The Role of the US Forest Service Amidst Change: A Framework for Effective Ecosystem Management in the Face of Climate Change

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College of William and Mary

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The Role of the US Forest Service Amidst Change:
A Framework for Effective Ecosystem Management in the Face of Climate Change

A thesis submitted in partial fulfillment of the requirement
for the degree of Bachelors of Arts in Environmental Science and Policy from
The College of William and Mary

by

Mr. Aubrey David Miller

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(Honors, High Honors, Highest Honors)

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Williamsburg, VA

May 5th, 2009
The Role of the US Forest Service Amidst Change:  
A Framework for Effective Ecosystem Management in the Face of Climate Change

Abstract

Current climate change poses a multitude of complex threats to the health of ecosystems throughout the United States. The US Forest Service has a responsibility to manage ecosystems to retain primary functions and provide vital services. In a time of rapid environmental change, the US Forest Service must take measures to effectively manage ecosystems, which will require revisions to current management structures. This paper (1) explores the threats to National Forest ecosystems posed by climate change; (2) outlines why current institutional management structures will not be adequate for effective resource management; (3) introduces tools, broadly adaptive management techniques as well as mechanisms to encourage collaboration and stakeholder engagement, which can be used to revise the current management structure; and (4) utilizes the tools to propose revisions to a National Forest Management Plan. Various case studies are used to highlight constraints on current management structures and to decipher where opportunities for achieving effective resource management can be found. Additionally, the special considerations for designated wilderness areas and climate change are introduced. The paper provides a framework for immediate action and durable policy creation on climate change by US Forest Service managers. The paper is in no way a panacea for effective ecosystem management in the midst of climate change, but rather designed to provide guidance on necessary initial management restructuring.

Key words: Climate change, resource management, United States Forest Service, adaptive management, collaboration, ecosystem functions, ecosystem services, federal institutional reform.
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<tr>
<th>Abbreviation</th>
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<tr>
<td>ACM</td>
<td>adaptive collaborative management</td>
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<tr>
<td>AM</td>
<td>adaptive management</td>
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<td>ARNF</td>
<td>Arapaho-Roosevelt National Forest</td>
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<tr>
<td>CNRM</td>
<td>collaborative natural resource management</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
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<tr>
<td>DOC</td>
<td>dissolved organic carbon</td>
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<tr>
<td>EBM</td>
<td>ecosystem-based management</td>
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<tr>
<td>ENSO</td>
<td>El Niño–Southern Oscillation</td>
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<tr>
<td>EPA</td>
<td>The United States Environmental Protection Agency</td>
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<tr>
<td>GHG</td>
<td>greenhouse gas</td>
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<td>HRM</td>
<td>holistic resource management</td>
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<td>IGO</td>
<td>inter-governmental organization</td>
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<tr>
<td>INRM</td>
<td>integrated natural resource management</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPWA</td>
<td>Indian Peaks Wilderness Area</td>
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<tr>
<td>MDC</td>
<td>multi-dimensional collaboration</td>
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<tr>
<td>N</td>
<td>nitrogen</td>
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<tr>
<td>NGO</td>
<td>non-governmental organization</td>
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<td>NFS</td>
<td>National Forest System</td>
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<td>NPP</td>
<td>net primary production</td>
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<tr>
<td>NWT-LTER</td>
<td>Niwot Ridge Long-Term Ecological Research Site</td>
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<tr>
<td>RMRS</td>
<td>Rocky Mountain Research Station</td>
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<tr>
<td>RNA</td>
<td>research natural area</td>
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<tr>
<td>UNEP</td>
<td>United Nations Environment Program</td>
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<tr>
<td>USDA</td>
<td>The United States Department of Agriculture</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>USFWS</td>
<td>The United States Fish and Wildlife Service</td>
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<td>USFS</td>
<td>The United States Forest Service</td>
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<tr>
<td>USGS</td>
<td>The United States Geologic Survey</td>
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<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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Chapter 1:

Introduction
1.1 Introduction

Drastic environmental changes throughout the planet’s history have resulted in altered ecosystems (Newell, 1967). Previous periods of drastic environmental change have been linked to changes in the composition of the atmosphere and warmer temperatures (Kiehl and Shields, 2005), which have coincided with mass extinctions (Hallam and Wignall, 1999). We are now embarking on a new period of drastic environmental change. It is becoming clear the global climate is changing (IPCC, 2007a), and ecological systems are likely to be disrupted as a result (IPCC, 2007b). Dynamism, while necessary to healthy ecological systems, is constrained by the ability of the system to absorb large or rapid perturbations, as evidenced by previous mass extinctions. Data suggest current climate change is largely human-caused (IPCC, 2007a). Therefore, we have a responsibility to take necessary measures to avoid severe ecological disruption or the next mass extinction.

Resource managers—individuals who design and implement techniques to protect ecosystem functions and services—attempt to understand the dynamism inherent in ecological systems and harmonize management actions accordingly. The US Forest Service (USFS) manages vast swaths of America’s ecological systems, with the stated mandate of maintaining environmental services for human use and ensuring continued ecological function (USDA Forest Service, 2009a). Resource management agencies such as the USFS are facing a new suite of ecological threats as a result of current climate change. These threats will test the ability of the agency to effectively manage ecosystems. Ecological systems will be directly or indirectly altered as a result of a warmer world, and
agencies such as the USFS must take immediate measures to assist ecosystems in adapting to climate change.

In this paper, I will examine the role of the US Forest Service amidst rapid climatic change and the challenges that change presents. Confronting climate change will require a refocusing of management efforts on emerging issues to anticipate challenges before they become too large to effectively address. The USFS must consider climate change the most critical long-term issue facing the agency and take actions accordingly—with diligence, expediency, fortitude, and resolve. There are hurdles to effectively assisting ecosystems to adapt to climate change, however. I will argue that despite such hurdles, it is not only possible but also necessary for the USFS to take measures immediately to confront the challenges posed by climate change.

Therefore, I will provide a framework for moving the US Forest Service closer to effective ecosystem management in the face of climate change. I will, by examining the structure of current USFS management processes and mechanisms, highlight the adjustments necessary to build the capacity for effective resource management. Before introducing the analyses and proposed revisions to USFS management I propose in this paper, however, it is necessary to more fully establish the context in which the paper was conceived.

1.2 Climate Change

In 1994, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established an international collaborative effort to explore the science behind observed climatic changes. This project, known as the
Intergovernmental Panel on Climate Change (IPCC), has brought together hundreds of the world’s leading physical and biological scientists and representatives of many of the world’s governments to provide a framework for a comprehensive global analysis of climate science. The panel performs various meta-analyses on current climatic research and synthesizes findings into Assessment Reports. The most recent Assessment Report (AR4) was published in 2007 and highlights a strong causal relationship between the actions of humans and an increase in the observed global mean temperature. As the IPCC has found, “warming of the climate system is unequivocal” and likely to alter the character of numerous ecological and social systems (IPCC 2007d, pp. 2). The IPCC has found that increasing levels of greenhouse gases in the atmosphere over the past century are causing the planet to warm. The IPCC cites human actions, especially since the dawn of the industrial revolution and the resulting consumption of fossil fuels, as the primary reason for such a drastic increase in levels of carbon dioxide (CO₂) and other greenhouse gases.

As the global mean temperature increases, certain geographic areas—especially those at higher latitudes—are likely to face much faster rates of temperature increases than other areas. This results from a multitude of factors including the role of positive feedback loops, as well as air and water circulation patterns. Drastic temperature increases cause disruption to the structure and functions of environmental systems. Some geographic areas may not see immediate temperature increases, but will still face indirect

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1 Each IPCC assessment report is split into three distinct sections or working groups. Each working group has a unique focus. Working Group I examines the “physical science basis” for climate change (IPCC, 2007a). Working Group II examines “impacts, adaptation and vulnerability” (IPCC, 2007b), and Working Group III focuses on “mitigation of climate change” (IPCC, 2007c).
effects of climate change. The current global mean temperature increase will be referred to in this paper as *climate change* because this term more accurately captures the dynamic unevenness in temperature increases across the globe. Climate change also refers to the varied effects on biotic and abiotic systems that are likely to result from global warming. A common example is the expected changes to precipitation patterns globally as a result of differential warming of the planet.

1.3 The US Forest Service

The US Forest Service (USFS) is a branch of the US Department of Agriculture. Congress established the agency in 1905 with the task of managing public lands called National Forests, and, later, National Grasslands were added to the domain of USFS. The National Forest System (NFS) encompasses 193 million acres, or roughly 300,000 square miles of public lands (USDA Forest Service, 2009a). The structure for managing this large area is based on four tiers of USFS offices: the national, regional, forest, and district offices. The national office focuses on administrative procedures and inter-agency relations as well as relations with Congress. There are nine regional offices, which monitor and manage national forest relations and activities. Then, there are 155 national forests each managed by a forest office (also known as the supervisor’s office). Finally, there are over 600 ranger districts, which is where the majority of on-the-ground operations occur (ibid.). The USFS also has a strong focus on scientific research and development, which is administered through regional research stations. There are five research stations throughout the US as well as centers focusing on research outside the US.
The US Forest Service is in a unique position with regard to climate change and natural resources. The mission of the USFS is to manage public lands for multiple uses in such a way as to “sustain the health, diversity and productivity of the nation’s forests and grasslands to meet the needs of present and future generations” (USDA Forest Service, 2009a). Multiple-use management is intended to ensure that various stakeholders have equal access to forests. These stakeholders can include individuals who use the national forest for recreation, for timber harvesting, or for a reliable source of clean water. Deciphering exactly what equal access to services means has been a continuing point of contention in USFS management practices (Crow, 2002). The USFS is also expected to be a leader in scientific research of environmental systems and to develop techniques to manage ecosystems sustainably.

Each chief of the Forest Service (an individual appointed by the president to lead the organization) highlights management foci for his or her tenure. The current chief, Gail Kimbell, who took office in early 2007, outlined “climate change, water, and kids” as her three primary management emphases. She has stated that climate change will be the greatest hurdle to effective resource management. Also, water will become an increasingly sought commodity and the NFS provides much of the nation’s clean water. Finally, Kimbell wants to reestablish the importance of the NFS as an educational opportunity, especially for kids (USDA Forest Service 2009a).

1.4 Fundamental Questions: Why is This Paper Necessary?

In this paper, I will answer five fundamental questions. The overall goal for this paper—to decipher what mechanisms are necessary to ensure the USFS effectively
Chapter 1

Introduction

manages ecosystems in the face of climate change—is rooted in these five questions. The questions are:

(A) What makes climate change such an important issue to USFS resource managers and the ecosystems they manage (Chapter 2)?
(B) What are the principal constraints on effective resource management when facing the complexity of climate change in the USFS management structure (Chapter 3)?
(C) What tools can be applied to revise the current management structure to afford better management practices (Chapter 4)?
(D) If we employ these tools, what will the revised management structure look like (Chapter 5)?
(E) Is the revised structure now adequate to facilitate effective ecosystem management in the face of climate change (Chapter 5)?

Additionally, a question explored in the Appendix, which is necessary to address if the USFS effectively confronts the challenges of climate change is: what unique characteristics necessitate special consideration for designated wilderness areas in a climate change-USFS discussion?

These questions should motivate resource managers to make adjustments to current USFS management structures. Chapter 2 makes the case that climate change is an important consequential and exigent threat to NFS ecosystems. It also argues that the complexity of climate change and the potential for drastic alterations to the character of NFS ecosystems create an imperative for action on the part of USFS managers. Rejection or denial of climate change as a predominant issue facing the USFS has dire consequences for continued ecosystem functions and services. I outline six fundamental threats to NFS ecosystems. They will occur in the form of: (1) water quantity and quality changes, generally decreasing on both fronts; (2) biodiversity and ecosystem composition changes with a high probability of biodiversity loss as result of a loss of suitable habitat, fragmentation, and species range-shifts; (3) the intensified proliferation of non-native
exotic species and their subversion of native species; (4) the spread and intensification of diseases and insect infestation within the NFS; (5) more frequent and severe extreme weather events; and (6) increases in the intensity, frequency, and scale of fire on national forests. These effects are highly interconnected and share numerous feedbacks, so the collectivity of the effects will also be discussed. This interconnectedness is such that a discussion of one effect necessarily requires an understanding of its relationship to the other effects.

After climate change has been established as one of the most important issues facing the USFS, Chapter 3 shows why the current management framework cannot adequately incorporate climate change into policy planning and implementation processes. These principle constraints are embedded within a system of reactionary responses to emerging issues, poor flexibility, and a “process predicament” inherent in current USFS management structures. This chapter explains a need for a new management framework to address climate change and introduces the various frames of analyses that will highlight this need for a new framework.

Specifically, I use the forest level of the USFS management structure to explore constraints and apply revisions, which will be made explicit in Chapter 5. I chose a specific national forest (the Arapaho-Roosevelt National Forest (ARNF) in Colorado) to examine and apply necessary revisions. This requires an analysis of the ARNF Forest Plan. A forest plan covers all major management goals and mechanisms to achieve those goals for a particular forest and is revised every 10-15 years. Another frame of analysis introduced in Chapter 3 is the role of alpine ecosystems in signaling climatic changes and early effects on ecosystems. Similarly, the role of designated wilderness areas in the
climate change-USFS management discussion is introduced in this chapter. This discussion is taken further in the Appendix.

