple goals, the USFS has developed a departmentalized structure, where budgets and staff focused on different goals are separate, and there is potential for competition between potentially conflicting goals. Prior research has demonstrated challenges for ecological restoration presented by this structure (Schultz et al., 2015), and our research highlights how this dynamic applies to adaptation as well. In particular, our interviews indicate that, in some instances, the expected impacts of climate change on particular resources may further divisions between resource areas; however, in others, decision processes set up to integrate different goals may offer opportunities to address climate change as an additional goal. Specifically, as our research indicates, the prospects of integrating adaptation with other goals may ultimately reflect how well managers are able to communicate this decision with key stakeholders.

For the USFS, political principals have used budgeting processes to influence what priorities agency managers pursue (Biber, 2009; Schultz et al., 2016). However, as other research also suggests, budgets have not changed to incorporate adaptation as a specific priority, and managers often point to capacity challenges as justification for not pursuing adaptation and other

"unfunded mandates" (Hagerman, 2016). Furthermore, frustrations with a limited budget, exacerbated by the large share of the agency's budget going to suppressing wildland fires, means that there is little money, staff, and time available to address climate change head-on, and managers are likely to spend time on other priorities, especially those with performance metric targets attached (Hagerman, 2016). Our interviews indicate that some managers have found ways to wrap adaptation activities into projects that happen as a result of other motivations.

The literature suggests that interactions between bureaucrats and non-state actors shape adaptation, and our research highlights the important role for external stakeholders in pushing climate change thinking in the U.S. Forest Service (Biesbroek et al., 2018b). As previous research has indicated, macro trends related to neoliberalization and adversarial legalism have created a dynamic where USFS managers must work with external stakeholders to develop adequate capacity and legitimacy to take on new management priorities (Abrams et al., 2017; Kagan, 1991; Maier and Abrams, 2018; McCarthy, 2005). Accordingly, engaging in adaptation requires managers to build legitimacy for adaptation actions with a range of stakeholders with varying interests. In some cases, external stakeholders will advocate for more robust considerations of climate change and offer technical analytic capacity in support of adaptation. In others, skepticism or a lack of interest from stakeholders in climate change may lead managers to either avoid discussing climate change explicitly and focus on projects with ecological restoration and resilience goals or to devote limited resources on projects with entirely unrelated goals that are in more demand from stakeholders, such as commodity production or providing opportunities for recreation.

In the USFS, punctuated changes in management paradigms have occurred; however, remnants of past paradigms continue to shape contemporary decision-making (Maier and

Abrams, 2018; Winkel, 2014). These paradigms capture the priorities, logics, routines, and institutions that guide decision-making amongst bureaucrats in the agency (Brown and Harris, 2000). The restoration of resilient ecosystems is a guiding paradigm in contemporary federal forest management, and is incorporated in policy and scholarly guidance regarding adaptation (Bone et al., 2016; Millar et al., 2007; Peterson et al., 2011; U.S. Forest Service, 2011a). As our research indicates, managers largely view resilience as an appropriate goal for climate change adaptation and have begun to mainstream adaptation actions through this paradigm. Managing for resilience requires both setting a goal of a resilient forest on the front-end but, also, subsequent work to figure out "what does that actually look like," as one participant put it. The emphasis on resilience, a potentially ambiguous goal, as a guide for climate change adaptation introduces an interesting set of questions for the study of adaptation in bureaucracies. Namely, there is a body of literature examining what influences the ambiguity of organizational goals and how managers grapple with this ambiguity (Pandey and Wright, 2006; Rainey and Jung, 2014). It would be useful to apply these understandings of ambiguity to the study of adaptation, where managers must contend with both an ambiguity in the goals guiding their activities but also uncertainty about the conditions of the environments in which they operate (Cairney et al., 2016).

The examples of the CGNF's planning process and the MBSNF's restoration strategy demonstrate how managers have navigated the USFS bureaucracy to pursue adaptation. In both processes, land managers completed technical analyses that provide grounding for the assumption that managing for resilience and restoration will prove to be adaptive to climate change. External stakeholders also advocated for climate change considerations, which legitimized agency managers' explicit considerations of the topic; however, these stakeholders

also reinforced this advocacy with additional technical capacity. These stakeholders "downscaled" information on climate change impacts, including from CCVAs, so that it is relevant to specific management units and to specific actual decision-making processes rather than to hypothetical conceptualizations of these processes. In making on-the-ground decisions, line officers and resource managers are often responding to their own interpretations of trends in local ecological and social conditions, and this type of downscaling should seek opportunities to connect scientific conclusions to these interpretations and the value systems through which these local bureaucrats operate (Cheng et al., 2015; Sabatier et al., 1995).

Both of the examples occurred because of work by agency employees working in roles that allow them to think about the "big picture," and who demonstrated an understanding of how to work with bureaucratic constraints and opportunities. Furthermore, the settings of both of these units provides them with access to external capacity through partnerships. The main office of the CGNF is located in Bozeman, Montana, which is also the location of Montana State University as well as several conservation non-governmental organizations. Furthermore, since prominent fires burned in Yellowstone National Park in 1988, there has been considerable scientific interest in Greater Yellowstone Ecosystem, and the CGNF planning process has benefited from having access to a relatively robust body of scientific knowledge (Romme et al., 2011). Similarly, the MBSNF is located near to the population centers of Washington State, and in an area that has also generated significant interest amongst the conservation and science communities especially as a result of the controversy surrounding the spotted owl and subsequent development and implementation of the Northwest Forest Plan. Other management units, such as rural units located far from universities and urban centers, may face persistent

challenges if adaptation success depends on access to external partnerships (Seekamp et al., 2018).

4.6 Conclusion

In this paper, we examine how the USFS, a bureaucratic agency, takes on climate change adaptation, including by forging new routines focused on science and incorporating adaptation into existing activities and processes. We discussed a potential tension between bureaucracies reliance on existing routines and the need for new routines and activities associated with innovation, and posit that this tension represents a key feature of adaptation to climate change in bureaucratic organizations. For the USFS, adaptation requires working with bureaucratic characteristics of the agency, which tend to reflect the historical institutional development of the agency and how legacies of past management activities remain apparent on forested landscapes. Our research also highlights how efforts by practitioners, including in collaboration with scientists will benefit from accounts that collect bureaucrats own perceptions of adaptation.

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CHAPTER 5: CONCLUSION

5.1 Introduction

In this section, I discuss how the three empirical chapters respond to the research objectives outlined in the first chapter, comment on key themes apparent across these chapters that highlight opportunities for future research, and discuss additional writing that builds on the research reported in this dissertation. This dissertation research comes as the USFS has pursued adaptation for around a decade, with some examples of successful practices having occurred during this period but also plenty of opportunities for further advances. My account of the topic addresses theoretical needs in the study of adaptation and provides guidance useful for practitioners working on adaptation in natural resource management. In particular, this dissertation demonstrates the value of examining adaptation in the context of a specific administrative agency, which has existing goals and characteristics that shape adaptation. In doing so, it shows how concepts like resilience and vulnerability are used in a specific administrative context.

As a federal agency, the Forest Service offers a particularly interesting case for the study of adaptation. The agency has a mandate to manage forested ecosystems, which experience impacts through complex interactions between climate change and disturbances. Furthermore, managing for multiple uses of public lands, as laws require, necessitates that managers navigate competing goals in making decisions. The agency's historical development over the last century has resulted in a layered institutional landscape, and some existing institutions may support adaptation, while others may warrant present challenges. As the remainder of this chapter indicates, there are opportunities to further advance knowledge on adaptation in the USFS,

natural resource management, and other policy sectors. The conclusions of this dissertation offer starting points for future inquiries.