Once the threat is established and principal constraints to the incorporation of climate change into management structures are explained, Chapter 4 introduces several tools that are necessary to revise current management structures. I apply the more salient aspects of a theoretical ecological management paradigm, adaptive management (AM), and establish mechanisms for translating AM theory into practice. I also introduce what I term multi-dimensional collaboration (MDC) and more appropriate stakeholder engagement in planning processes as vital tools needed for management structure reform.

Chapter 5 includes proposed revisions for the Arapaho-Roosevelt National Forest Plan and management framework. I cover the principal impediments to implementation of the proposed changes and argue why implementation is justified despite such impediments. This chapter also discusses the potential for extrapolation of the analysis methodologies and proposals to other levels of USFS management and to other resource management agencies.

Finally, in the Appendix, I bring the unique case of designated wilderness areas into the discussion of climate change and USFS management. Wilderness areas have laws designed to protect them from human impacts and remove them from most human influences. The effects of a warming world threaten wilderness areas and the laws protecting them, but these areas also provide an important service to USFS managers in the face of climate change. Namely, they can help resource managers more clearly differentiate climate change-related impacts from other human impacts and from natural
variation. Climate change poses moral, political, and ecological considerations for wilderness areas that must be addressed by USFS managers. For the USFS to adequately confront climate change, they must incorporate the role of wilderness areas into the discussion.

This paper is designed to shed light on the importance of climate change as a resource management issue. I lay a framework for immediate action on climate change in the following chapters, but it will be the job of US Forest Service managers to develop the proposals further and implement policies uniquely tailored to each level of USFS management structures.

1.5 Contexts and Assumptions

The analyses performed in this paper will rely on several basic assumptions, which require context and elucidation. First, how USFS managers define “naturalness” in environmental systems is important when developing the most appropriate management course for a given system. The common conception of “nature,” and the limitations of such a conception, will be an important part of the Appendix, but it is necessary to at least partially confront the challenge of establishing what “naturalness” is in ecological systems.

Many conceive of “nature” as a resilient static entity existing in perpetuity independent of human actions. In reality, nature is a dynamic interplay between all organisms on the planet, and whose condition is shaped in part by human influences. In this paper, I chose to conceive of naturalness as a socially constructed characterization of the innumerable interactions between ecological variables, including humans. Earth’s
systems are in a constant state of flux; change is positive. Artificially conceiving of a “natural state” will inhibit efforts to maintain the structural integrity of an ecosystem in a time of ecological disruption posed by a human issue such as climate change. I will use the term “natural” in this paper to refer to the historically demonstrated and normalized dynamism of an environmental system.

Naturalness, in other words, will refer to the trends of a system through time. For example, the annual peak snowmelt for an alpine area occurs within a relatively small window of time every year. This occurrence is “natural” because it has happened every year within a time period on the order of weeks since the last ice age. Selecting a time frame for a natural occurrence helps narrow management directions, but it can also limit the utility of managing for naturalness. A certain level of subjectivity is inherent and unavoidable in the establishment of a concrete conception of naturalness because some ecological components have seen drastic change through the planet’s history while others have changed very little. So, as the USFS designs plans to manage resource with the goal of maintaining or reestablishing naturalness, they will be deciphering the best ways to retain ecosystem functions and services rather than retaining a single fixed characterization of a given ecosystem.

It is necessary to clarify the use of the phrase “ecosystem functions and services.” Interactions between ecological variables define an ecosystem, and the structure of an ecosystem can be conceived of as the normalization of ecological variables through time. Individual interactions constantly change, but collective interactions can be characterized and categorized in order to decipher patterns. It becomes clear that certain interactions are more “valuable” to the functions and services of an ecosystem. For example, keystone
species—species that have a disproportionate impact on their community relative to their abundance—are vital to ecosystem function. Additionally, dominant species—species that are very common in an ecosystem such as a conifer tree in boreal forests—play an important role in maintaining the integrity of an ecosystem. If a keystone or dominant species fails to perform its ecological function, perhaps as a result of drastic population declines, the entire ecosystem structure is at risk of collapse. These “valuable” species are also important in providing services to other species, including humans, who rely on a given ecosystem structure for basic survival needs.

The health of an ecosystem, therefore, can be measured by the ability of an ecosystem to carry out functions and provide services through retention of primary structural components. The function on an ecosystem—important dependently and independently of human needs—affects ecological services, many of which are utilized by humans. I chose the phrase “ecosystem functions and services” to suggest that an issue such as climate change threatens many different aspects of the natural world simultaneously. Both intrinsic and socioeconomic values of ecological systems are threatened. Insofar as humans are concerned, climate change threatens our own survival through impacts on the rendering of necessary ecological services.

Finally, the term “equilibrium” requires clarification for use in this paper. Traditionally, resource managers have connected naturalness to attaining and/or maintaining equilibrium in an ecological system. When a system is disrupted by a perturbation—whether human related or not—the goal has been to manage the system in such a way as to return it to the pre-perturbation state. Many managers are now realizing, however, that a single steady state equilibrium in an ecosystem is not a commonly-
occurring phenomenon. Rather, ecological equilibria shift through time as a result of the dynamism inherent in ecosystems. It is difficult—and quite counter-productive—to quantify a single static state from which to define naturalness and base management decisions (Gunderson, 1999). We can establish changing trends in ecosystems and focus management efforts on retaining ecosystem functions and services rather than pursuing a single static state. In other words, resource managers must be flexible in their projects to keep pace with the dynamism in environmental systems.

1.6 A Responsibility, an Opportunity

Now that the goals and methodologies of this paper have been introduced, it is pertinent to understand the overarching motivation behind this paper’s construction and constitution. The impetus for the paper comes from what I see as the confluence of a responsibility to act and an opportunity to gain for the US Forest Service. The agency has a responsibility to act on climate change with immediacy but also with a long-term commitment because of the unprecedented challenges posed to the mission of the organization and the uncertain future associated with a warmer planet. The USFS also has a unique opportunity to further scientific understanding, further codify its position as a leader in natural resource management, and protect vital ecosystems in the process. The US Forest Service must act on both its responsibility and its opportunity to effectively confront climate change. This paper is designed to ensure steps are taken to do just that.

The US Forest Service has signaled an interest in approaching climate change from several distinct perspectives. Namely, to make agency operations more sustainable and cut greenhouse gas emissions throughout agency operations, to explore technologies
and research that would mitigate the emissions of greenhouse gases, and to ensure management actions are designed to ensure ecosystems adapt to climate change (USDA, Forest Service, 2009a). While sustainable operations and mitigation are each vital inputs to the larger climate change equation, I will be focusing only on the adaptation side in this paper to focus on ecosystem management.
Chapter 2:

An Imperative to Act
2.1 Introduction

Current climate change threatens the health and integrity of ecosystems throughout the National Forest System (NFS). The issue of climate change is multi-faceted, dynamic, borderless, and certain to muddle our common conception of “naturalness.” In order to understand the role the US Forest Service (USFS) must play in managing ecosystems under various climate change scenarios, it is necessary to determine what the main threats posed by climate change are and how USFS resource managers must conceive of the issue.

Change to ecosystem functions and character is certain and undeniable. Therefore, the way managers must confront disturbed ecosystems must change also. However, determining exactly where ecosystems will change, by how much, and in what ways remains exceptionally difficult given our finite, limited base of knowledge about the natural world. Despite the difficulty of quantifying future changes, general trends are now discernable and patterns of disruption attributable to human-induced global warming are becoming more obvious. In this chapter, I show how current changes to the atmosphere are affecting NFS ecosystems. I then explore the probable future effects of climate change on NFS ecosystems and describe how, when taken together, the effects of climate change create a serious challenge for USFS resource managers.

Climate change creates new stressors and exacerbates existing stressors to ecosystem functions and services. An ecosystem stressor can be defined as an alteration to an existing natural disturbance (i.e. exacerbating the disturbance intensity, scale, or frequency) or a stressor can be a new disturbance that threatens the ability of the natural
system to absorb the shock or adapt to it (USDA Forest Service, 2007a; US Environmental Protection Agency, 2000).

For example, fire is a natural disturbance, encouraging new undergrowth and allowing trees with thicker bark or seed cones that open only in response to heat from fire to maintain ecological fitness. However, changes to fire ignition conditions and increased fuel-loading (both natural and human-induced) create circumstances for disturbances occurring outside the normal season or in geographical areas previously lacking regular fire disturbance regimes (Joyce et al. 2008). Altered disturbance regimes “become stressors to ecosystems, and affect ecosystem services and natural resources within NFS ecosystems” (Joyce et al. 2008, pp. 11).

2.1.1 What are the Main Threats to National Forest Ecosystem Functions and Services Posed by Climate Change?

Human-induced climate change exacerbates existing stressors and also creates a large number of possible new future stressors to ecosystem health. After reviewing available literature on climate change and NFS ecosystems, I have established the most apparent and potentially consequential threats to ecosystem health. These threats will occur in the form of: (1) water quantity and quality changes, generally decreasing on both fronts; (2) biodiversity and ecosystem composition changes with a high probability of biodiversity loss as result of a loss of suitable habitat, fragmentation, and species range-shifts; (3) the intensified proliferation of non-native exotic species and their subversion of native species; (4) the spread and intensification of diseases and insect infestation within the NFS; (5) more frequent and severe extreme weather events; and (6) increases in the intensity, frequency, and scale of fire on national forests. As will be evidenced, these
primary effects are extremely interconnected and share feedbacks. Therefore, it is not possible to discuss the effects in an isolated, independent framework. Rather, a discussion of one necessarily requires the discussion of the others.

The interrelated nature of the effects of climate change and the causal relationships existing between the various effects aggregate to create a complex and wide-scale issue that will disrupt the integrity of many ecosystems. Positive feedback loops will intensify many effects and add to the complexity of the changes. The unknown interactions and responses to climate change necessitate adaptive management techniques to maintain essential ecosystem functions, both for the sake of ecological survivorship and for a continued human reliance on ecosystem services.

It is necessary to dissect the most pressing threats posed by climate change before addressing the role of USFS management structures and policy. Section 2.2 discusses the threat to water resources in both an ecological and anthropocentric perspective. Section 2.3 explores alterations to ecosystem composition and diversity, including a discussion of the role of mathematical modeling in biodiversity conservation and resource management. Section 2.4 covers the interactions between native and non-native species. Section investigates the changes to interactions between climate and disease and insect infestation patterns throughout the NFS. The mountain pine beetle will provide a case study of such changing interactions. Section 2.6 briefly touches on the role of extreme weather events affecting NFS ecosystems. Section 2.7 explores the prevalence and intensity of wildland fire within the NFS. This chapter finishes with Section 2.8, which highlights the imperative for the USFS to confront the challenges posed by climate change.
2.2 Water

Diminished water quantity and quality is likely throughout the western US in the coming decades.\(^2\) Quantity issues will take the form of increased frequency of prolonged and more severe drought with many areas facing water shortages and increased demand (Arnell, 1999), decreased snow-pack levels and changes in the amount of precipitation that falls as snow versus rain (Mote et al. 2005), earlier spring snow melt resulting in earlier peak discharges in streams and rivers (Barnett et al. 2005; Stewart et al. 2004), and an increase in the frequency of extreme storm cycles (Groisman et al. 2005; Karl and Knight, 1998) resulting in new and exacerbated disturbances to ecosystems throughout the US (Bates et al. 2008; Dettinger et al. 2004). NFS ecosystems, especially in the arid regions of the US, will face negative impacts of water shortages as a result of climate change (Seager et al. 2007; Hayhoe et al. 2004). The chart below (Figure 2-A) depicts trends in water resources over the past century in North America and provides clues as to what water resource trends under “business as usual” conditions for future greenhouse gas GHG emissions and correlated warming will look like over the coming century.

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Figure 2-A) From Bates et al. 2008: Observed changes in North American water resources during the past century (↑ = increase, ↓ = decrease). [ ] indicate IPCC studies supporting these findings. See IPCC (2007a) for the Fourth Assessment Report (AR4) by Working Group I (WGI) and IPCC (2007b) for the AR4 report by Working Group II (WGII).