5.2 Responding to research objectives

As described in the opening chapter, I guide this dissertation with three primary objectives. First, I sought to examine how land managers operationalize resilience in planning processes in light of scientific information, public expectations, and governance factors. Chapter 2 of this dissertation addresses this objective by examining the Kaibab National Forest's planning process, completed in 2014. As our research uncovers, the plan emphasizes resilience as a guiding theme for the forest's management for climate change and ecological stressors like fire. This use of resilience aligns with the regional emphasis on the restoration of forests that are adapted to fire, which involves using fire as a management tool. This approach to resilience reflects the region's ecological context; the Ponderosa pine and dry mixed conifer forest types prevalent in the region would historically have experienced relatively frequent but low severity fires. However, a history of fire suppression in the region, coupled with the legacy impacts of other activities, including logging and grazing, has created a need for ecological restoration. Addressing this ecological need provided managers with a relatively straight-forward path for understanding the potentially ambiguous concept of resilience. Nonetheless, the planning team and its partners encountered some challenges. The policy direction guiding planning involved considerable ambiguity that reflects layered institutions in federal forest management; however, the planning team was able to adeptly navigate this ambiguity, including through collaboration with external partners who provided scientific expertise. This suggests the importance of external collaboration in innovation in forest management. In enhancing the role of fire on the landscape,

managers have had to reshape institutions guiding fire management. While the forest's revised plan provides managers with more discretion in making decisions, these managers have had to draw on collaboration with the public to ensure accountability and legitimacy. This chapter contributes to the literature by providing insight on the operationalization of resilience in a particular context and how managers encounter and navigate institutional challenges in pursuing management approaches oriented towards resilience and adaptation. In particular, it highlights the tension between discretion and flexibility, on one hand, and accountability and legitimacy, on the other. Institutional work activities allow actors opportunities to work through this tension.

The second objective of this dissertation is to investigate the practice of climate change vulnerability assessment in the USFS. Chapter 3 addresses this objective, summarizing an analysis of vulnerability assessment documents developed in the USFS. This study of vulnerability research in a specific context considers several key questions related to the participants and processes involved in vulnerability assessment, scopes of assessments, approaches to defining and assessing vulnerability, and the application of these sources in decision-making. By addressing these topics, this paper provides an overview of an important element of the USFS's adaptation strategy, which will underpin subsequent adaptation activities into the future. Still, as the chapter highlights, more work is needed to understand how these vulnerability assessments are guiding management actions, a topic addressed in Chapter 4.

The third objective of this dissertation is to explore how adaptation planning integrates with existing approaches to decision-making in specific contexts. Chapter 4 addresses this objective by examining adaptation practices in the USFS and how the agency's bureaucratic characteristics shape these practices. Using interviews of managers and scientists, I provide an overview of how vulnerability assessments have become a dedicated routine for climate change

adaptation within the agency. These assessments have begun to inform decisions in existing policy processes, though the USFS has largely found existing management activities as conducive to adaptation with few examples of entirely new management approaches being implemented in response to climate change. As a bureaucratic agency, the USFS operates through a hierarchical structure but with decentralized decision-making. In this structure, current political priorities and budgeting makes it challenging to pursue dedicated adaptation actions; however, some managers have found ways to mainstream adaptation through existing routines and activities. For the literature on bureaucracies and adaptation, this chapter highlights the value of examining the individual agencies that make up nation-wide bureaucracies.

5.3 Prominent themes and opportunities for future research

Across the three empirical chapters of this dissertation, there are several cross-cutting themes that I summarize here with the dual intents of outlining contributions of this dissertation to the literature and highlighting opportunities for future research. Specific themes that I discuss include the nature of adaptation in federal forests, the role of the current paradigm of restoration of resilient ecosystems in adaptation, the importance of land management planning for adaptation, and why social-ecological context of the places where the agency works matters in shaping adaptation. Collectively, these different themes demonstrate the multifaceted nature of adaptation, which warrants research that recognizes that adaptation to climate change will require supportive policy, innovative implementers, useful scientific information, various forms of collaboration, among other necessary qualities. A conceptual model organizing these different elements would offer useful structure for future research, and I provide an preliminary presentation of this conceptual model.

5.3.1 Adaptation in forest management: a novel challenge?

This dissertation highlights complexities in adaptation in the context of forest management, especially under a multiple-use mandate that already requires managers to meet a range of goals. The timescales over which forests develop and change are extended and often do not align with the timescales at which social preferences are realized (Fischer, 2018a). Trees grow slowly, especially in the western United States, and, accordingly, the legacies of past management decisions remain apparent over time. This is relevant to the forests of the Southwest, considered in the case study on the Kaibab, where contemporary management centers on restoration of forests that bear evidence of a history of fire exclusion. Similarly, the third empirical chapter shows how managers in other regions also view contemporary stressors as linked to the legacies of past management decisions associated with timber harvesting, road construction, and fire suppression. Management objectives tend to emphasize addressing the contemporary manifestation of these legacies, which can help with regards to adaptation but may preclude dedicated climate change adaptations.

Other papers have explored this dynamic in the context of the private forest management, suggesting distinctions between intentional and incidental adaptation (Boag et al., 2018) and coping and adapting (Fischer, 2019). Similarly, other papers have argued that a community's ability to adapt to prior non-climate stressors may prepare them to adapt to climate change (Fischer, 2018b; Wyborn et al., 2015). Collectively, these perspectives point to the question of whether adaptation to climate change is a novel endeavor or a continuation of existing activities. On one hand, many existing management activities will also prove useful in adapting to climate change. Thinning trees to create resilience to drought will prove useful as climate change makes droughts more frequent, and, in some contexts, represents a response to past management

decisions that have allowed forests to become more dense than they would be absent fire exclusion. Prescribed burning to reintroduce fire to fire-adapted forests will become more and more useful in a future defined by climate change, but also comes as a response to past management decisions. The USFS, as an agency, has been adapting or refusing to adapt to ecological change throughout its history, leading to punctuated but notable shifts in the paradigms guiding the agency. However, climate change will yield novel conditions and potentially novel uses for forests. For example, stewarding forests as carbon sinks is becoming especially important in light of climate change. Thus, fundamentally new forest management approaches may prove necessary in the future. According it is worth asking: does adaptation to climate change require a fundamentally new land management paradigm? How would a change in paradigms occur? Would it take top-down political intervention, bottom-up innovations and learning, or a combination of bottom-up and top-down efforts? This dissertation does not reach a conclusive answer to these questions but highlights how the dynamics of management paradigms and how they change in bureaucratic organizations underpins the future trajectory of adaptation in the USFS. Understanding this question requires taking into account how bureaucratic characteristics of the agency and existing institutions will mediate the paths that it can take in pursuing adaptation. Furthermore, agencies in the federal bureaucracy like the USFS operate in environments affected by national and local politics, and the framing of adaptation by managers reflects these political dynamics as well.

5.3.2 Adaptation and the current emphasis on restoration of resilience ecosystems

As we expected, resilience plays a central role in the USFS's approach to adaptation. As our case study of the Kaibab National Forest indicates, ongoing efforts to restore resilient forests

in response to a history of fire suppression and other management activities offer a path for adaptation to climate change. Activities associated with the restoration and resilience paradigm will presumably prepare these forests for a future where fires will be more severe and frequent. Chapter 4 highlights how managers working in other contexts also view resilience and restoration as a useful paradigm for climate change adaptation. Ultimately, this perspective involves the assumption that managing for resilience to a range of stressors will also help prepare for climate change, since climate change will exacerbate many of these stressors. The USFS's policy guidance elevates resilience as a key element of adaptation and resilience has gained traction as a management goal in the agency outside of explicit consideration of resilience (Bone et al., 2016). Accordingly, managing for resilience offers an opportunity to mainstream adaptation activities that, in some circumstances, might not be viewed as legitimate if framed as primarily focused on climate change.

Our findings regarding resilience offer some perspective to understand criticisms of resilience, which are common the literature. Notably, Bone and coauthors (2016) suggest a need for improved clarity in uses of resilience in the USFS. They point out that uses of resilience with regards to climate change, in particular, often lack necessary details to support implementation (Bone et al., 2016). In some ways, the findings of Chapter 4 support this criticism in that managers discuss resilience primarily in general terms; however, as Chapter 2 indicates, when we consider resilience in a specific context, it appears that managers have a relatively robust understanding of the concept and how it will guide management actions at least in this specific context. However, as this chapter alludes, resilience may prove more challenging to operationalize in ecosystems other than frequent fire forest types. Ultimately, scholars interested in bringing clarity to resilience should tailor recommendations to different types of ecological,

social, and governance systems. Case studies like the one included in Chapter 2 offer useful perspective for supporting these efforts.

5.3.3 Land management planning as a key venue for adaptation

The literature suggests a need for research to identify and understand the specific policy processes through which governments pursue adaptation (Biesbroek et al., 2017, 2015; Wellstead et al., 2013). Given a lack of substantive environmental legislation passed in the last several decades in the United States, bureaucratic decision-making processes are especially important in this context (Biesbroek et al., 2018b; Klyza and Sousa, 2008). As is clear across the three empirical chapters, land management planning processes are important venues for considering climate change in the USFS. The 2012 planning rule, more so than other agency policies, explicitly requires consideration of climate change, but even plans conducted in the past decade under prior regulations have addressed climate change, as the case study of the Kaibab demonstrates. Our research highlights that the 2012 planning rule, considered one of the most significant policy changes for federal forest management in decades, creates a decision-making framework that supports adaptation beyond its explicit requirements for considering climate change, including by increasing flexibility and opportunities for adaptive management and integrating considerations of social and ecological dimensions (Schultz et al., 2013). By nature, planning also requires managers to think across scale levels, an important perspective to take when addressing adaptation (Fischer, 2018a; Schultz et al., 2019). Land management plans focus on entire national forest units, allowing managers to consider how management activities focused on smaller spatial extents contribute to landscape-level trends. Furthermore, plans are intended to cover timeframes of a decade or two, but these processes also offer opportunities for

managers to consider how past actions have contributed to the current status of forests, as well as how present-day management decisions will guide the trajectory of forests well into the future. Planning processes provide openings for the use of scientific information in setting management direction and involve significant collaboration with the public, which support the consideration of climate change.

There are several implications of this emphasis on planning. While planning regulations set general requirements for the consideration of climate change, the decentralized nature of decision-making in the USFS, coupled with the range of contexts in which the agency operates, suggests that different units may take varying approaches to adaptation, and it would be useful to examine how different units have addressed adaptation to climate change in recent plan revisions. Recent research has evaluated climate change adaptation in planning in other contexts, including cities, protected areas, and national plans. These studies analyze plans in terms of principles for climate change adaptation, including whether they use projections of future climate, monitoring strategies, and public involvement (Geyer et al., 2017; Stults and Woodruff, 2017; Woodruff and Regan, 2018). Accordingly, future research could use the criteria from these studies of planning in other contexts to analyze how forest plans completed in the past decade address climate change and how characteristics of different units contribute to different levels of robustness of climate change considerations. This could offer an opportunity to examine adaptation planning across different sectors, including urban planning and public land management, in a particular geographic region. Furthermore, comparing adaptation planning across different sectors could identify higher level governance characteristics that correspond with better preparedness for climate change adaptation.

Another topic for future research related to planning and climate change adaptation involves examining the management activities implemented in line with these plans. In the USFS, land management plans set goals and sideboards for management but do not result in the implementation of specific management activities. Accordingly, while forest plan revisions can lead to new goals related to climate change adaptation, subsequent implementation of these goals through project-level NEPA planning processes will prove necessary for on-the-ground adaptation actions to occur. Scholars have argued that, while plans have begun to incorporate adaptation objectives, there often exists a deficit in the implementation of these goals through on-the-ground actions (Dupuis and Knoepfel, 2013). As such, an opportunity for future research would be to supplement studies of planning processes with research into the implementation of these plans' climate change goals in project-level planning processes.

Finally, the current principles for planning in the USFS and in other contexts assume an ability to anticipate the future and make advance decisions about how to prepare for the future. However, the novelty and uncertainty associated with climate change may violate these assumptions, thus requiring new principles to guide planning efforts that embrace uncertainty and non-linear change (Benson and Garmestani, 2011a; Craig, 2010). This calls into question the utility of current approaches to planning, and new approaches to planning that prioritize adaptivity, innovation, and flexibility may prove necessary. However, implementing these new approaches may prove challenging in the contemporary institutional landscape. This dissertation highlights some ways in which this challenge has arisen, but more work is needed in the future to understand the relevance of planning in a future defined by novelty and uncertainty.

5.3.4 Understanding and leveraging context in climate change adaptation

As this dissertation highlights, context matters for adaptation both in terms of determining what adaptation strategies might prove effective and providing resources that support adaptation efforts. Even for a single agency like the USFS, pursuing adaptation requires a portfolio of different strategies tailored to the specific ecological and social characteristics of the locations in which the agency operates. These characteristics determine the specific ways in which forested ecosystems and associated resources are vulnerable to climate change. Furthermore, these characteristics determine the paths that land managers can take for adaptation. As the second chapter demonstrates, the Kaibab National Forest's approach to operationalizing resilience and, in turn, adapting to climate change reflects the ecological context of the area, including the frequent fire forest types present in the region, and, also, the Kaibab staff's ability to leverage resources available in its social context, including partnerships with academic researchers and high-capacity non-governmental organizations. As the third chapter highlights, vulnerability assessment processes provide a venue for scientists and managers to work together to determine how climate change will affect social-ecological systems in a particular context and the appropriate adaptation strategies to respond accordingly. The fourth chapter focuses on the bureaucratic characteristics of the USFS. While these characteristics can be uniform across the agency, the specific challenges that they present for adaptation, as well as the strategies that managers come up with to deal with these challenges, are context-specific. Examples in the fourth chapter clarify how the adept adapter is attuned to the vulnerabilities of the resources that they manage and finds opportunities rooted in local context to pursue adaptation.

The importance of context has two main implications for research. For one, researchers should use case studies focused on specific locations and decision-making processes to explore how contextual factors shape adaptation, including through context-specific institutions. Inquiries into adaptation should also look to compare across cases and leverage quantitative surveys to determine how different contexts shape adaptation outcomes. For example, the analysis of land management plans discussed above could weigh how contextual factors shape considerations of climate change. In particular, Chapters 2 and 4 indicate that management units may benefit from analytic capacity provided by nearby universities and non-governmental organizations that conduct applied scientific research, and a study of this nature could examine how a unit's proximity to universities and other sources of analytic capacity shape their adaptation approaches. In addition, as findings of this dissertation suggest, it would be useful to consider how adaptation approaches differ across different ecological contexts, especially in terms of disturbance regimes.

5.3.5 The need for a conceptual model

The themes discussed above and throughout this dissertation demonstrate how adaptation is a multi-faceted issue that incorporates science, policy and politics, social-ecological system dynamics, among other subjects. The first chapter examines a particular planning process with a focus on how institutional dynamics and elements of local context shape the operationalization of resilience. Though it touches on other aspects of adaptation, the second chapter focuses on the science element of adaptation. Then, the third chapter focuses on characteristics of the USFS as a bureaucratic agency and adaptation strategies. The complexity of the topic means that a single study cannot simultaneously address all relevant elements of adaptation, but there is a need to

integrate these different elements of adaptation. A conceptual model for adaptation in the USFS could offer a structure to organize future research and clarify how inquiries into different aspects of adaptation relate to one another. The development of this model could draw on existing frameworks for studying policy implementation in the USFS (Moseley and Charnley, 2014) and for studying adaptation specifically (Colloff et al., 2017).

I have begun work on this endeavor as part of this dissertation and will continue to refine this model in the future. Figure 5.1 presents an initial look at this model. Specifically, the overall structure of this model proposes that adaptation practitioners implement adaptation through policy-driven decision-making processes based on their interpretations of a series of starting conditions categorized in terms of science and knowledge, institutions and policy, and context. Specific decision-making processes include land management planning, strategic planning, and project planning. As discussed in Chapter 4, adaptation actions range on a spectrum from being intentionally focused on adaptation to occurring as a result of other motivations.

The literature has established scientific information as an important input into adaptation decision-making in the context of managing ecosystems (Archie et al., 2012). Many of the foundational ideas in the Forest Service's adaptation strategy reflect contributions from peer-reviewed literature and formal empirical scientific research on topics including forest and disturbance ecology (e.g., Millar et al., 2007). However, managers may face challenges in using peer-reviewed journal articles in decision-making (Archie et al., 2014). Processes like vulnerability assessments and the production of other technical reports offer opportunities to make information in peer-reviewed literature relevant to managers (Archie et al., 2014; J. E. Halofsky et al., 2018a). Other processes for producing information relevant to land managers' decision-making include scenario planning processes, which the National Park Service, another

federal land management agency in the United States, has used extensively (Knapp et al., 2017; Miller et al., 2017; Rowland et al., 2014). In addition to formal science, decision-making in natural resource management often reflects experiential local knowledge of stakeholders and managers, developed from working with ecosystems over extended periods of time (Ascher et al., 2010; Charnley et al., 2017; Fleischman and Briske, 2016). Furthermore, climate change adaptation efforts in natural resource management may also benefit from traditional ecological knowledge possessed by indigenous peoples; however, the use of this knowledge must occur in ways that respect the sovereignty of indigenous peoples regarding this knowledge (Long and Lake, 2018; Williams and Hardison, 2013).