<table>
<thead>
<tr>
<th>Water resource change</th>
<th>Examples from AR4</th>
</tr>
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<tbody>
<tr>
<td>1–4 week earlier peak streamflow due to earlier warming-driven snowmelt</td>
<td>US West and US New England regions, Canada [WGI 1.3, 14.2]</td>
</tr>
<tr>
<td>↓ Proportion of precipitation falling as snow</td>
<td>Western Canada and prairies, US West [WGI 14.2, WGI 4.2]</td>
</tr>
<tr>
<td>↓ Duration and extent of snow cover</td>
<td>Most of North America [WGI 4.2]</td>
</tr>
<tr>
<td>↑ Annual precipitation</td>
<td>Most of North America [WGI 3.3]</td>
</tr>
<tr>
<td>↓ Mountain snow water equivalent</td>
<td>Western North America [WGI 4.2]</td>
</tr>
<tr>
<td>↓ Annual precipitation</td>
<td>Central Rockies, south-western USA, Canadian prairies and eastern Arctic [WGI 14.2]</td>
</tr>
<tr>
<td>↑ Frequency of heavy precipitation events</td>
<td>Most of USA [WGI 14.2]</td>
</tr>
<tr>
<td>↓ Runoff and streamflow</td>
<td>Colorado and Columbia River Basins [WGI 14.2]</td>
</tr>
<tr>
<td>Widespread thawing of permafrost</td>
<td>Most of northern Canada and Alaska [WGI 14.4, 15.7]</td>
</tr>
<tr>
<td>↑ Water temperature of lakes (0.1–1.5°C)</td>
<td>Most of North America [WGI 1.3]</td>
</tr>
<tr>
<td>↑ Streamflow</td>
<td>Most of the eastern USA [WGI 14.2]</td>
</tr>
<tr>
<td>Glacial shrinkage</td>
<td>US western mountains, Alaska and Canada [WGI 4.ES, 4.5]</td>
</tr>
<tr>
<td>↓ Ice cover</td>
<td>Great Lakes, Gulf of St. Lawrence [WGI 4.4, 14.2]</td>
</tr>
<tr>
<td>Salinisation of coastal surfacewaters</td>
<td>Florida, Louisiana [WGI 6.4]</td>
</tr>
<tr>
<td>↑ Periods of drought</td>
<td>Western USA, southern Canada [WGI 14.2]</td>
</tr>
</tbody>
</table>
Forecasting future changes in hydrological variables and the interactions that occur between the variables is difficult (Bates et al. 2008). There is “abundant evidence from observational records and climate projections” that water resources are likely to be “strongly impacted” by climate change (Bates et al. 2008, pp. 135). Quantifying many future changes and their impacts on ecosystems, however, is not possible under current limits in the availability of observational data and the complexity of the interactions between hydrologic variables, which creates significant uncertainty about future changes (ibid.). This uncertainty, while inherent in any future modeling scenario, is especially problematic for understanding future hydrological changes in the context of climate change because of influences from a number of unquantifiable variables. These variables, according to Bates et al. (2008), include the “range of socio-economic development scenarios, the range of climate model projections for a given scenario, the downscaling of climate effects to local/regional scales, impacts assessments, and feedbacks from adaptation and mitigation activities” (Bates et al. 2008, pp. 47-48). Despite the limitations of uncertainty, it is possible to see how general trends in future changes to hydrological variables will affect NFS ecosystem health.

2.2.1 Effects on Freshwater Ecosystems

There are innumerable potential effects of climate change on freshwater ecosystems. I will present a few of the most likely ones to affect the health of freshwater
Chapter 2

An Imperative to Act

NFS ecosystems. The effects will be highly localized. First, temperature, transparency, and the acidity of the water affect its chemistry, exacerbating eutrophication in some areas and altering the species composition in many ecosystems. Second, changes to precipitation patterns and characteristics, as well as a decrease in total snow-cover, alter phenological patterns, especially at higher latitudes and elevations. Finally, the relationship between NFS ecosystems and the hydrological services they provide humans is likely to be disrupted by climate change and it is necessary to explore how.

**Chemical and Biological Changes**

IPCC Fourth Assessment Report models estimate mean global air temperature increases of between 0.5 and 2°C by 2030 (IPCC, 2007a), which will warm freshwater resources such as lakes, ponds, streams, and rivers. Both surface and deep-water temperatures have already increased as a result of climate warming in freshwater systems (by between 0.2 and 2.0°C for surface water in North American lakes since 1960) and is expected to increase in coming decades (Bates et al. 2008). Warmer water temperatures decrease the amount of oxygen available to organisms in the water during warm months (an exacerbated stressor), which can threaten the survival of coldwater-adapted species (Schindler, 2001; Schindler et al. 1990). Warmer air temperatures are likely to enhance thermal stratification—the layering of warmer, less dense water (known as the epilimnion) over colder, denser water (the hypolimnion)—in systems such as lakes. Increasing the size of the epilimnion and thus decreasing the size of the hypolimnion will alter the chemistry of the water. Stratification changes oxygen and other dissolved

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3 See Abell (2000) for a description of the ecoregions of the US and how each is characterized by their freshwater resources. Understanding regional and local environmental differences is vital to understanding what and where changes are most likely to occur.
mineral distribution and cycling throughout the water system (Boehrer and Schultze, 2008). Changed thermal gradients affect the ways in which dissolved nutrients physically move through the water column, which makes nutrients more available to some species and less available to others depending on what water characteristics they are adapted to, i.e. cold, bottom dwelling vs. warm, surface dwelling organisms (Bates et al. 2008).

However, some (Keller et al. 2006; Schindler et al. 1996) have shown that temperature alone does not fully characterize stratification, and rather the transparency of the water more accurately affects the size of the epilimnion. Transparency is affected by climate change as well. The dissolved organic carbon (DOC) created by decayed biomass entering the water system can change the pH level of the water and alter the transparency—more DOC makes the water less transparent (Keller et al. 2006). Climate change is likely to alter DOC levels because of changes in biomass decay levels and a decrease in acid deposition as a function of warmer temperatures and changes in precipitation patterns. This can change the color of the water, affecting primary production and the water quality (Evans et al. 2005). Overall, the water will become more eutrophic and less suitable for many species in the food chain.

Eutrophication is an issue that has been affecting both estuarine and freshwater systems independent of climate change but related to human actions, namely as a result of agricultural practices and land-use change (Carpenter et al. 1998). It can be described as an excess amount of nutrients, most often nitrogen and phosphorus—which are usually the limiting nutrients in an ecosystem—being dissolved in the water system, which promotes growth of algae and other species that comprise the primary production (the nutrients usually enter the system as run-off from human landscapes or from erosion of
the adjacent area). The survival of organisms further up the food chain is threatened as a result (UNESCO, 2008). Warmer water temperatures can support algal growth later in the year and less will die-off in winter, further exacerbating eutrophication and altering the species composition in many systems (Flanagan et al. 2003).

**Changes to Ice/Snow Cover and Phenology**

Changes to the timing of seasons are perhaps the most noticeable and disruptive effect of climate change on water systems at high altitudes or latitudes. Some NFS alpine ecosystems are experiencing glacial retreats and a net decrease in snowpack. The global cryosphere—the sum of all freshwater stored as snow, ice, and permafrost, or frozen ground—is shrinking. The total snow and ice cover on NFS land, mirrors the global trend and is also shrinking. Peak run-off is occurring earlier, leaving less water to run in late summer and early fall. Lower water levels result in warmer water temperatures, threatening habitat for keystone species such as the bull trout (*Salvelinus confluentus*) in

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4 An interesting paradox presented by climate change effects on small aquatic ecosystems, especially ponds in the northern US, is the decreased frequency and severity of “winterkill” that has been modeled under future warming scenarios. Winterkill occurs when cold air temperatures cause an increase in ice build-up on the surface of ponds. Often the ice gets thick enough that the dissolved oxygen needed for aquatic life (especially fish) to survive is compromised by human-induced eutrophication of the system. Managers have been forced to aerate many ponds in the northern US to prevent extirpation of species living in the ponds. See Fang and Stefan (2000) for an example. A warmer climate will likely decrease the stress on these aquatic organisms in the short term, however this remains only one effect of climate change on these ecosystems and, as described above, there are other effects that will threaten their survival. This example shows how uneven the effects of climate change can be and how complex the relationship between effects is.

5 While the total cryosphere is shrinking, the effects are extremely localized and uneven. Some areas will see more snowfall but a decrease in ice thickness and extent while some areas will see the opposite. Higher latitudes are experiencing the greatest warming and the greatest decrease in the mass and extent of the cryosphere, but as Barry (2005) finds, there is a decrease in total snow and ice cover at lower latitudes as well. As far as NFS ecosystems are concerned, some will see increases in snow and ice cover, but overall, there will be a decrease. See Bates et al. 2008; IPCC, 2007a; Rosenzweig et al. 2007; Barry, 2005; and Brown, 2000.

6 As far as NFS ecosystems are concerned, some will see increases in snow and ice cover, but overall, there will be a decrease. See Bates et al. 2008; IPCC, 2007a; Rosenzweig et al. 2007; Barry, 2005 and; Brown, 2000.
areas such as the Columbia River Basin (Reiman et al. 2007). A warming climate will affect the length of seasons and shift many phenological events such as peak water run-off and the first autumn frost. Changes in phenology—the timing of reoccurring ecological events such as annual bird migrations, the date when plants or flowers bloom in the spring, etc.—will alter interactions between species. Seasonality changes have uneven effects on both individual species and ecosystems more broadly. Warmer temperatures have brought an earlier spring arrival to many NFS ecosystems, and the growing season is likely to continue to increase in most areas (Walther et al. 2002). Phenological changes as they relate to biodiversity and species composition in general will be discussed further in Section 2.3.

Phenology and seasonality as they relate to freshwater ecosystems are important to understand because with warmer temperatures rivers, lakes, and other freshwater systems are free of snow and ice for a longer period each year. This affects the amount of sunlight coming into the water systems increasing the primary production in the system (Bates et al. 2008). Changing the primary production will change the species composition for the system. Also, although research thus far is incipient, there is potential for changes in erosion rates and sediment deposition levels into many freshwater ecosystems as a result of changing precipitation patterns and more frequent extreme weather events (ibid.). While the outcome of changing erosion rates is not certain, there is potential for greater nutrient inputs to freshwater systems resulting in acidification and eutrophication of the system.

According to Bates et al. (2008), the cryosphere accounts for about 75% of the world’s total freshwater, and the volume of total freshwater stored in the cryosphere is
decreasing. Global mean warming is responsible for an overall decreasing trend in snowfall, however, the localized effects of warming are mixed and some areas may see an increase in annual snowfall. Warmer temperatures at higher latitudes and elevations may result in increased snowfall because the air condenses sooner and precipitation falls with warmer regimes, however, at lower latitudes and elevations, precipitation that has fallen as snow in the past may fall as rain in the future because there are fewer days below freezing (Bates et al. 2008). Changes in precipitation patterns will affect freshwater systems differently depending on local topography, geography, and other local, regional and global factors such as El Niño–Southern Oscillation (ENSO) patterns and severity.

**Alpine Hazards and Altered Landscapes**

Finally, as shown in IPCC (2007a) there is ample paleoecological and glaciological evidence that shows a creation or large expansion of lakes at the terminus of the glacier (the lowest elevational point of the glacier where melt-water escapes) as a result of retreating glaciers. As the glacier retreats uphill, it leaves behind a terminal moraine, or wall of debris—usually rock and dirt or large blocks of ice—that act as a dam holding in melt-water. This is a natural process resulting from glacial movement up and down the slope, but the increasing rate of ablation (glacial melt) observed in many glaciers recently is transforming alpine ecosystems and creating heightened human and ecological hazards (IPCC, 2007a; Kaeaeb, 2007).

Not only do the terminal lakes pose a threat of flooding because of the weak nature of the earthen dam, the lakes are also home to new ecosystems that have not, in
geologic timescales, recently existed. Terminal lake outburst floods have naturally occurred in alpine areas and are often responsible for the highest annual peak discharge of the river or stream below the glacier, characterizing the downstream channel morphology and affecting water quality (Neal, 2007). Outbursts not only pose a risk to human life, infrastructure, and services but some (Kaeaeb et al. 2005; Horstmann, 2004) expect downstream ecosystems to be altered by the outbursts. Exactly how they will change is still not known.

2.2.2 National Forest Ecosystems, Water, and People

According to the USFS charter, one of the founding principles of the National Forest System is to secure “favorable conditions of water flows” (Organic Administration Act, 1897). An estimated sixty-six million people in the US rely on National Forests for their water source (USDA Forest Service, 2008a). According to the USFS, “healthy forests capture and store water, naturally regulate streamflows and water quality, reduce flood and storm damage, control erosion, and replenish ground water,” all of which are benefits to humans who rely on the most socially important ecosystem service, clean water (USDA Forest Service, 2008a, pp. 1). There is an imperative to maintain healthy ecosystems for the sake of the ecosystem as well as for human use, which the USFS makes clear in their Sustaining Healthy Watersheds Initiative (USDA Forest Service, 2008a).

The table below (Figure 2-B) depicts changes to freshwater NFS ecosystems and likely effects both for the ecosystem and for human services. A general trend in increased drought severity and duration not only affects an ecosystem’s ability to perform its
ecological functions, but it also impairs the resilience of the ecosystem to other shocks and disturbances, whether directly human-induced or not. Decreased water quantity, quality, and changes in timing will force social change—communities in drought-prone areas will be forced to transport water over greater distances—and without effective and creative management policies to protect NFS freshwater ecosystems, human services will be compromised. As water resources on national forests become more scarce, competition between ecosystems and people will become more problematic and decisions will have to be made whether to make ecological survivorship the priority over maintaining human-use of the resource or vice versa.