As this dissertation argues, policy dimensions shape adaptation. Accordingly, it is useful to consider how policy priorities, agency guidance and directives, and key concepts shape adaptation efforts in bureaucratic organizations. In addition to the making and implementation of policies specific to climate change adaptation, decisions about climate change adaptation will reflect the influence of existing institutions, how they have developed over time, and how practitioners interact with these institutions (Moseley and Charnley, 2014). Policies, including statutes like the National Forest Management Act of 1976 and the National Environmental Policy Act of 1970, lay the procedural groundwork for decision-making regarding climate change adaptation (Timberlake and Schultz, 2017).

As our study establishes, the bureaucratic structure of the Forest Service and the complexity of its policy framework create space for discretionary and decentralized decision-making. Accordingly, managers across different units do not implement policies in general and especially adaptation policies in uniform ways (Biesbroek et al., 2018b). Social-ecological and institutional context thus plays an important role in adaptation (Colloff et al., 2017).

Furthermore, as this dissertation establishes, individual practitioners play an important role in determining the trajectory of adaptation activities. Their willingness to pursue adaptation and how they interpret scientific information, institutions, and their context have significant implications for adaptation outputs and outcomes. As it appears here (Figure 5.1), this conceptual model offers a preliminary take on the topic that primarily reflects findings included in this dissertation. In subsequent writing, I will further develop this model.

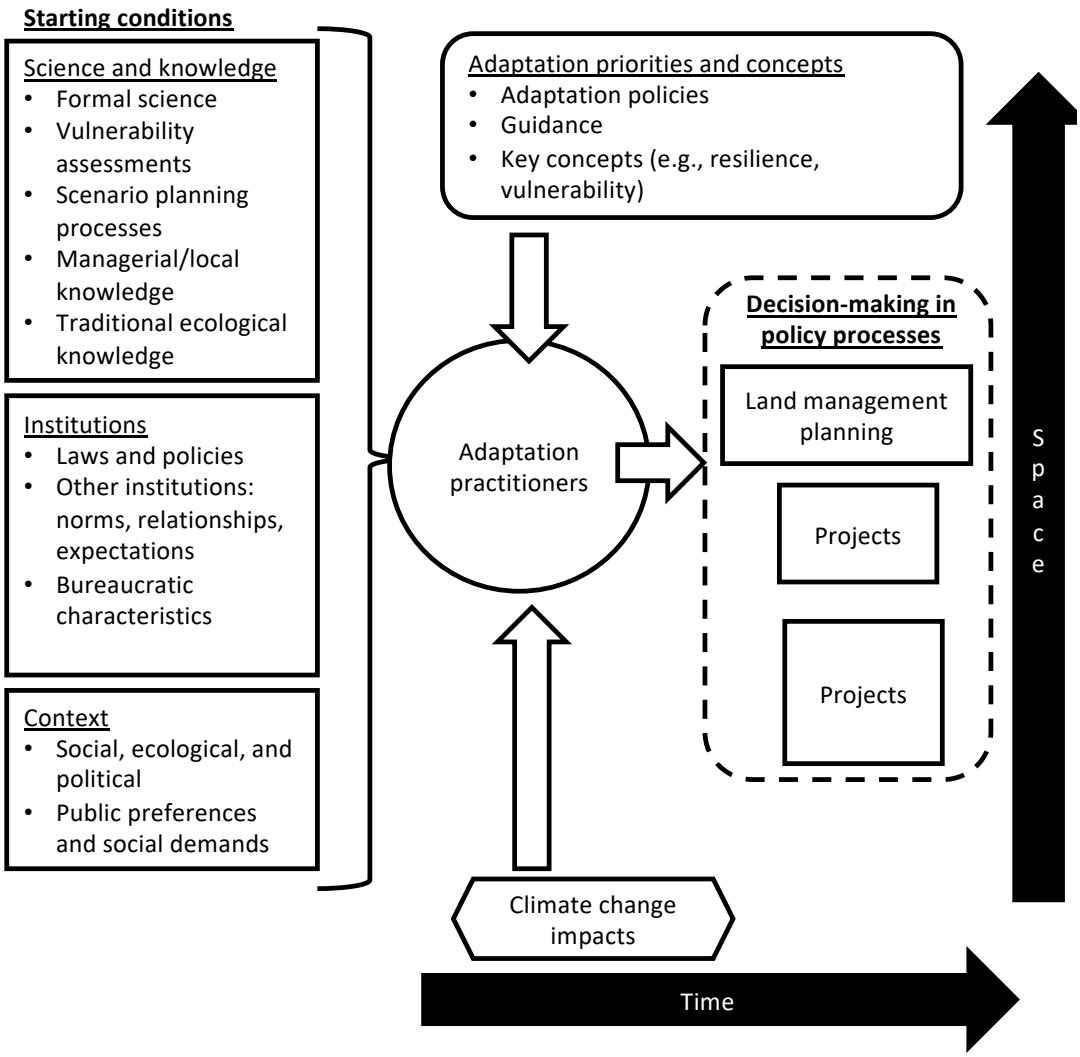

Figure 5.1 - Preliminary conceptual model for climate change adaptation in federal land management

5.4 Additional planned research and writing

In line with the topics discussed above, additional work is occurring as part of the projects that provided funding support for this dissertation. Here, I summarize my involvement in these efforts.

5.4.1 Additional research on resilience

The case study of the Kaibab National Forest presented in Chapter 2 is the first of three case studies of forest planning processes. I also participated in our team's field research for the second case study in Spring of 2018, which examines forest plan revision on the Francis Marion National Forest in coastal South Carolina. This planning process, completed in 2016, was the first fully complete revision under the 2012 planning rule. Climate change adaptation and resilience are central to this plan. Unlike many other national forests, the Francis Marion will experience impacts from sea-level rise, in addition to impacts of climate change related to drought and fire that are more common across the National Forest System. As our interviews highlight, managing for resilience in this context involves restoring the ecological processes of fire and hydrology. These efforts fit into a broader paradigm in the Southeastern United States focused on the restoration of longleaf pine (*Pinus palustris*) forests in areas that once hosted this species but had been converted to loblolly pine (*Pinus taeda*), a species historically considered to be more economically productive. The restoration of longleaf pine forests is also thought to have adaptation benefits, as this species is generally more resilient to various climate-related stressors. Longleaf pine forests benefit from frequent fire.

Similar to the case of the Kaibab, the social context of the Francis Marion has shaped its approach to operationalizing resilience. The forest borders the urban area of Charleston, South Carolina, which is rapidly growing in population. The forest directly neighbors large proposed

housing developments and includes within its boundary numerous private land inholdings. In implementing prescribed fire treatments, the Francis Marion has had to navigate challenges related to risk and smoke impacts, made more difficult due to this population growth; several participants mentioned efforts to implement smoke easements in subdivision development plans and housing sales. Furthermore, the Francis Marion has built partnerships, including with non-governmental organizations like The Nature Conservancy, which help with the implementation of prescribed burning. The third case study will focus on the Inyo National Forest in California.

Collectively, the three case studies will support a comparative case study research design, where we are able to examine themes across different contexts. For example, the Kaibab and Francis Marion case studies focus on two units that are very different but that both contain frequent-fire forest types, which affects how these units operationalize resilience. A third case study, focused on a unit with different forest types, could help to clarify how the operationalization of resilience differs across ecological settings. Furthermore, examining these three case studies could allow us to explore the institutions shaping land management planning in different locations and how land managers and their partners work with these institutions. Collectively, these case studies will address key research needs, including understanding the operationalization of resilience, how this endeavor interacts with land management policies, and how institutional work activities help managers achieve an appropriate balance between the flexibility to respond to changing conditions and the stability expected from the federal government (Benson and Garmestani, 2011b; Beunen et al., 2017; Bone et al., 2016).

In addition to the case study research, our project will also include a survey of land managers about the concept of resilience and an analysis of NEPA documents that discuss resilience. These research tasks will allow us to examine themes uncovered in the case study

research across a broader set of contexts and supplement our qualitative findings with quantitative analysis. Furthermore, our case studies focus on plan revision processes, which are crucial but infrequent administrative routines, and many units are operationalizing resilience in NEPA project planning, especially through landscape restoration projects, without engaging in forest plan revision. Analyzing NEPA documents and surveying managers thus captures information on the use of resilience in contexts other than land management planning. Collectively, our research will provide a comprehensive view of the operationalization of resilience in the USFS, which will contribute to knowledge on forest policy and the study of resilience.

5.4.2 Additional writing based on data collection for Chapter 4

Data collection for Chapter 4 involved interviews with 55 individuals, as well as document analysis. While Chapter 4 discusses overall findings from this effort, there are also opportunities to focus on specific topics highlighted through this research. For example, Chapter 4 discusses climate change considerations in a few different contexts, shedding light on context-specific innovations happening on the Custer-Gallatin National Forest and the Mt. Baker-Snoqualmie National Forest. Summarizing these innovations and the contexts in which they occur could offer useful guidance for practitioners who are also grappling with the question of how to incorporate adaptation into decisions occurring in the complex institutional framework of the USFS. In addition, our research for this chapter included 12 interviews with managers on the White River National Forest, highlighting climate change considerations on a somewhat unique national forest, which receives the highest amount of recreational visitation in the country. In this context, land management reflects a complex web of decisions occurring in different venues.

Examining this case alone could shed light on how the complexity of contemporary environmental governance interacts with adaptation in a specific context.

An additional interest for future research based on this chapter as well as Chapter 2 involves examining how public administration theories on goal ambiguity, a key feature of public bureaucracies, could help illuminate the study of adaptation and its key concepts, including resilience (Rainey and Jung, 2014). As this dissertation highlights, concepts like resilience prove somewhat ambiguous; furthermore, understanding what constitutes successful adaptation in advance can prove challenging. Accordingly, unpacking this ambiguity and its relationship with the uncertainty brought on by climate change could fill in a key area of study regarding bureaucracies and climate change adaptation.

5.4.3 Additional work with the USFS Office of Sustainability and Climate

My dissertation focuses on the first two phases of our project funded by the Office of Sustainability and Climate; this work will also involve subsequent phases. Specifically, I have helped with the design of a survey that will be implemented across management units in several regions. The survey will examine what characteristics of national forest units and their staff and leadership contribute to robust considerations of climate change. The findings from our work in phase 1 and 2 of this project, which are summarized in Chapters 3 and 4 of this dissertation, directly inform the survey design and research approach that we are employing. This survey will supplement our findings presented in Chapter 4 and allow us to make conclusions based on mixed methods analysis.

5.5 Conclusion

The USFS has been pursuing climate change adaptation for about a decade on top of other management priorities. Over a similar time period, scholars have begun to regard adaptation across a range of sectors and contexts as a viable topic for research. As the discipline has evolved, scholars have argued for the need to consider how the making and implementation of public policies shape adaptation. This dissertation merges these two topics by examining adaptation as a policy priority for the USFS, highlighting how the agency's characteristics and the institutions that land managers have established over time structure ongoing adaptation efforts. The qualitative research methods used in this study allow me to provide descriptive accounts of the USFS's adaptation efforts in decision-making processes occurring in different contexts. As I discuss above, several opportunities for follow-up research exist and adaptation will remain a key topic in the study of natural resource management and public policy well into the future.

Managing national forests for adaptation requires managers to face a series of challenges that complicate the endeavor. First, past management practices, including widespread logging and the exclusion of fire from forests that ecologically rely on fire, have left lasting ecological and institutional legacies, and pursuing adaptation involves working through these legacies. Second, throughout the Forest Service's century-long history, formal policies and the informal institutions underpinning these policies have evolved such that the agency's institutional commitments are layered on top of one another and managers must balance multiple goals, which sometimes conflict, in making decisions. However, it is also important to note that legislative policy changes have largely not occurred in the past several decades, thus placing the burden on administrative agencies like the Forest Service and their staff to figure out appropriate

paths through this layered policy landscape. Third, for this agency, adapting ecosystems to climate change reflects, in some ways, the agency's past efforts to respond to ecological change and policy shocks; however, the complex ways in which climate change will impact ecosystems may require entirely new management paradigms. Fourth, as a federal agency, the Forest Service must involve the public in its decisions, and the governance system has evolved in such a way that contemporary land managers often rely on collaboration with external partners to carry out necessary activities. What all of these points suggest is that adaptation—in most contexts and especially when carried out by governments—ultimately does not occur on a blank slate but rather occurs in complex institutional landscapes. Accordingly, while adaptation requires technical know-how, including an understanding of the science on climate change and its impacts, it also requires that adaptation practitioners develop a skillset that allows them to assess existing policies and institutions and identify appropriate paths forward.

How will forests change in the future and what can managers do to respond to these changes? Answering this question is what climate change adaptation in forest management ultimately involves, and a question of this breadth requires input from a range of research disciplines. This question is not solely a topic for academic research but also warrants input from the public and, especially, forest managers. Qualitative research studies, like the one presented here, offer a useful mechanism for ensuring that practitioners have a voice in the academic debates on this topic. Accordingly, future studies of global change in forests and appropriate responses should seek out opportunities to hear from the forest managers who face this question in their day-to-day work.

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APPENDIX A: ADDITIONAL INFORMATION FOR CHAPTER 2

Interview guide
Note: Because we are using a semi-structured approach, the following should be seen as a broad guide for the kinds of questions we will be asking; we will inevitably ask clarifying and follow-up questions asked that are not listed here, and not every question will be asked of every research participant.

Questions in **bold** text are mandatory; all others are optional.

1. **Introduction**
   - **1.1. Tell me about your background: your current position (in the agency, organization, etc.), previous work you've done, education, etc.**
   - **1.2. How does your current work relate to the forest planning process?**
   - **1.3. Where is this forest currently in the forest plan revision process (e.g., drafting, out for review and comment, signed, under litigation, etc.)?**
   - **1.4. What have been some of the key issues and challenges associated with this plan?**

2. **Topic: How did formal institutions associated with the planning process challenge or facilitate planning for resilient landscapes**
   - **2.1. Was this forest planning process conducted under the 2012 planning rule? If not, was any of the language in the 2012 rule used to guide the planning process?**
   - **2.2. How did the plan approach the issue of climate change impacts and implications?**
   - **2.3. Does this forest (or region) have an operational definition of "resilience" or "resilient landscapes" that was utilized in the planning process?**
     - 2.3.1. Does this definition include ecological, social, or combined social-ecological components?
   - **2.4. Explain how an emphasis on resilient landscapes was integrated into the planning process**
     - 2.4.1. **What did this imply for thinking about the role of fire or other disturbances?**
     - 2.4.2. **Did planning for resilient landscapes include any consideration of thresholds or "tipping points"?**
     - 2.4.3. **Did planning for resilient landscapes include any consideration of the connections between dynamics at different scales?**
     - 2.4.4. **Did planning for resilient landscapes include any consideration of the relationships between social and ecological systems?**

2.5. Were there any aspects of the planning process (or planning regulations) that made it difficult for you to incorporate resilience or climate issues?

3. Topic: How did informal institutions associated with agency practice, knowledge, and culture adapt to a resilience approach

3.1. Did you note any resistance, confusion, or frustration among planning staff with aspects of the 2012 rule? What, specifically, seemed to give people trouble?

3.2. Do you feel that individuals on the planning team understood resilience and climate science enough to include these in planning, or were there concepts that remained unclear?

3.3. Compared with previous planning guidance, how radical a departure is it for people to plan for resilient landscapes and to include climate change considerations?

3.4. To what extent has the planning staff here adjusted to the process outlined in the 2012 rule?To the extent that you noted struggles with the new rule and concepts, was this largely at the level of individual planning staff, forest leadership, the region?

3.5. Did the planning team develop any new procedures or practices to adequately deal with concepts like resilient landscapes, climate change, or other aspects of the new planning rule?

4. Topic: What innovations, resources, or novel practices were used to inform the planning process and how were they incorporated

4.1. Explain how climate change science was integrated into the planning process

4.1.1. **What kinds of climate science data, models, tools, or other resources were used in the plan?**

4.1.2. **How was climate science integrated with science on disturbance regimes?**

4.1.3. Where did the climate science used in the plan come from?

4.1.4. How did the planning team deal with uncertainty in climate forecasts / modeling?

4.2. In what ways did the USFS support the planning process through dedicated science teams (e.g., climate science, fire science, etc.)?

4.2.1. How did these teams interact with the planning team?

4.2.2. What kinds of information were provided?

4.2.3. Were there any shortcomings in these teams in terms of content, quality, or communication?

4.3. In what ways (if at all) did you work with people or organizations from outside the USFS in putting this plan together?