Figure 2-B) From USDA Forest Service, 2008: Three examples of current and projected climatic changes, their effects on ecosystems, and potential consequences to the supply and delivery of watershed services. Climatic changes are based on current trends and projections from the Intergovernmental Panel on Climate Change Fourth Assessment Report (2007). For all changes, uncertainty is substantial and the geographic variability is expected to be high. ↑ = probable increase, ↓ = probable decrease, p = change.

<table>
<thead>
<tr>
<th>Climatic Changes</th>
<th>Location</th>
<th>Ecosystem Effects</th>
<th>Consequences for Watershed Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>warmer air temperatures</td>
<td>Widespread greatest change in mountains and northern latitudes</td>
<td>↓ Precipitation as snow, faster and earlier snowmelt ↑ Evapotranspiration and primary productivity ↑ Winter temperatures ↑ Sea level coastal erosion and saltwater intrusion into freshwater supplies</td>
<td>↑ Amount, type, quality, and distribution of organic habitat and biota ↑ Water availability and recreational and cultural experiences ↑ Water quality and timing ↓ Function and operation of existing water infrastructure in coastal areas</td>
</tr>
<tr>
<td>changes in precipitation patterns (projected changes vary by location and have substantial uncertainty)</td>
<td>Less winter precipitation at lower latitudes (Southwest, Intermountain West)</td>
<td>↑ Snow, changes in streamflow timing ↑ Risk of disturbance, e.g., drought, wildfires, insects, disease ↓ Vegetation growth, changes in composition</td>
<td>↑ Water supplies for people, agriculture, energy, and other uses ↑ Water demand, ground water withdrawals, and consumptive use of surface waters ↑ Fisheries and water-based tourism</td>
</tr>
<tr>
<td>more precipitation at higher latitudes (Pacific Northwest, New England)</td>
<td>More precipitation at higher latitudes (Pacific Northwest, New England)</td>
<td>↑ Streamflow ↑ Vegetation growth and composition ↑ Soil erosion and landslides</td>
<td>↑ Freshwater supplies ↑ Improvements in warm water fisheries</td>
</tr>
<tr>
<td>greater variability in precipitation from year to year</td>
<td>Everywhere</td>
<td>↑ Variability in stream, lake, and riparian habitats ↑ Risk of aquatic and riparian species extirpation ↑ Soil erosion, stream and lake sedimentation, and landslides</td>
<td>↑ Uncertainty in water supply ↑ Uncertainty for reservoir operations ↑ Risk to aquatic habitat and water supply infrastructure</td>
</tr>
<tr>
<td>more extreme floods and droughts</td>
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<td></td>
</tr>
</tbody>
</table>

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2.2.3 Concluding Thoughts on Water and National Forest Ecosystems

Freshwater ecosystems on national forests are likely to experience drastic changes as a result of climate change (Bates et al. 2008). Freshwater ecosystems face stressors that will alter their composition and threaten the maintenance of basic functions and services. Interactions between members of the community will be disrupted and species will be forced to either adapt or face extirpation.

For policymakers and resource managers, it is necessary to balance both human and ecological needs—both of which are intrinsically linked—in order to manage water systems effectively. Confronting this challenge, which raises tough moral and political questions, will be essential if managers intend to successfully address the severity of threats to NFS freshwater systems.

2.3 Changes to Ecosystem Composition and Diversity

Climate change threatens the integrity of intricate community structures within NFS ecosystems. The effects of climate change have implications for the maintenance of vital interactions between organisms and their surrounding environment. Current climate change has been found by some\textsuperscript{7} to be responsible for numerous shifts in the distribution and abundance of species throughout the planet, and it has been clearly linked to several species-level extinctions (Pounds et al. 1999). Thomas et al. (2004) have found that climate change has the potential to cause extensive species-level extinctions over the 21\textsuperscript{st} century and beyond. For the roughly 20\% of total terrestrial surfaces sampled, models

\textsuperscript{7} Root et al. (2003) and Parmesan and Yohe (2003) have found drastic changes to the abundance and distribution of species as a result of altered habitat and phenology. These ecosystem structural changes can be traced back to a distinct “fingerprint” left by global warming and its local, regional, and global effects.
“predict, on the basis of mid-range climate-warming scenarios for 2050, that 15–37% of species in [the] sample of regions and taxa will be ‘committed to extinction’” (Thomas et al. 2004, pp. 145). Levels of extinction could be much higher as many factors such as the continued importance of land-use change are difficult to quantify and model independently from the effects of climate change (ibid.). Additionally, without sudden and significant cuts in GHG emissions, the period between 2050-2100 is likely to yield much higher rates of extinction (ibid.). Such potential for biodiversity loss poses a major threat to the holistic integrity of ecosystems. Ecosystem composition is certain to change, deciphering exactly how must be a top priority for NFS resource managers.

2.3.1 Where Will the Changes Occur?

Changes to ecosystem structure—the distribution of species and the hierarchy of species’ niche, interaction, and abundance within the system—are certain to negatively affect the health of ecosystems at both the local scale and at the global scale. NFS ecosystems will experience many of the global trends. In simple terms, “species that are rare, threatened, endangered, narrowly distributed, and endemic, as well as those with limited dispersal ability, will be at particular risk under climate change” (Joyce et al. 2008, pp. 26). Dispersal is a function of both abiotic factors—such as changes in the climate—and biotic factors—such as mutualisms or competition with other species. These factors will affect where a species can survive. One particularly important measure of abiotic factors is the species “climate envelope” (Woodward and Lomas, 2004).

9 For examples of species especially at risk from climate changes and verified extinction causally related to climate changes, see Pounds et al. (2006).
Species facing a loss of suitable habitat or other altered physical living conditions as a result of climate change either adapt to the new and altered environment or face extirpation. Adaptation, as historical climate changes have shown, tends to result in individualized species responses. Species respond by migrating to a new geographical area that contains their customary suitable habitat and climate envelope, or they make slow genetic changes to adapt to changes in their environment and remain in their current geographical ranges. Paleo-historical records show that if species failed to migrate to new geographic ranges or adapt *in situ* then they faced extirpation or extinction (Midgley and Thuiller, 2005).

**Genetic Adaptation vs. Migration**

Current climatic changes are proving to alter environments at much faster rates than in previous periods of climate change, and the likelihood of genetic adaptation as a mechanism of species diversity richness could be much harder for species in coming decades (Malcolm et al. 2002; Walther et al. 2002). The accumulating data now show that the rapidity of current climatic change may pose too difficult a stressor or collection of endogenous and exogenous shocks for species to adapt or emigrate from.\(^\text{10}\) There are quantified data that suggest with “very high confidence” that rapidly changing climates are causing species’ range shifts with a migration to higher latitudes and to higher elevations (Parmesan and Yohe, 2003, pp. 37; Parmesan, 1996).

Evidence from past post-glacial warming periods suggests that attempts by species to migrate uphill and to higher latitudes greatly alters ecosystem structures and

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\(^{10}\) See Nielson et al. 2005; Wilmking et al. 2004; Hansen et al. 2001 for examples of species failing to adapt or migrate based on the rate of change.
composition (Malcolm et al. 2002). Also, paleo-historical evidence suggests some tree species migrated at average rates of ~100 meters per year for upwards of thousands of years during periods of warming (King and Herstrom, 1997; Delcourt and Delcourt, 1987); however land-use changes since the last glacial maximum and extensive human infrastructure networks pose new barriers to natural migration.

Changes to the structure of ecosystems are likely to be amplified by climate change; both from disturbances induced by climate change and exogenous shocks to the system, such as the introduction of non-native species or from fire regimes not previously a natural system stressor. It is clear that “ecosystem disturbances, caused either by humans or by natural events, accelerate both loss of native species and invasion of exotics” (IPCC, 2007b, pp. 629). The role of non-native species in changing ecosystem structure will be discussed in Section 2.3.

**Decolonization and Recolonization**

Additionally, species composition and richness are likely to change whereby some species will disappear and others will colonize those geographic areas. Spruce-fir forests in the New England could extirpate, and maple-beech-birch forests be greatly reduced in area, and yet at the same time, oak-hickory and oak-pine forests are likely to increase in area (Bachelot et al. 2001; Iverson and Prasad, 2001). Many coniferous forests and other water-limited ecosystems at high altitudes and latitudes are highly vulnerable to climatic changes, and their composition is likely to be altered (Malcolm et al. 2006; Thomas et al. 2004). The western US, in areas such as the Great Basin, Colorado River Basin, Columbia River Basin and Alaska, have seen average temperature increases over
the past decade rise higher than the global average increase of −0.74°C during the period of 1905-2006 (see Figure 2-C below), which has resulted in wide-scale forest die-back. Evidence of tree mortality has received popular attention and is linked to periods of prolonged drought and the proliferation of native and non-native pests such as bark beetles—both attributable to climate change (van Mantgem et al. 2009; Millar et al. 2007).

11 In the period of 2003-2007, the continental western US saw an average temperature increase 70% higher than the 20th century global average found by the IPCC. See IPCC (2007a) for discussion of global average increases and Saunders et al. (2008) for report on the warming trends in the western US.

12 See New York Times article on forest die-back and drought. Recent data suggest that die-back is more extensive than previously thought (Navarra, 2009).
Dynamic Trophic Richness: The Role of Primary Production

At high latitudes, several models simulate net primary production (NPP) increases as a result of expansion of forests into tundra bioregions and longer growing seasons (Berthelot et al. 2002). In the mid-latitudes, simulated changes in NPP are variable, depending on whether there is sufficient enhancement of precipitation to offset increased evapotranspiration in a warmer climate (ibid.). Changes in net primary production affect all other trophic levels and are translated through the food-chain, affecting all species in an ecosystem (Stenseth et al. 2002; Harrington et al. 1999).

Increases in NPP (from increased levels of CO$_2$) is leveling out and will actually decrease over the remainder of the 21st century. “The mean maximum sink capacity over the 20th century is small, at 25 gC m$^{-2}$ year$^{-1}$, or approximately 1% of gross primary production… [and] simulations of vegetation dynamics under a scenario of future global warming indicate a gradual decline in the terrestrial carbon sink, with the capacity to absorb human emissions of CO$_2$ being reduced from 20% in 2000 to approximately 2% between 2075 and 2100” (Woodward and Lomas, 2004, pp. 643). As an example, “growth of white spruce in Québec, Canada will be enhanced by a 1°C temperature increase but depressed with a 4°C increase” (IPCC, 2007b, pp. 630; Andalo et al. 2005).

Dynamic Trophic Richness: Physiological vs. Communal Effects

The climate characterizes floral, and thus faunal, physiology (Stenseth et al. 2002). Changes in temperature, atmospheric composition of CO$_2$ and other gases, and

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$^{13}$ See also: Woodward and Lomas, 2004; Berthelot et al., 2002; Bachelet et al., 2001.
changes in radiation are all drivers of plant growth and ecosystem richness. Therefore, changes in the climate directly affect the physical characteristics—metabolic and reproductive processes—of flora as well as fauna (ibid.). At the same time, climate changes indirectly affect organisms through predator-prey interactions, competition, and mutualisms (ibid.).

As the climate warms and weather patterns change, according to Stenseth et al. (2002), there are several principal effects to consider: (1) the relative timing of food requirement and food availability may not match as they have in the past; (2) reproduction and early development of young are threatened by phenological changes; and (3) climate variability differentially influences sexes and age-classes. This means that with some species one particular sex or a particular age class is more adaptable to changes in the climate than another. Stenseth et al. (2002) argue that with all ecological change as a result of climate fluctuation, there will be both linear and non-linear effects on biological processes, which may or may not be immediately discernable to scientists studying the species-level and communal-level interactions.

**Dispersal and Fragmentation**

As with species colonization of new geographical areas, species dispersal is an important consideration of climate-driven ecosystem change. Some species’ ranges will be dramatically reduced as a result of suitable habitat loss and habitat fragmentation. Dispersal patterns—the spatial characterization of species density and extent—will aid species that are well-adaptable to the new environment and will harm others unable to
easily adapt (Joyce et al. 2008; Johst and Brandl, 1997). Collectively, biodiversity is affected by dispersal changes.

A possible scenario, which is especially relevant to NFS ecosystems in the mountains regions of the western US, as warmer temperatures allow for tree colonization of higher elevations, there will be less suitable habitat for alpine flora and many species could be “pushed” off the top of the mountains (Bachelet et al. 2001). The result of which could be a loss of the alpine ecosystem and the establishment of the boreal forest in areas further south or at lower elevations, i.e. some isolated areas in the Southern Rocky Mountains. Figure (2-D) below illustrates the transformative properties of predominant forest types.

**Figure 2-D: From Woodward and Lomas, 2004: The climatic envelopes of different vegetation types of the World. Arrows indicate four numbered scenarios of climatic change. The first arrow signifies a shift from tundra to boreal forest with 2°C warming.**
Additionally, fragmentation of these alpine ecosystems will cut off genetic flows between the new “islands” of habitat and decrease biodiversity through time. Fragmentation is an established human-induced stressor to many NFS ecosystems, however current climate change heightens the threat to species adaptability (Joyce et al. 2008).