4.3.1. **What did these outside entities contribute (e.g., scientific information, planning resources, connections to communities of interest, etc.)?**

4.3.2. How were these connections / collaborations made—did they grow out of the planning process or were they already in place?

4.4. Did you use any other forms of guidance, planning frameworks, models, or other science input to inform the planning process?

What kind of guidance on resilience and climate change did you receive from the regional office?

5. Topic: What were the implications of a resilience approach for the use of science, public participation, management planning, and monitoring and adaptive management

5.1. How did the inclusion of resilient landscapes and climate change as focal areas influence how you conduct monitoring?

5.1.1. Are there particular indicators or processes that you will use to measure resilience?

5.1.2. How do you incorporate climate change science into monitoring?

5.2. How did the inclusion of resilient landscapes and climate change influence your approach to adaptive management?

5.2.1. How, if at all, was adaptive management included in the plan?

5.2.2. How is this different than it would have been under the prior planning rule?

5.3. How did resilience and climate change concerns inform your interactions with the public?

5.3.1. Were these concepts specifically included in public outreach and involvement?

5.3.2. Did members of the public bring up these concepts in their comments, objections, or other forms of involvement?

6. Looking ahead

6.1. Have you been involved in other forest planning processes? In what ways was this process different?

6.2. What aspects, if any, did you feel were problematic or did not go well?

6.2.1. **What kinds of information or resources do you feel you would need to improve on the weaknesses in this process?**

6.3. What worked best about this planning process (what was the most successful outcome or what aspect of the plan felt the strongest to you)?Are there any other issues related to resilience planning or use of climate change in planning that we haven't discussed?

6.4. Who else should we speak with about these topics?

Thank you for your time!!

APPENDIX B: ADDITIONAL INFORMATION FOR CHAPTER 3

Table B.1—Assessment approaches by region

Region	Assessment approach	Details
Region 1 - Northern	Region-wide, multi-resource assessment	All management units are covered by the multi-resource NRAP assessment conducted by the Adaptation Partners group. The assessment process began in 2014 and a General Technical Report summarizing the process was published in 2018. The assessment covers a range of resources, including vegetation, snowpack and water, fish and wildlife, ecological disturbance, recreation, ecosystem services, and cultural resources. In addition, several smaller-scale assessments have been conducted for individual forests in the region, primarily in support of forest plan revision. These include a socio-economic assessment for the Nez Perce-Clearwater National Forest and a watershed assessment for the Lolo National Forest.
Region 2 – Rocky Mountain	Region-wide assessments for ecosystems and infrastructure	Published in 2018 as a General Technical Report, a region-wide assessment covers six priority ecosystem types, including glaciated valleys, spruce-fir, and Ponderosa pine. Units in the region also have access to a region-wide assessment of infrastructure published as a white paper in 2016. Other assessments focused on single units include two collaborative assessments covering the Gunnison Valley and the San Juan National Forest, and a literature synthesis assessments intended to support plan revision on the Shoshone National Forest.
Region 3 – Southwestern	Several region-wide assessments covering different resources	Several different region-wide assessments cover Region 3, including one that covers general climate trends, one that summarizes literature on ecological impacts, and an unpublished

		effort projecting potential vegetation change. In addition, Forest Service staff published in 2018 a General Technical Report analyzing socio-economic vulnerability in the region that includes recommendations about how the assessment aligns with policy requirements for forest planning.
Region 4 - Intermountain	Region-wide, multi-resource assessment	All management units are covered by the multi-resource IAP assessment conducted by the Adaptation Partners group. The assessment process began in 2015 and a General Technical Report summarizing the process was published in 2018. The assessment covers a range of resources, including vegetation, hydrology and water, fish and wildlife, ecological disturbance, recreation, ecosystem services, and cultural resources. In addition, researchers have completed General Technical Reports assessing vulnerability for aquatic resources and aspen using the NEAFWA approach for the Uintah-Wasatch-Cache and Ashley National Forests in Utah.
Region 5 – Pacific Southwest	Multiple sub-regional assessments done by EcoAdapt focused on ecosystems	Using the NEAFWA approach, EcoAdapt completed several ecosystem assessments for different national forests distributed across several sub-regions in California; these assessments are not published through a peer-reviewed venue. While we were conducting this research, the Adaptation Partners group began a vulnerability assessment of recreation and infrastructure for the national forests in the Sierra Nevada.
Region 6 – Pacific Northwest	Multiple sub-regional, multi-resource assessments	Beginning in 2008, the Adaptation Partners group has completed a series of multi-resource assessments focused on one or more contiguous national forests and national parks. Authors of these assessments include both researchers, NFS managers, and other partners. Accounts of these assessments have been published as General Technical Reports and in peer-reviewed journals. These

		assessments cover nearly all units in the region, aside from the Siuslaw National Forest. Forest Service scientists have also published a General Technical Report in 2012 that covers the entire region; it assesses vulnerability of tree species found in the region based on their genetics. Results from this assessment have been incorporated in Adaptation Partners assessments described above.
Region 8 – Southern	Region-wide briefing papers based on TACCIMO; intended to cover forests under other ownerships	The USDA Southeast Regional Climate Hub published a white paper vulnerability assessment in 2015 that covers the entire region. Several other fact sheets have been developed in the region intended to support private landowners. The TACCIMO tool, developed in this region, provides an additional tool for managers looking for information on climate change vulnerabilities. The TACCIMO tool informed the development of a literature synthesis vulnerability assessment for the El Yunque National Forest used in its forest plan revision process.
Region 9 - Eastern	Multiple sub-regional assessments focused on ecosystems; assessments focused on forests under multiple ownerships	The CCRF group has developed a series of assessments focused on bioregions throughout the Midwest and Northeast, including the majority of national forests in the region. The Midewin National Tallgrass Prairie is the only management unit in the NFS not covered by a vulnerability assessment covered in this analysis.
Region 10 - Alaska	Individual assessments for each of the two national forests in this region	In 2014, EcoAdapt developed an assessment of aquatic resources on the Tongass National Forest. A General Technical Report published in 2017 assessed vulnerability on the Chugach National Forest.

Table B.2—Common vulnerability assessment approaches used in the U.S. Forest Service

Approach	Scale	Target resources	Approach to assessing vulnerability	Example assessments
Adaptation Partners	Several national forests NFS region	• Vegetation • Disturbances • Hydrology • fish and wildlife • recreation • ecosystem services • cultural resources	These assessments employ a "state-of-the-science" approach. Chapters for each resource use different approaches that generally draw on models that project impacts of climate change on resources. Modeling results are used to identify geographic areas that are vulnerable and to rank differential vulnerability across species or vegetation types. Assessment chapters also draw on reviews of peer-reviewed literature.	Northern Region Adaptation Partnership
Climate Change Response Framework	Bioregion	• Vegetation types	This approach uses climate projections, literature review, and projection results from several different vegetation models as the basis for expert elicitation processes. In these processes, participants rate the vulnerability of forest types based on the potential impact of climate change, which is a combination of exposure and sensitivity, and the forest type's adaptive capacity.	New England and Northern New York Forest Ecosystem Vulnerability Assessment
Northeastern Association of Fish and Wildlife Agencies and Manomet Center	Several national forests	• Vegetation • Wildlife habitat • Watersheds	This approach uses expert elicitation to rate the vulnerability of the endpoint on a 5- or 7-point scale for several different criteria. A common set of 7-criteria that are often used include: range shift capacity; vulnerability of cold-adapted, foundation, or keystone species; sensitivity to extreme climatic events (drought, heat, floods); intrinsic adaptive capacity; dependence on a specific hydrologic regime; potential for climate change to exacerbate effects of non-climate stressors, or vice versa; and, likelihood of managing or alleviating climate change effects.	Rocky Mountain Region Aquatic and Terrestrial Ecosystems Vulnerability Assessment