2.3.2 Tracking the Changes

Discerning where, when, and how the changes to ecosystem structure will occur is difficult. Mathematical modeling remains the necessary first step in determining how to best approach the issue and decide where resources should be allocated, however models are not in themselves a viable solution to taking action to assist ecosystems.

Biodiversity Modeling is Necessary and Limiting

Models remain useful as a preliminary conservation tool designed to delineate trends in regional and global biodiversity responses to climate change; however, they are limited by their resolution and the extensive complexity of species-level interaction (Suttle et al. 2007; Thomas et al. 2004). As Suttle et al. highlight, “models are powerful initial tools with which to explore consequences of alternative climate scenarios, but they cannot forecast lagged impacts of altered higher-order interactions that will govern the trajectories of ecosystems under sustained climatic change” (Suttle et al. 2007, pp. 641-642). In other words, since “forecasts of range shifts and extinction probabilities are based largely on species-climate envelope models” and fail to appreciate local differences in taxa and underlying differences in species-level interactions based on local

14 According to Suttle et al. (2007), models tend to forecast species and climate envelope interactions well (Thuiller et al. 2005; Thomas et al. 2004; Peterson et al. 2002) but have not successfully moved beyond this level to more fully capture the consequences of climate change on species distribution and abundance.
environmental factors, models are not a panacea and should only be relied on for initial management prescription (ibid.).

As Joyce et al. find, “models typically rely on directional shifts following equilibrium dynamics of entire plant communities…whereas especially in heterogeneous and mountainous regions, patchy environments increase the likelihood of complex, individualistic responses” to ecosystem disturbances attributable to climate change (Joyce et al. 2008, pp. 42). There are ways to better focus forecasts of expected changes including harmonizing modeling with long-term field experimentation and scenario analyses.

Long-term experimentation in “natural field settings” provides a better understanding of species interaction and is necessary for a more realistic understanding of ecological responses to climate change (Suttle et al. 2007). The unknown number of potential variables that must be included in a model to get accurate response forecasts are not adequately captured in models because of our limited and finite knowledge of ecological interactions. 15 While some methods have been designed to help to narrow the scope of species responses models, uncertainty remains about the utility of models for management creation. 16 Araújo et al. designed “approaches that explore the central tendency (consensus) of model projections” and was then “able to improve agreement between projected and observed [species] shifts significantly” from past model constructions (Araújo et al 2005, pp. 529).

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15 For more on the limitations of mathematical modeling posed by the complexity of the natural world and our limited understanding of its complexity, see the detailed narrative by Pilkey and Pilkey-Jarvis (2007).
16 See Araújo et al. (2005), Bennett et al. (2003), and Peterson et al. (2003) for methods on narrowing the scope of response models.
Bennett et al. (2003) and Peterson et al. (2003) use scenario analysis to generate a wide range of potential future climate scenarios and harmonize these scenarios with species response models in order to generate a wider range—both geographically and physiologically—of possible responses to climatic variability.

Models are a vital tool for resource managers and provide directional trends in species and community-level responses to climate change. They are a necessary first step in delineating general trends and in time, they will certainly become more accurate as our understanding of ecological interactions improves and more data exist on such interactions. They will through time be able to forecast at more localized levels and provide more useful management prescriptions. At this time, however, it is necessary to avoid a complete reliance on models for the creation of important management decisions, and resource managers must harmonize modeling with other management techniques.

2.3.3 Concluding Thoughts on Changed Ecosystem Composition and Diversity

Biodiversity loss is very likely as a result of climate change (Thomas et al. 2004). Ecosystems will likely face structural changes as well (Stenseth et al. 2002). It will be necessary to accumulate more data pertaining to how these changes will occur in time and space to better assist ecosystems in natural adaptation processes such as migration and a smoother transition to habituating new environments. Forest Service managers must employ all available tools to anticipate these changes and prevent extinction. Coupled systematic modeling and field observations must be accompanied with experimentation to increase our base of knowledge pertaining to the ecological response to climate change.
2.4 Interactions Between Native and Non-Native Species

The third primary effect of climate change on NFS ecosystems is the exacerbation of non-native\textsuperscript{17} species infestation in various environments. Non-native species have pushed out many native species over the past several centuries and the USFS spends a considerable amount of resources on fighting invasive species and preserving areas of native habitat where non-native species have not yet colonized (USDA Forest Service, 2003). The social and ecological impact of invasive species has been estimated to “cost the American public... $138 billion each year” and can greatly diminish the quality of ecological services provided by NFS ecosystems (USDA Forest Service, 2003, pp. 2). Climate change intensifies the stresses on native ecosystems by invasive species (Joyce et al. 2008).\textsuperscript{18}

2.4.1 Increased CO\textsubscript{2} Concentrations and a Competitive Advantage

Many invasive species are ecological generalists—they can adapt to changed environments much more easily than native species and are not so narrowly dependent on specific interactions with other species. This provides a competitive advantage over ecological specialists in a time of drastic environmental change. Also, many invasive species are disturbance-adapted and thrive after extreme weather events, increased fire regimes, etc. Invasive species are more likely to throw ecosystems out of equilibrium and

\textsuperscript{17} Also known as “exotic” species, they can often become invasive in habitats they previously did not exist in. Non-native species that become invasive can disrupt ecosystem functions and services. The USFS has defined an invasive species “as a species that is 1) non-native to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health” (USDA Forest Service, 2003).

\textsuperscript{18} See also Chornesky et al. 2005; Carlton, 2001.
disrupt vital ecosystem services such as clean water and erosion control (USDA Forest Service, 2003).

More research is needed to better understand the population and community dynamics of invasive species in order to elucidate how changes in the climate will affect the interaction between native and non-native species. There are clear examples, however, of invasive species thriving with a warmer world. Not only do warmer temperatures help some invasive species expand their range and push-out native species disrupting ecosystem composition, but higher CO$_2$ concentrations in the atmosphere can also create a competitive advantage for some invasive species.$^{19}$

As Joyce et al. note on the research performed by Ziska (2003), the data indicate continued subversion of native habitat by invasive species. “The positive response to current (from pre-industrial) levels of atmospheric CO$_2$ by six invasive weeds—Canada thistle (Cirsium arvense (L.) Scop.), field bindweed (Convolvulus arvensis L.), leafy spurge (Euphorbia esula L.), perennial sowthistle (Sonchus L.), spotted knapweed (Centaurea stoebe L.), and yellow star-thistle (Centaurea solstitialis L.)—suggests that 20$^{th}$ century increases in atmospheric CO$_2$ may have been a factor in the expansion of these invasives” (Joyce et al. 2008, pp. 24). Additionally, “invasive species with a C4 photosynthetic pathway (e.g., itchgrass, Rottboellia cochinchinensis) are particularly likely to invade more northerly regions as frost hardiness zones shift northward” (Joyce et al. 2008, pp. 24; Dukes and Mooney, 1999).

$^{19}$ The literature on this particular advantage of invasive species adapting to climate change is extensive and growing, for an overview of how increased CO$_2$ concentrations benefit many invasive species growth more than many native species, see especially Weltzin et al. 2003; Ziska, 2003 and; Smith et al. 2000.
2.4.2 New Roles: Natives Become Invasive

As changing climatic patterns force species to migrate, many will invade new geographic regions and pose a threat to existing taxa, in essence becoming an invasive species. Some dispersing native species are likely to “become problematic invaders that place many threatened and endangered species at greater risk of local extinction due to enhanced competition, herbivory, predation, and parasitism” (Joyce et al. 2008, pp. 25; Neilson et al. 2005). As Joyce et al. write, “in the Pacific Northwest, barred owls (*Strix varia*), which are rapidly migrating generalists from eastern forests of the United States, have invaded the spotted owl’s range in the Pacific Northwest and are now competing with the northern spotted owl (*Strix occidentalis caurina*) for nest sites,” altering the structures of interaction among species and transforming native species into invasive, non-native species (Joyce et al. 2008, pp. 25). Species assemblages will become altered and it will be important to investigate exactly how the functions of the new assemblages will change.

2.5 Diseases and Insect Infestation Throughout the National Forest System

The impact of native and invasive insect proliferation and spreadable disease will be considerable and is likely to transform NFS ecosystem dynamics. Research on insect and disease in the NFS is extensive, and the connection to climate change is currently garnering extensive examination. Results thus far indicate a strong relationship between

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20 For more on the controversy, science, and politics concerning the barred and spotted owl, see Gutierrez et al. 2007; Noon and Blakesley, 2006; Kelly et al. 2003.
21 See Joyce et al. (2008) for a brief yet detailed review of the literature on insects and disease on National Forests.
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disease and insect outbreaks and a warmer climate.\footnote{For the relationship between pathogens and diseases affecting ecosystems and climate change, see Hance et al. 2007; Parmesan, 2006; Pounds et al. 2006 and; Harvell et al. 2002. For the connection between insects (indigenous to the US and not), see Logan et al. 2007; Carroll et al. 2004; Logan et al. 2003; Logan and Powell, 2001; Volney and Fleming, 2000 and; Ungerer et al. 1999.} The two main threats posed by insects and disease to NFS ecosystems in a warmer world are the spread northward and to higher elevations by bark beetles and pathogens previously contained only in more southern or lower elevation ecosystems. I will discuss the threat posed by the mountain pine beetle (Coleoptera scolytidae) to illustrate how a natural stressor present in many NFS ecosystems has, as a result of climate change, broken through biological constraints to its geographic range and is responsible for a sharp increase in tree mortality.

2.5.1 The Mountain Pine Beetle: An Unstoppable Force?

Logan and Powell (2001) have shown that warmer temperatures accelerate the life cycle of the pine beetle. Living longer—they are born earlier in the spring and die later in the autumn—they consumer more biomass and increase tree mortality rates. The pine beetle borrows into the bark of various species of pine trees in the western US. Most species in the Pinus family are susceptible to infestation, however, climatic conditions have historically limited the range of the beetle and therefore left certain species, such as ponderosa pine (Pinus ponderosae Lawson) and lodgepole pine (Pinus contorta Douglas), more susceptible to hosting than other species (Logan and Powell, 2001).

Expanding Range

However, as temperatures warm, the range of the pine beetle is expanding (Logan et al. 2003), and species not previously host to the beetle are now becoming susceptible
(Logan and Powell, 2005). According to Logan et al., data analyses “indicate that all aspects of insect outbreak behavior will intensify as the climate warms” and transform forests at the landscape level (Logan et al. 2003, pp. 130). The processes whereby climate change exacerbates an existing stressor (insect infestation) and creates new mechanisms for proliferation has already been linked to expansive tree mortality, and this trend is likely to increase over coming decades.²³

The beetle is a natural forest disturbance mechanism and periodic die-back of weaker individual trees through time has led to healthier forest systems. A process of evolution, the beetles provide a mechanism for encouraging healthy, strong trees to survive, and as a result the beetles decrease understory density and encourage beneficial fire regimes (fires that burn less hot and are more frequent) within forest ecosystems (Logan and Powell, 2005). Some species such as lodgepole pine have evolved a mutualism with the beetle. They rely on the beetle for creating habitat that is prone to periodic fire disturbances, which enables healthier lodgepole stands (Logan and Powell, 2001). While the beetle encourages specific fire ecology within the generally homogenous lodgepole forests under historical climatic trends, under current climatic trends, the rate of mortality in forest stands has greatly increased to the point where fire uncontrollably devastates forest ecosystems and their services (ibid.).

The Loss of Natural Biological Controls

An example of beetle-related tree mortality that breaks any historical variation can be seen in Colorado, which over the past twelve years, acreage infested with the

²³ The discussion of the mountain pine beetle has received national mainstream media coverage in recently (See Smith, 2009; New York Times Video, 2008), in large part because of the economic consequences and the threat to private property.
mountain pine beetle has risen to two million acres (400,000 more acres in 2008 than 2007). This greatly expanded range is attributable to an uphill movement of the beetle (Smith, 2009; Logan and Powell, 2005). The past decade has seen extreme drought conditions in much of Colorado, and when coupled with warmer winter temperatures and hotter summers, it becomes clear why the rate of tree mortality has increased so rapidly (Logan and Powell, 2005; Logan et al. 2003).

Additionally, the number of frost-days and successive days of extreme cold are decreasing, limiting natural predation and the effectiveness of biotic controls that control the life cycle of the beetle. This is resulting in increased tree mortality extent (Joyce et al. 2008; Hance et al. 2007). As Joyce et al. summarize, “hard freezes in winter have been shown to kill more than 99% of pathogen populations annually. The hard freezes necessary to slow the spread of insect and disease outbreaks may become less effective” (Joyce et al. 2008, pp. 32). Warmer winters and especially higher minimum temperatures have prevented seasonally consistent beetle die-back (see Figure 2-E below) as has occurred in the past (Harvell et al. 2002; Logan and Powell, 2001). Globally, the relative number of cold nights is decreasing and unseasonably warm nights are responsible for longer life cycles of the beetles (Logan and Powell, 2001).
Diseases and insect infestations will stress ecosystems and are certain to change the composition and threaten the abilities of ecosystems to perform ecological functions. The discussion of the mountain pine beetle in this section has shown the complexity of climate change. A native species vital to the long-term integrity of ecosystems, because
of a loss of natural ecological control mechanisms, is now characterized as an invasive species in many parts of the western US and threatens ecological stability.

The period of severe drought plaguing much of the West combined with warmer winters over the past decade has both weakened the trees—making them less likely to survive a beetle infestation—and put new species at risk of infestation where ranges between the species previously did not cross (Olsen, 2008; Logan and Powell, 2005). In the coming decades, bark beetle-induced tree mortality will continue to increase and compromise vital NFS ecosystem services such as clean water and erosion control. Additionally, fire scale and intensity is likely to increase as a result of the high rate of fuel-loading from beetle-kill.

2.6 Extreme Weather Events

The remaining two primary effects of climate change on NFS ecosystems (the role of extreme weather events and fire regimes in shaping landscapes) highlight the causal relationships and positive feedbacks that exist between the interactions of ecological variables.

2.6.1 Ecosystem Disturbances and Extreme Events

Extreme events such as periods of above-average high temperatures and heat waves, extreme cold periods, intense drought, intense and/or prolonged precipitation events, floods, high winds and cyclonic events, mass movement such as landslides, and wildfires are expected to increase in frequency and magnitude as a result of climate change (Easterling et al. 2000; Meehl et al. 2000). These events create disturbances in
ecosystems and are a natural part of any ecosystem, however, heightened frequency and severity have a much greater impact on ecosystem functions and services. Extreme weather such as drought and prolonged heavy rain affect soil chemistry and can either cause water stress in plants or lead to oxygen deficits because of an excess of water (Kreyling et al. 2008). In addition, the ability of plants to extract nutrients is affected by these extreme events, leading to changes in NPP composition (ibid.).

As Kreyling et al. (2008) found, the total productivity changes little when communities are exposed to extreme weather, however, more complex systems suffered greater composition disruptions than less complex systems. Additionally, some disturbance-adapted species are likely to benefit as a result of the extreme weather and some of these species have the potential to disrupt ecosystem functions (Dale et al. 2001).

Climate change-driven disturbance cycles are likely to exacerbate existing threats to NFS ecosystems such as invasive exotic species proliferation, issues with seasonal water distribution, and phenology patterns. Extreme weather events are another link in the complex chain of feedbacks and causal interactions between the ecological effects of climate change and understanding future trends in ecosystem functions is made more difficult by the unpredictability of more frequent and severe extreme weather events.

### 2.7 Fire and Climate Change

Fire is perhaps the greatest managerial focus and certainly the greatest fiscal focus of the USFS. Fire is a healthy and necessary disturbance in NFS ecosystems. However,

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24 The USFS devotes more of its budget to fighting wildland fires than any other activity. Roughly 50% of the USFS discretionary budget is devoted to the fire program (USDA Forest Service 2020).
climate change, in addition to agency fire suppression tactics of the past ~75 years, has transformed fire into a landscape-altering ecological variable, shifting away from its historic role into a force that disrupts equilibria within NFS ecosystems.\textsuperscript{25} The fire danger throughout the western US is expected to increase “through increasing fire season length, potential size of fires, and areas vulnerable to fire, as well as by altering vegetation, which in turn will influence fuel loadings and consequently fire behavior” (Joyce et al. 2008, pp. 22).

2.7.1 Hotter and Larger Fires: The Role of Climate and Other Variables Affecting Fire Extent and Severity

With projected temperature increases of between 2-5\(^\circ\)C by the middle of the century and up to a 15% decrease in precipitation throughout much of the western US, fire scale and intensity will certainly increase (Running, 2006). See Figure (2-F) and Figure (2-G) below for a visual representation of the climatic changes projected and their relationship to fire activity.

\textsuperscript{25}See especially Westerling et al. 2006. See also Westerling and Bryant, 2008; McKenzie et al. 2004 and; Rapp, 2003.
Figure 2-F) From Westerling et al. 2006: Average difference between early and late snowmelt years in average precipitation from October through May (A) and average temperature from March through August (B). Contours enclose regions in which a t test for the difference in mean between 11 early and 11 late years was significant (P < 0.05). See Fig. (1G) for a definition of early, mid-, and late snowmelt years.

Figure 2-G) From Westerling et al. 2006: (A) Annual frequency of large (>400 ha) western US forest wildfires (bars) and mean March through August temperature for the western United States (line) (26, 30). Spearman’s rank correlation between the two series is 0.76 (P < 0.001). Wilcoxon test for change in mean large-forest fire frequency after 1987 was significant (W = 42; P < 0.001). (B) First principle component of center timing of stream-flow in snowmelt dominated streams (line). Low (pink shading), middle (no shading), and high (light blue shading) tercile values indicate early, mid-, and late timing of spring snowmelt, respectively. (C) Annual time between first and last large-fire ignition, and last large-fire control.
The extent of area and total biomass burned as a result of a warmer, drier western US has been “projected to increase from 1.5-4 times historical levels for all western states (except California and Nevada) by the 2070-2100 period” with the highest increases projected in Utah and New Mexico (Joyce et al. 2008, pp. 23; McKenzie et al. 2004). For Alaska, warmer summer-time temperatures and longer growing seasons are likely to result in changes to both total biomass and to composition. These changes have been
forecasted under several future climate models to double or triple the area of forests burned (Bachelet et al. 2005). Additionally, areas further south are likely to face increased fire danger. As Westerling et al. found, “The greatest [fire danger] increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt” (Westerling et al. 2006, pp. 940).

Mountain Pine Beetle mortality is already increasing fuel-loading in many areas and is responsible for hotter and larger fires (Logan and Powell, 2001). More frequent intense fires that crown—or burn all the way up the tree—often lead to total forest mortality rather than limiting mortality to the lower-canopy and allowing for survival of larger old-growth trees. Bark beetle infestation weakens the trees and makes them more susceptible to crowning and therefore likely to die from fire (McHugh et al. 2003). As a result, many forests are facing a twofold fire and bark beetle infestation threat.

Fire is a necessary disturbance in NFS ecosystems, however fire activity over the past several decades and projections about future fire activity highlight the multitude of feedbacks and exacerbations of climate variables affecting the role of fire as a disturbance mechanism. Fire will undoubtedly continue to garner the focus of the USFS, both fiscally and managerially because of the potential for loss of life and property, especially in “urban corridors” where people live on the periphery of national forests. Future modeling will help resource managers better estimate the scale and location of future fires, however, fire remains a highly variable and uncontrollable ecological phenomenon, and forecasting how and where fire will affect ecosystems will be challenging.
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2.8 Where is the Imperative to Act?

The nature of the climate change issue requires policymakers and resource managers to conceive of management policies and actions differently. It is a global issue that is localized and unique in many areas, which requires a new set of tools to confront the issue effectively. Chapter Three will address this need for a new management paradigm in detail, but it is first useful to characterize the nature of climate change as the ultimate issue facing resource managers.

2.8.1 The Net Effect: How do Threats to National Forest Ecosystems Fit Together?

I have outlined the six principal threats NFS ecosystems face under various climate-warming projections. This list does not exhaust all possible effects of climate change; on the contrary, these are only the most fundamental management issues and those certain to change ecosystem functions and services. Many other changes will be caused by and furthered by the basic effects mentioned here. There are an unknown number of potential threats of which we will become more aware of as ecological variables are better understood and we accumulate a greater amount of observational data measuring species-level and community-level interactions. A vast uncertainty exists between what we understand about such interactions. The complexity of the natural world necessarily requires us to strive to increase our knowledge of its systems and interactions, and at the same time accept that there will always be a certain amount of error associated with forecasting how changes to ecosystems will come to fruition in the future.
Climate Change: A Pressing and Consequential Threat; A Long-Term Threat

The interconnected nature of the principal effects of climate change creates an ecological issue that is more disruptive to equilibria than perhaps any issue in human history. The scale, intensity, and rapidity of change, as well as the vast uncertainty associated with the future character of the environment, will create a uniquely important issue. The aggregated effects are boundless, and changes will be felt at the local, regional, and global level. NFS ecosystems will, in many cases, experience multiple effects of climate change, most of which will interact with each other. For instance, temperature increases and precipitation decreases interact and create positive feedbacks, resulting in a wide range of potential ecological responses and overall a heightened risk to ecosystem health.

2.8.2 A Responsibility to Act

The fact that this issue is attributable to human actions obligates a responsibility to effectively address it. The USFS is in a unique position to take actions to address climate change throughout a large percentage of America’s ecosystems. The organization is mandated to protect natural resources from the ill-effects of human interactions with, and use of, resources to ensure future generations have adequate access to ecological services such as clean water (USDA Forest Service, 2009a). There is also a strong scientific focus maintained within the agency. USFS research scientists have contributed immensely to the amount and quality of observational data collected over the past several decades providing a baseline from which to measure current and future changes in ecosystems. Additionally, the USFS manages many resources that remain in a mostly
“pristine state”—areas devoid of human influences—protected as designated wilderness areas. These areas provide a unique study site where a higher number of variables can be controlled. For example, it is easier to differentiate between the effects of climate change and land-use change, timber sales, motorized recreation etc. on NFS ecosystems. Wilderness areas are thus a proxy for climate change and can act as an early-warning system for ecological change occurring beyond the bounds of natural variation. The role of wilderness areas will be discussed in much greater detail in subsequent chapters.

There are political and moral imperatives for the USFS implementation of policies intended to ensure ecosystems maintain basic functions and services in the face of rapid climate change. The imperative for the USFS to act aggressively and with commitment on climate change is centered on a biocentric perspective—where creating and implementing policies to maintain ecosystem health for the sake of stewardship of the natural world and an ecological intrinsic value provide ample motivation for policymakers and resource managers to act. But the imperative is also centered on an anthropocentric perspective, where maintaining ecosystem health for the continued rendering of ecological services to humans is ample motivation to act. It is clear the USFS has an imperative to act on one of the most complex and pressing issue of our time. Dissecting exactly how the USFS must adjust its management structure to accommodate effective policy creation and adequate implementation will be the subject of subsequent chapters.
Chapter 3:

The Need for a New Management Framework
3.1 Introduction

The purpose of the previous chapter was to establish climate change as a critical and pervasive threat to NFS ecosystem functions and services. The consequences of this global issue will either directly or indirectly affect every community on the planet. Natural processes driving climatic changes have been altered in such a way that our commonly held conceptions of equilibria in the natural world are becoming hard to quantify and distinguish from growing disequilibria. The rate of change is unprecedented (IPCC, 2007a), and the bounds of natural variation are failing to contain the extent and rate of both observed and predicted effects of climate change. As a result, interactions between ecological systems are becoming more complex and harder to understand.

Thus, the US Forest Service (USFS) faces a management issue unrivaled in scale and significance from anything in the agency’s past. Thus, resource managers and policymakers must make confronting the challenges of climate change the top management priority. The complexity of climate change will test the organization’s mandated structural mechanisms designed to manage the nation’s forests and grasslands for sustained ecological protection and efficient human-use, both for present and future generations. The existing USFS management framework will be insufficient to meet the challenges posed by climate change. Therefore, a revised, uniquely-tailored framework must be created and implemented at every level of USFS management, from the national office, down to regional offices, forest offices, and finally down to the district-level. These changes must be made as one comprehensive reformation.
While many changes I present here can be applied to all levels of USFS management, I concentrate specifically at the forest-level to balance the potential for feasible implementation of management prescriptions and tangible, useful results. As the limitations of the current USFS management framework become clear, the foundations required for the new framework will be put in context.

Section 3.2 highlights the problems associated with managing national forests under varied warming scenarios with current structural parameters. Section 3.3 focuses on how, with structural changes, the USFS is in a unique position to exact real progress in assisting ecosystems in adaptation to climate change. Section 3.4 introduces case studies and various lenses through which we can begin to understand the limitations of the current management structures and opportunities for breaking through them. The perspectives gained through this examination provide the basis of a new management structure. Section 3.5 provides concluding thoughts on the lenses of examination presented in this chapter and the principal constraints to effective incorporation of climate change into USFS management structures.

3.2 Systemic Organizational Constraints on Effective US Forest Service Management Under a Warming Climate

The inevitability of drastic alterations to ecosystems as a result of climate change necessitates a revision of management emphases to reflect the imminence of changes to ecosystem functions and services. There must be a coordinated top-down and bottom-up approach to incorporate climate change into management plans. Feedback and input from managers on the ground who observe changes to ecosystems must accompany direction from senior administrators and policymakers.
In order to effectively incentivize a two-way, multi-faceted, collaborative approach to policy prescription and implementation, the USFS must buck a historical trend of reacting to issues after they arise. Rather, the agency must proactively prepare for impending issues in order to more effectively meet management goals. This will require a reformation of the policy structures within the USFS to streamline bureaucratic requirements and make it easier for policymakers and resource managers to implement—and then act on—policies designed to assist ecosystems in the face of rapid climate change.

To date, managers have often been over-burdened by agency requirements on project planning that distract from the goals driving the project and the larger underlying policy. This is a major impediment to incorporating climate change policy into the existing USFS management structure. Additionally, systemic constraints exist throughout the USFS management chain—from congressional and presidential mandates and unofficial influences all the way down to district-level policy implementation—that prevent managers from effectively prioritizing management goals and achieving necessary results.