Watershed vulnerability assessments	Single national forest	• Watersheds and associated values (e.g., infrastructure, fish)	These assessments generally draw on geospatial models exposure, namely projected changes in temperature and precipitation, and sensitivity for watersheds at the 6th level hydrologic unit (i.e., HUC-6 or sub-watershed). This assessment approach provides a useful resource for prioritizing different watersheds. Similar approaches are used for chapters on watersheds and hydrology in some Adaptation Partners assessments.	Lolo National Forest Watershed Vulnerability Assessment
Literature synthesis	Single national forest	• Vegetation disturbances hydrology fish and wildlife recreation ecosystem services cultural resources	This approach, often conducted to support forest plan revision, focuses on synthesizing information in the peer-reviewed literature about climate change impacts on different resources. Tools like the Forest Service's Template for Assessing Climate Change Impacts and Management Options (TACCIMO) support these assessments.	Climate Change on the Shoshone National Forest, Wyoming: A Synthesis of Past Climate, Climate Projections, and Ecosystem Implications
Socio-economic assessments	Single national forest NFS region	• Ecosystem services (grazing, forest products, water, recreation)	An assessment for the Southwest Region analyzes socio-economic vulnerability in terms of its three subcomponents. For exposure, the assessment considers the risk of vegetation change in areas that provide ecosystem services. For sensitivity, the assessment analyzes economic contributions of ecosystem services from national forests to regional economies. The assessment uses socioeconomic characteristics to assess adaptive capacity.	Socioeconomic Vulnerability to Ecological Changes to National Forests and Grasslands in the Southwest

Table B.3—Vulnerability assessments reviewed

	Region	Name	Approach	Scale (acres)	Scale (description)	Resources
1	R-1, R-2, R-3, R-4, R-5, R-6, R-8, R-9, R-10	Assessing the Vulnerability of Watersheds to Climate Change	Watershed Vulnerability Assessment	Various; includes multiple forests	Several national forests in different regions	Terrestrial and aquatic ecosystems; Fish/aquatic species; Water, hydrology, snowpack; Recreation; Infrastructure; Other ecosystem services/human uses
2	R-1	Northern Rockies Adaptation Partnership	Adaptation Partners	27 million	NFS Region	Terrestrial and aquatic ecosystems; Vegetation species; Disturbances/processes; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Recreation; Other ecosystem services/human uses
3	R-1	A Climate Change Vulnerability Assessment for Resources of Nez Perce-Clearwater National Forests	Northeastern Association of Fish and Wildlife Agencies and Manomet	4.0 million	One national forest	Terrestrial and aquatic ecosystems; Vegetation species; Disturbances/ processes; Wildlife; Water, hydrology, snowpack; Recreation; Other ecosystem services/human uses
4	R-1	Nez-Perce National Forests Forest Plan Assessment: Socioeconomic Climate Change Vulnerability Assessment	Other expert elicitation	4.0 million	One national forest	Water, hydrology, snowpack; Infrastructure; Other ecosystem services/human uses
5	R-1	Watershed Vulnerability Assessment Lolo National Forest	Watershed Vulnerability Assessment	3.3 million	One national forest	Fish/aquatic species; Water, hydrology, snowpack
6	R-1	Kootenai Idaho Panhandle Zone Climate Change Report	Literature synthesis	5.4 million	Several national forests	Terrestrial and aquatic ecosystems; Vegetation species; Disturbances/ processes; Wildlife; Water, hydrology, snowpack; Recreation;

	Region	Name	Approach	Scale (acres)	Scale (description)	Resources
						Other ecosystem services/human uses
7	R-2	Climate Change Vulnerability Assessment of Aquatic and Terrestrial Ecosystems in the U.S. Forest Service Rocky Mountain Region	Northeastern Association of Fish and Wildlife Agencies and Manomet	22 million	NFS Region	Terrestrial and aquatic ecosystems
8	R-2	San Juan/Tres Rios Climate Change Ecosystem Vulnerability Assessment	Northeastern Association of Fish and Wildlife Agencies and Manomet	5 million (1.9 million USFS)	One national forest and neighboring public land	Terrestrial and aquatic ecosystems
9	R-2	Climate Change on the Shoshone National Forest, Wyoming	Literature synthesis	2.4 million	One national forest	Terrestrial and aquatic ecosystems; Disturbances/ processes; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Recreation; Other ecosystem services/human uses
10	R-2	Regional-Scale Climate Change Vulnerability Assessment for Infrastructure in the National Forests and Grasslands of the Rocky Mountain Region	Other spatial analysis	22 million	NFS Region	Infrastructure
11	R-2	Gunnison Basin Climate Change Vulnerability Assessment	Northeastern Association of Fish and Wildlife Agencies and Manomet	2.4 million (1.3 million USFS)	One national forest and neighboring public land	Terrestrial and aquatic ecosystems; Vegetation species; Wildlife; Other ecosystem services/human uses
12	R-3	Assessing Climate Change Vulnerability for Ecosystems of the Southwestern U.S.	Literature synthesis	20 million	NFS Region	Terrestrial and aquatic ecosystems; Vegetation species; Wildlife; Water, hydrology, snowpack
13	R-3	Southwestern Region Climate Change Trends and Forest Planning	Literature synthesis	20 million	NFS Region	Terrestrial and aquatic ecosystems; Vegetation species; Disturbances/ processes; Wildlife; Fish/aquatic species; Water, hydrology,

	Region	Name	Approach	Scale (acres)	Scale (description)	Resources
						snowpack; Recreation; Other ecosystem service/human use
14	R-3	Socio-Economic Vulnerability to Climate-Related Changes to National Forests in the Southwest	Economic analysis	20 million	NFS Region	Water, hydrology, snowpack; Recreation; Other ecosystem services/human uses
15	R-4	Assessment of Watershed Vulnerability to Climate Change for the Uinta-Wasatch- Cache and Ashley National Forests, Utah	Northeastern Association of Fish and Wildlife Agencies and Manomet	3.6 million acres	Several national forests	Terrestrial and aquatic ecosystems; Vegetation species; Wildlife; Disturbances/ processes; Water, hydrology, snowpack
16	R-4	Assessment of Aspen Ecosystem Vulnerability to Climate Change for the Uinta-Wasatch- Cache and Ashley National Forests, Utah	Northeastern Association of Fish and Wildlife Agencies and Manomet	3.6 million	Several national forests	Terrestrial and aquatic ecosystems; Vegetation species
17	R-4	Intermountain Adaptation Partnership	Adaptation Partners	34 million	NFS Region	Terrestrial and aquatic ecosystems; Vegetation species; Disturbances/ processes; Wildlife; Water, hydrology, snowpack; Recreation; Infrastructure; Other ecosystem service/human use
18	R-5	Climate Adaptation Project for the Sierra Nevada	Northeastern Association of Fish and Wildlife Agencies and Manomet	12.4 million	Several national forests	Terrestrial and aquatic ecosystems; Disturbances/ processes; Wildlife; Recreation; Other ecosystem services/human uses
19	R-5	Southern California Climate Adaptation Project	Northeastern Association of Fish and Wildlife Agencies and Manomet	3.7 million	Several national forests	Terrestrial and aquatic ecosystems

	Region	Name	Approach	Scale (acres)	Scale (description)	Resources
20	R-5	Northern California Climate Adaptation Project	Northeastern Association of Fish and Wildlife Agencies and Manomet	6.5 million	Several national forests	Terrestrial and aquatic ecosystems
21	R-5	Sierra Nevada Recreation and Infrastructure Vulnerability Assessment	Adaptation Partners	11 million	Several national forests	Infrastructure; Recreation
22	R-6	Blue Mountains Adaptation Partnership	Adaptation Partners	5.3 million	Several national forests	Terrestrial and aquatic ecosystems; Fish/aquatic species; Water, hydrology, snowpack; Infrastructure
23	R-6	North Cascadia Adaptation Partnership	Adaptation Partners	5.9 million	Several national forests and neighboring public land	Terrestrial and aquatic ecosystems; Wildlife; Water, hydrology, snowpack; Infrastructure
24	R-6	South Central Oregon Adaptation Partnership	Adaptation Partners	5.3 million	Several national forests and neighboring public land	Terrestrial and aquatic ecosystems; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Recreation; Other ecosystem services/human uses
25	R-6	Southwest Washington Adaptation Partnership	Adaptation Partners	1.3 million acres	Single national forest and neighboring public land	Terrestrial and aquatic ecosystems; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Infrastructure
26	R-6	Olympic Adaptation Partnership	Adaptation Partners	1.6 million	Single national forest and neighboring public land	Terrestrial and aquatic ecosystems; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Infrastructure
27	R-6	Southwest Oregon Adaptation Partnership	Adaptation Partners	2.7 million acres	Several national forests and neighboring public land	Terrestrial and aquatic ecosystems; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Recreation;