3.2.1 “The Process Predicament”

In 2002, the USFS published an internal report on “how statutory, regulatory, and administrative factors affect national forest management,” in what they called “The Process Predicament” (USDA Forest Service, 2002, pp. 7). The report found that policy-to-practice systems are inefficient in their current form. This “predicament” has kept the agency from effectively addressing rapid declines in forest health, has impeded nearly
every other aspect of multiple-use management, and will prevent an appropriate response to the effects of climate change.

The predicament is embedded within three principal shortcomings of the USFS management structure. Namely, “(1) Excessive analysis—confusion, delays, costs, and risk management associated with the required consultations and studies; (2) Ineffective public involvement—procedural requirements that create disincentives to collaboration in national forest management; and (3) Management inefficiencies—poor planning and decision-making, a deteriorating skills base, and inflexible funding rules, problems that are compounded by the sheer volume of the required paperwork and the associated proliferation of opportunities to misinterpret or misapply required procedures” (USDA Forest Service, 2002, pp. 5).

**Excessive Analysis**

Excessive analysis within the USFS has been a compounding issue over the past several decades as the work-load for resource managers has increased and “too often, the Forest Service is so busy meeting procedural requirements, such as preparing voluminous plans, studies, and associated documentation, that it has trouble fulfilling its historic mission: to sustain the health, diversity, and productivity of the nation’s forests and grasslands to meet the needs of present and future generations” (USDA Forest Service, 2002, pp. 7). The USFS is required under a variety of laws, such as the National Environmental Policy Act (NEPA) passed in 1970 and the Endangered Species Act (ESA) passed in 1973, to perform environmental impact assessment reports and gain public feedback from all policy implementations and changes to management practices.
These policies are designed to ensure that any management action the USFS takes will not have adverse effects on other systems (ecological and/or social). They are designed to slow the policy process and encourage better decision-making and compliance with existing regulations. These regulatory mechanisms have arguably benefited the environment, especially for individual threatened or endangered species such as the spotted owl in the Pacific Northwest. However, a debate exists as to whether emphasizing species-level environmental health (inherent in laws such as the ESA) rather than more holistic ecosystem health has resulted in a trend of USFS misallocation of resources and a failure to achieve broader management goals.26

While few would argue the motivating factors behind environmental laws steering USFS policy are inherently wrong or misguided, the laws do slow reaction time in dealing with emerging issues and interfere with efforts to take action proactively before they become unmanageable. The ability of the USFS to take drastic management actions, such as large-scale invasive weed prevention programs implemented within a season of outbreak, is exceedingly difficult under a system of regulations designed to slow down the review and implementation processes. Climate change exacerbates the shortfalls of this structural framework in such a way that making measurable progress on the issue is not possible unless time-frames required to create and implement policy can be cut down.

Excessive analysis can result in litigation instead of project completion. Inability to manage resources flexibly means the integration of new information and data often

26 See USDA Forest Service (2002) for case studies where the environment has benefited in isolated circumstances from strict compliance regulations such as the ESA or NEPA as well as arguments for how prioritizing individual species health inherent in the ESA, for example, has led to decreased holistic environmental health because managers do not have sufficient resources to maintain a small-scale and large-scale approach to meeting management goals.
requires freezing current NEPA environmental impact assessments to allow for supplemental environmental analysis. This can result in either judicial reviews and litigation and/or the halting of the management project altogether because of a lack of managerial resources to handle the extra work within the required time-frame (USDA Forest Service, 2002).

Detailed and extensive analysis is beneficial to effective policy creation and implementation, but only insofar as the larger management goals remain in focus and managers are able to incorporate new emerging issues into existing management frameworks in an effective way. To date, balancing flexibility and a feasible workload has not been possible.

**Ineffective Public Involvement**

The USFS has established mechanisms to encourage public participation with management decisions in order to implement policies that are favored by a greater proportion of the public. This system of participation, while not fundamentally flawed, in practice poses a great hurdle to timely implementation of USFS policies. The USFS’s procedure for administrative appeals allows citizens to challenge a manager’s decision to proceed with a project. With the passing of the 1993 Interior and Related Agencies Appropriations Act, the USFS is now required to give public notice and a provide a comment period for proposed actions, even with proposed actions that found no significant impacts to resources or social systems under the NEPA analysis (USDA Forest Service, 2002).
The *Process Predicament* report aptly describes the problems associated with administrative appeals and the disincentive to collaboration the procedural processes often cause.

Administrative appeals can greatly delay a project. For time-sensitive projects, results can be disastrous. For example, unless insect-infested trees are swiftly removed, infestations can spread to healthy forests and even to nonfederal lands. In the Southeast, southern pine beetle infestations have repeatedly spread from national forests to private lands because the Forest Service was unable to complete environmental analysis and take action soon enough to prevent it.

Moreover, the opportunity to appeal can discourage collaboration. If a group’s only chance to affect an outcome is before a decision is made, its incentive to engage from the outset in collaborative decision-making will be strong. However, if the group can later appeal the decision, it can ignore opportunities for predecisional collaboration and focus instead on postdecisional challenges. Instead of helping parties work out their differences, the appeals process can all too easily become a tool for obstruction (*USDA Forest Service*, 2002, pp. 28).

Procedural delays can also plague the USFS process of incorporating public input into management decisions because often, in an effort to cope with required procedural mandates, managers expect litigation and administrative appeals in response to management proposals and therefore spend considerable time and effort on procedural processes to appease public concerns only to find that the public is outraged by the slow movement of project implementation. This can result in the loss of public partnerships and frustration of inaction by all stakeholders. Also, some public partnerships fall into decay because the USFS lacks the institutional capacity for invested long-term collaboration and adherence to commitments. Shifting personnel assignments mean it can be hard for long-term relationships to exist between individuals, and the USFS can fail to maintain vital localized public-private relationships as a result.
Management Inefficiencies

While the USFS is successful in maintaining flexibility in certain management areas—inventorying acres at risk of wildfire and collecting visitor-use information with regards to recreation (USDA Forest Service, 2002), for example—the USFS faces inefficiencies in other areas such as fiscal planning and funding allocation. The General Accountability Office (GAO) suggested the USFS focus on five mechanisms to better-manage its planning process: 27 (1) improving agency accountability for performance; (2) improving agency commitment to monitoring and evaluation, including standardized protocols; (3) adopting the recommendations of internal efficiency review teams; (4) involving the public more actively at the beginning of the planning process; and (5) developing common socioeconomic and environmental databases for use by forest planners and managers. While these recommendations are a useful place to initiate reform, they only touch the surface of the management inefficiencies if applied to managing resources under various climate change scenarios.

Other inefficiencies include confusion about planning requirements because of multi-tiered planning analysis structures. Forest-level requirements often differ from project-level requirements and managers have to dissect, often with little direction from higher-level officials, which requirement to follow. This delays project implementation and goal-achievement and can lead to resource waste. Large-scale environmental analysis is a relatively new third tier of planning requirements and has further complicated expectations (USDA Forest Service, 2002). Confusion over requirements is a basic systemic issue that impedes progress towards goals.

27 See USDA Forest Service (2002) for a description of the GAO report.
Another inefficiency is the set of rules governing funding of projects and management areas. Projects with multiple objectives, such as a watershed improvement projects that also restore wildlife habitat, reduces fuel loads, and cuts down on recreation impacts should draw on various sources of funding. However, budget rules do not always allow for streamlined project funding (USDA Forest Service, 2002). With climate change, there will rarely be a project that is contained within a singular objective; on the contrary, to effectively manage ecosystems with the multitude of interconnections and feedback loops associated with a warming planet, the USFS will need to draw on all funding and management divisions in unison. Objectives can only be met when issues are not bound to organizational structural constraints. Without flexible, adequate, and timely funding for projects, managing for climate change will not be possible.

Finally, the over-burdened workforce makes resource management inefficient. The USFS manages 193 million acres (8.5% of the total land area of the US). The USFS has a total workforce of ~30,000 (including seasonal employees, as well as secretarial positions, mechanics and other support staff not directly managing resources). With a total workforce of 30,000, each employee is responsible for managing roughly 6,433 NFS acres. As a result of planning requirements such as processes required under NEPA, for example, agency employees must devote a considerable amount of their time to paperwork rather than fieldwork. This shift away from field-based management and into computer-oriented, office-based resource management has implications for the ability of managers to effectively monitor ecosystem changes and respond to early warnings of drastic alterations such as those probable as a result of climate change.
3.2.2 The Lack (mostly) of Strong Leadership and Clear Communication

Only within the last several years have high-level USFS policymakers labeled the effects of climate change as a threat to ecosystems. The executive branch of the government exerts an underlying management direction over the USFS through mechanisms such as executive orders and statements of policy direction. Until 2005, President Bush did not acknowledge the human-relationship to—and the threat of—climate change (Clarke, 2005). When President Bush did acknowledge climate change, the USFS scrambled to formulate a position on the issue and the agency’s role in addressing it. When the current Chief of the Forest Service took her oath in February of 2007, climate change became a central emphasis of managers within the agency. Chief Kimbell appointed a senior official as her Special Advisor on Climate Change and named climate change one of the three primary management foci for her tenure with the USFS.

The agency, because of executive branch influences, was slow to acknowledge—let alone respond—to climate change. Under the new Obama administration, there are signals the trend is now moving towards action. Despite the positive changes in the past several years, the USFS still struggles to encourage strong leadership throughout all levels of management. While direction has started to come from the national level, it seems to be lacking from the regional and district levels. Resource managers are confused about what proactive actions they can and should take with regard to climate change (Brown, 2008) and there is a sense that managers are overstretched and not eager to increase their workload without a specific directive to do so from higher officials within the agency.
Within the last year specific guidance been passed down from the national-level to lower levels. In the fall of 2008, the agency released the *Forest Service Strategic Framework for Responding to Climate Change*, which, while more explicit than any previous directive, still lacks the site-specific, project-level guidance that managers need to be able to take action. In January 2009, the agency released two new directives making guidance more explicit. A memo was sent to national- and regional-level managers by the Deputy Chief, which included both the *Climate Change Considerations in Land Management Plan Revisions* and the *Climate Change Considerations in Project Level NEPA Analysis* directives. These two briefs provided managers with more structured guidance for incorporating climate change into management plans. This is a major step forward, however, both documents lack the incentive structures for prioritizing climate change as the ultimate management issue.

The intent of the memos is to help managers fit climate change within existing structures. When examining existing management plans, especially at the forest-level, it becomes clear, however, that attempting to fit climate change into existing plans cannot result in a holistic and effective approach to managing deeply altered ecosystems. There must be reforms that work bidirectionally. A two-stage reformation will be necessary for the USFS to effectively manage resources.

In addition to vague or insufficient direction from top-level policymakers to managers at lower levels, mid-level managers lack motivation to provide useful guidance for project-level changes. However, this is beginning to change with guidance, for example, from the *Climate Change Considerations in Project Level NEPA Analysis*. This indicates how to apply NEPA analysis standards to project proposals where impact
assessments suggest climate change is an impacting factor, or where the assessment finds the emission of GHGs as a result of USFS management actions to be a constraining factor on project implementation (USDA Forest Service, 2009b). Project-level changes to management prescriptions mandated by forest-level officials, however, have not been made clear in any great detail. Guidance from the report *Climate Change Considerations in Land Management Plan Revisions* is a strong first step, but, as the authors would surely agree, is not fully encompassing (USDA Forest Service, 2009c).

### 3.2.3 What is the Ultimate Goal of US Forest Service Resource Management?

It is the ultimate goal of USFS resource managers to maintain the functions and services of NFS ecosystems. Traditionally, this has meant that managing a “natural” landscape would require maintaining or re-establishing conditions prior to European arrival and the consequent impacts—such as logging, mining, development etc.—on resources. “Naturalness” has been conceived of in terms of finding and maintaining the steady-state equilibrium within ecosystems. This conception of successful resource management is changing however as managers are realizing natural variation is wider than many believed and that a single steady-state might not aptly capture the true character of naturalness (Millar et al. 2007).

It is necessary, however, to decide what the best measure of successful management is. Should the goal of management policies remain the maintenance or re-establishment of perceived equilibrium? Or should success be measured differently? There is evidence the USFS is now making the important distinction between managing for a singular equilibrium in ecosystems and managing for a wider conception of
naturalness that more fully captures ecosystem functions. However, this is mostly the product of individuals and thus far not an institutional focus.

3.3 The Status-quo Will Not Suffice, Yet Hope is not Lost

In providing examples of systemic constraints on organizational flexibility in the last section, I have highlighted where reforms must occur in order to address far-reaching issues such as climate change. To provide a truly convincing argument for why the USFS can, and must, reform agency management structures, it is necessary to highlight the aspects of its policy structures and organizational mandate that provide the agency with a tangible opportunity to manage resources effectively in a time of rapid climate change. Despite certain systemic constraints, the USFS performs a lot of tasks well. The following section explores a few effective aspects of USFS management structures.