	Region	Name	Approach	Scale (acres)	Scale (description)	Resources
						Other ecosystem services/human uses
28	R-6	Columbia River Gorge National Scenic Area, Mount Hood National Forest, & Willamette National Forest Adaptation Partnership (CMWAP)	Adaptation Partners	2.8 million acres	Several national forests and neighboring public land	Terrestrial and aquatic ecosystems; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Infrastructure; Recreation; Other ecosystem services/human uses
29	R-6	Climate Change and Forest Trees in the Pacific Northwest: A Vulnerability Assessment and Recommended Actions for National Forests	Tree species modelling	25 million	NFS Region	Terrestrial and aquatic ecosystems; Vegetation species
30	R-8	Southeast Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies	Literature synthesis	Not targeted to a specific area	Private land	Terrestrial and aquatic ecosystems; Other ecosystem services/human uses
31	R-8	North Carolina's Emerging Forest Threats: Management Options for Healthy Forests	Literature synthesis	Not targeted to a specific area	Private land	Terrestrial and aquatic ecosystems; Vegetation species; Wildlife; Fish/aquatic species; Other ecosystem services/human uses
32	R-8	Protecting Your Forest Asset: Managing Risks in Changing Times	Literature synthesis	Not targeted to a specific area	Private land	Terrestrial and aquatic ecosystems Disturbances/ processes;
33	R-8	Climate change effects in El Yunque National Forest, Puerto Rico, and the Caribbean region	Literature synthesis	28,000	Single national forest	Terrestrial and aquatic ecosystems; Vegetation species; Disturbances/ processes; Wildlife; Fish/aquatic species; Recreation
34	R-9	Central Appalachians Forest Ecosystem Vulnerability Assessment and Synthesis: A Report from the Central Appalachians Climate	Climate Change Response Framework	19 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species

	Region	Name	Approach	Scale (acres)	Scale (description)	Resources
		Change Response Framework Project				
35	R-9	Forest ecosystem vulnerability assessment and synthesis for northern Wisconsin and western Upper Michigan	Climate Change Response Framework	16 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
36	R-9	Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis	Climate Change Response Framework	23 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
37	R-9	Michigan Forest Ecosystem Vulnerability Assessment and Synthesis	Climate Change Response Framework	17 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
38	R-9	Ecosystem Vulnerability Assessment and Synthesis: A Report from the Climate Change Response Framework Project in Northern Wisconsin	Climate Change Response Framework	19 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
39	R-9	Chicago Wilderness Region Urban Forest Vulnerability Assessment and Synthesis	Climate Change Response Framework	7 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
40	R-9	Central Hardwoods Ecosystem Vulnerability Assessment and Synthesis	Climate Change Response Framework	42 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
41	R-9	Mid-Atlantic Forest Ecosystem Vulnerability Assessment and Synthesis	Climate Change Response Framework	60 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
42	R-9	New England and New York Forest Ecosystem Vulnerability Assessment and Synthesis	Climate Change Response Framework	53 million	Ecoregion	Terrestrial and aquatic ecosystems; Vegetation species
43	R-10	A Climate Change Vulnerability Assessment for Aquatic Resources in the Tongass National Forest	Northeastern Association of Fish and Wildlife Agencies and Manomet	17 million	Single national forest	Terrestrial and aquatic ecosystems; Fish/aquatic species; Water, hydrology, snowpack

	Region	Name	Approach	Scale (acres)	Scale (description)	Resources
44	R-10	Climate Change Vulnerability Assessment for the Chugach National Forest and the Kenai Peninsula	Literature synthesis	7 million	Single national forest	Terrestrial and aquatic ecosystems; Wildlife; Fish/aquatic species; Water, hydrology, snowpack; Infrastructure; Other ecosystem services/human uses

APPENDIX C: ADDITIONAL INFORMATION FOR CHAPTER 4

Interview guide

CCVA Phase 2 Interview Guide - Scientists

1. Describe your **involvement in developing** vulnerability assessments.
2. What was the **most recent assessment** you worked on? What role did you play?
    a. Describe the **process for developing** that assessment.
    b. Do you recall **any key moments** in the process?
3. Looking back, are you aware of **any mistakes** that you made in past assessments?
4. What have you **learned about conducting vulnerability assessments** over time?
5. Has the process of developing vulnerability assessments **changed your beliefs/ideas** about forest management?
6. Based on this learning, have you **changed your approach** to developing vulnerability assessments?
7. Have you noticed **differences in management contexts** covered by assessments?
    a. Was there anything surprising to you about the management contexts covered by the assessments?
    b. How did you change your assessment approach to suit these different contexts?
8. In your impression, **how do managers make management decisions**? What factors to they consider?
9. What do you hope forest managers **will get out of vulnerability assessments**?
10. Are you aware of **recent management decisions/actions** motivated by the assessments?
11. Do you have any **suggestions about how to improve the application** of vulnerability assessments?
12. What are **next steps** for vulnerability assessment processes?

CCVA Phase 2 Interview Guide – Regional staff

1. **Professional background and responsibilities.**
    a. What is your **current position**? **How long** have you had that position?
    b. Relevant past positions and relevant education.
    c. What are your **primary work responsibilities** (related to climate change)?
        i. Are you dealing with any especially challenging issues at the moment?
2. **Climate change and vulnerability assessment.**
    a. How does climate change **intersect with your work**?
    b. Are you **aware of climate change vulnerability assessments** conducted for your region?
    c. What **motivated the development** of the vulnerability assessment(s)?
    d. Are there **other factors** that more generally influence consideration of climate change? **Public interest**?
    e. **Policy requirements** pertaining to climate change?
    f. Did you **participate** in the development of the vulnerability assessment?
    g. What were your **impressions of the process**? What worked? What didn't?
    h. Have you used the **resulting document**? Do you intend to? Why?
        i. Have you **worked with others** on implementing the vulnerability assessment? Talked with others?
    i. Can you recall any examples of things you learned from the vulnerability assessment?
    j. Are you aware of any **recent projects** that incorporate climate change/pursue climate change adaptation?
        i. Ask about how those projects developed over time.
    k. Based on the vulnerability assessment process/document, have you changed how you operate? Examples?
    l. What **policy/institutional changes** would support better incorporation of climate change into your work?
    m. Room for mistakes/learning?

CCVA Phase 2 Interview Guide – National Forest level

1. **Professional background.**
    a. What is your **current position**? **How long** have you had that position?
    b. Relevant past positions and relevant education.
    c. What are your **primary work responsibilities**?
2. **Climate change and vulnerability assessment**
    a. How does climate change **intersect with your work**?
    b. Are you **aware of climate change vulnerability assessments** conducted for your national forest?
    c. What **factors influence your consideration of climate change**?
        i. Do **members of the public and/or stakeholder groups** discuss/provide input on climate change?
        ii. What **policies** require consideration of climate change? What about agency guidance/strategy?
    d. Did you **participate** in the development of the vulnerability assessment?
        i. *If yes:* What **motivated the development** of the vulnerability assessment(s)?
        ii. *If yes:* What were your **impressions of the process**? What worked? What didn't?
    e. Have you used the **resulting document**? Do you intend to? Why?
        i. *If yes:* Has the vulnerability assessment process/document **changed how you make decisions?**
    f. Are you aware of any **recent projects** that incorporate climate change/pursue climate change adaptation?
    g. How **vulnerable** would you say your forest/region is to climate change?
    h. Are there **specific locations** on the forest that you think would benefit from adaptation actions?
    i. What **suggested improvements** to the vulnerability assessment do you have?
    j. Are there **other sources of scientific information** that you consult regarding climate change?
    k. Room for mistakes/learning in implementing?
3. **For plan revision forests: planning specific questions (supplements section 4)**
    a. Where in the **plan revision process** is your forest?
    b. What **role** do you play in plan revision?
    c. How does your forest make **decisions about plan components** (or other aspects of planning)?
        i. Are they a product of ID team meetings? Do individual resource staff write out draft plan components and share them with the group?
    d. What parts of plan revision are **most challenging**? What causes friction with the public and stakeholders?
    e. How are you addressing **climate change in the plan?**
    f. Discuss how the assessment phase proceeded related to climate change.
        i. Is this where vulnerability assessments feed into planning?
        ii. Was there group deliberation in this phase?

4. **Management setting.**
    a. What makes your national forest **unique** in the region?
    b. Do any particularly challenging management issues come to mind? Anything you've been recently dealing with?
    c. Who are your **key stakeholders**? What is the **public interested in**?
5. **Looking forward**
    a. What **policy/institutional changes** would support better incorporation of climate change into your work?
    b. What are some **key needs** that would help you better incorporate climate change?