3.3.1 Science in Resource Management and Connected Infrastructure Networks

Of the largest federal resource management agencies, the USFS most fully emphasizes the role of science in guiding policy prescription as evidenced by their large science staff and devotion of fiscal resources to their Research Stations throughout the NFS,\(^\text{28}\) as well as the heavy emphasis on science language throughout the USFS mission.

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\(^{28}\) The USFS, along with the Bureau of Land Management (BLM) and National Park Service (NPS) manage the most terrestrial acreage within the US. These three organizations have wide mandates and the NPS also makes science a foundation of its mandate to preserve the most treasured resources in the US. However, the NPS, as opposed to the USFS, often encourages research specialties specific to a local issue or feature, where the USFS encourages a broader application of research scientist’s specialties as seen with the installation of Research Stations within each region and the maintenance of experimental forests throughout the NFS.
While many of the policymakers and top-level administrators are not scientists, the role of science and quantifiable management is still emphasized within policy and planning processes.

With a four-tiered management structure, the USFS is able to delegate responsibility throughout management levels to ensure specialization and avoid wasted managerial resources. The agency has extensive research infrastructure in many different ecoregions throughout the nation, which helps create a solid foundation of baseline data against which ecosystem health changes can be measured. Also, the network of monitoring infrastructure—such as experimental forests—can be augmented with research sites maintained by other agencies, providing a more complete mosaic of monitoring data. The USFS has strong relations with other federal and state agencies and if effective capacity-building and collaborative steps are initiated and maintained, the USFS can remain in the center of monitoring projects.

3.3.2 Concluding Thoughts on the Need for a New Management Framework

The USFS has an imperative to take immediate and effective action to assist ecosystems in the face of climate change. As I have shown in this chapter, there are structural impediments to achieving effective management goals. The most fundamental systemic constraints are embedded within a “process predicament” where excessive analysis, cumbersome public involvement, and management inefficiencies characterize

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certain aspects of USFS policy processes. A lack of clear communication and high-level direction also affects the ability of the USFS to confront issues of the 21st century.

Despite these hurdles to effective resource management, there are signs that the USFS has the organizational strength to confront the challenges and achieve results. A foundation of science through all levels of management will underpin policies based on forward-thinking management creativity and ingenuity. The agency is large enough to make real progress and the extent of monitoring infrastructure will help yield good baseline data and provide an opportunity to measure change. All in all, the USFS is in a unique position to confront climate change and ensure ecosystem integrity is maintained as the planet warms. The USFS has a responsibility to act expediently and take measures to ensure agency structural constraints do not prevent adequate responses to emerging issues and effective management.

3.4 Case Studies: Descriptions and Methodology

I have selected several frames of analysis through which one can gain insight into how applying the current USFS management framework to a NFS characterized by a rapidly changing climate will not be possible without changed language and incentive structures. The following case studies will then become the backdrop for applying a new USFS management framework in subsequent chapters. First, I have selected the Arapaho-Roosevelt National Forest (ARNF) in Colorado to highlight the shortfalls of the current management framework and apply the new framework that will be outlined in Chapter Five. Second, I have chosen to specifically look at alpine ecosystems since changes to ecosystem functions and services are already quantifiably discernable and this biome is
arguably most at risk from rapid climate change. Finally, I have selected a designated wilderness area under ARNF jurisdiction, the Indian Peaks Wilderness Area (IPWA), to show how creating a unique set of parameters to manage ecosystems in wilderness is necessary when confronting such an explicitly human-caused issue. A deeper discussion of the special wilderness parameters can be found in the Appendix.

3.4.1 Description and Methodology: A Forest-Level Analysis on the Arapaho-Roosevelt National Forest

The ARNF was chosen for a number of reasons. First, there is a large diversity of ecological resources managed by the ARNF. From high alpine environments with elevations over 14,000 ft. to grasslands on the eastern plains of Colorado with elevations below 5,000 ft., there is a plethora of ecosystems exhibiting both endemism as well as traits that can be found in other ecosystems throughout the western US. There are over 500 species of wildlife found on the ARNF, including several threatened or endangered species, and a wide range of floral systems as well (USDA Forest Service, 1997b). The ARNF manages 1.5 million acres, which is roughly 0.7% of the total USFS managed land area. These 1.5 million acres include ten designated wilderness areas, which total 373,259 acres. The Forest also administers twelve Research Natural Areas as well as the Fraser Experimental Forest, which provide a large amount of observational data creating a baseline from which managers can measure changes to ecosystems observed over the past several decades. The experimental forest provides an opportunity for managers to develop creative new management techniques and examine intricate species interactions on a local scale.
Science plays a major role in organizational emphases on the ARNF. The USFS Rocky Mountain Research Station (RMRS) has its headquarters on the ARNF. Home to over 100 research scientists and 300 support staff, the research station provides scientific specialization on all the major threats facing the NFS, including those related to climate change (RMRS, 2008). The principal foci of managers and scientists on the ARNF are noxious (invasive) weeds, mountain pine beetle infestation, fire ecology, high visitor-use and recreation, retaining clean watersheds, and maintaining wilderness character (USDA Forest Service, 2008c). These foci drive management actions and characterize funding allocation.

While the role of science is emphasized on the ARNF, issues relating to recreation and visitor-use are also heavily emphasized. The ARNF is considered an “urban forest.” The forest is within close proximity to major urban centers along the Colorado Front Range (see Fig. 3-A below), and as a result, the forest sees visitor-use numbers well above the national average. Estimated annual visitation to NFS lands nationwide is 204.8 million forest visits, and estimations show that the ARNF is the most visited forest in the US with approximately six million visits annually. As a result, any discussion of resource management and ecological health requires a consideration of the impact of recreation on NFS ecosystems. Distinguishing what impacts are directly attributable to the effects of visitation versus to the effects of climate change is useful. However, to effectively manage resources in a warming world, we have to accept the continued presence and influence of recreation and focus efforts to assist ecosystems accordingly.

30 These estimations exclude ski area visits, which, if included in estimations, would keep ARNF in the top ten of visited forests. See USDA Forest Service (2004) for a detailed explanation of visitor-use numbers and how each visit is categorized.
Figure 3-A) Modified from USDA Forest Service 2008c: A map of the ARNF. Notice the proximity to the Colorado Front Range and major urban centers such as Denver, Boulder, and Fort Collins. Also notice the wide geographic range the forest covers.
The ARNF has a diverse and expansive management spectrum, and I chose the forest for this reason. Climate change cannot be approached independently of other management issues; rather, the ways in which climate change is handled must include the role of other management issues facing the USFS, i.e. increasing visitor use numbers and the resulting impact on resources. The ARNF must balance the interests of many different stakeholders—both ecological and social—to manage resources effectively.

The Arapaho-Roosevelt National Forest Plan

Each national forest is governed by a unique forest-level management plan (referred to as the Forest Plan) that is revised every ten to fifteen years. This plan sets management, protection, and use goals and guidelines for each forest. It also outlines principal management issues the forest faces. Each plan is broken into several chapters. The first chapter describes the broad, forest-wide direction forest managers intend to take management policies. The second chapter breaks down direction into smaller geographic areas, sectioned into districts of the forest. In the second chapter, each management unit is given specific attention and principal attributes are described. The third chapter highlights the management area direction. This chapter contains "templates" for managing areas in particular ways called management area prescriptions. Each one describes the area's desired condition and the governing standards and guidelines associated with each area. These standards and guidelines apply in addition to the forest-wide direction specified in chapter one. Chapter four speaks to the role of monitoring and evaluation of the plan. It describes how the USFS will ensure that the Forest Plan remains current and yields the intended results (USDA Forest Service, 1997a).
The ARNF Forest Plan was last revised in 1997. The report is substantial (over 400 pages), and each aspect of the forest’s physical characteristics and management needs are detailed. Since the focus of this paper will be on alpine ecosystems and wilderness areas, I will focus primarily on the sections of the ARNF Forest Plan that relate to these aspects of ARNF management. However, first, I will give more general background on how the ARNF Forest Plan is constructed and how it is used by managers before I delve into the specifics of alpine environments and wilderness on the ARNF.

Forest Plan: Chapter One

The first chapter in the ARNF Forest Plan discusses the broad forest-level management goals and objectives. The plan makes an important between its use of the terms goal and objective. According to the plan, “goals describe desired end-results and are normally expressed in broad, general terms. Forest Plan goals link broad agency goals as set forth by law, executive order, regulation, agency directives and the Resource Planning Act (RPA) program...Objectives are concise statements of measurable, desired results intended to promote achievement of Forest Plan goals. Objectives describe (1) desired resource conditions in the area covered by the Plan, either in the next decade or longer, and (2) desired levels of goods and services that the Plan is capable of producing in the next decade” (USDA Forest Service, 1997a, pp. ii).

Additionally, the plan defines forest-wide standards and guidelines. The Forest Plan describes standards as “courses of action or levels of attainment required to achieve goals and objectives. Standards are mandatory and...are developed (1) when laws or policies do not exist or benefit from further clarification, (2) when standards are critical to objectives, and (3) when unacceptable impacts are expected if a standard were not in
place.” Guidelines are less strict and are only “preferred or advisable courses of action or levels of attainment designed to achieve the goals and objectives. Guidelines are developed in the following circumstances: (1) when they contribute to achievement of goals; (2) in response to variable site conditions; (3) in response to variable overall conditions; and (4) when professional expertise is needed” (USDA Forest Service, 1997a, pp. 11).

In order to explain the necessary processes undertaken by the ARNF to classify management goals and objectives, and to outline how the goals and objectives are met with standards and guidelines, I will briefly introduce the structure and methodology inherent in chapter one of the ARNF Forest Plan. The forest-level goals are broken into five parts: (1) physical resources, such as water resources and air quality; (2) biological resources, such as biodiversity and wildlife management; (3) disturbance processes, such as fire, invasive species, and insect infestation; (4) managing for recreational users; and (5) administration, such as NFS infrastructure.

For each of these five parts, goals are outlined and then standards for meeting goals are enumerated. For example, under the physical resources category, water resources are emphasized. The goal is to “work cooperatively with national, state and local interests to protect water related values in perpetuity on National Forest System lands” (USDA Forest Service, 1997a, pp. 13). The standards designed to meet this goal are broken into small categories such as hydrologic function or erosion and sediment within which are explicit standards. For instance, under hydrologic function, standards require the ARNF to “manage land treatments to conserve site moisture and to protect long-term stream health from damage by increased runoff” (ibid.). Another standard
under the same category requires the ARNF to “manage land treatments to maintain enough organic ground cover in each land unity to prevent harmful increased runoff” (ibid.).

The latter section of chapter one of the ARNF Forest Plan states the goals for biological resources. This section highlights the importance of indicator species evaluation and the protection of threatened and endangered species on the ARNF. Indicator communities and species were outlined so that managers can notice alterations to ecosystems before they become catastrophic. For example, the montane riparian area and wetland indicator community has three principal indicator species residing within it, the wilson’s warbler, northern leopard frog and boreal toad. The ARNF Forest Plan dictates that these species must be monitored, and as a result, a decrease in population levels of these species acts as an early-warning system for managers that larger, ecosystem-level change is imminent. These species exhibit certain characteristics that make them keystone species in the ecosystem and if there are ecological variables negatively affecting their health and their population levels, then the negative impact of those variables will be transferred throughout the rest of the ecosystem.

The ways in which the Forest Plan enumerates standards for reaching forest-wide management goals lays a solid foundation of incentives for managers to notice and act on threats to ecosystem functions and services before the threat is too challenging to overcome. However, despite the existence of strong incentives within the structure of the Forest Plan, managers have thus far lacked the motivation to apply this foundation to the wider-scale threat of climate change. It is for this reason that the Forest Plan must be made more explicit and better incorporate both existing and new threats from climate
change.

**The Forest Plan: Chapter Two**

The second chapter in the ARNF Forest Plan focuses management goals and objectives at the local scale. While some of the forest-wide management goals might be applicable to localized management compartments, there are also unique local issues that require attention even if they might not be representative of the larger forest. The forest is broken down by ranger districts—there are six geographically-distributed districts within the ARNF—and management goals are unique to each. I will be focusing on the Indian Peaks Wilderness area, which is within the Boulder Ranger District.

**The Forest Plan: Chapter Three**

Chapter three of the ARNF Plan provides guidance on management of areas with similar characteristics or issue themes. The ARNF is divided into management area categories, which is simply a summary of management area characteristics and reflective of the multi-use focus of the USFS. These categories are (1) Wilderness Areas; (2) Research Natural Areas; (3) Special Interest Areas; (4) Scenic or Dispersed Recreation Areas; (5) General Forest and Rangeland Areas; (6) Mid-Composition Areas; (7) Intermix areas; and (8) Developed Recreation Areas.

These management areas strike a balance between an emphasis on human and ecological needs and cover a spectrum of needs. Wilderness areas are on one extreme of the spectrum and ecological needs take precedence over human needs. On the other end of the spectrum are developed recreation areas where human needs take precedence over ecological needs. We should expect a permanent human influence in these areas.
Research natural areas (RNAs) will be an important part of the proposed revisions in Chapter 5 of this paper and must be explored in some detail. These RNAs do not have legal protections against human infrastructure and development, however they tend to be small enough and remote enough that they are mostly removed from human influence. The exception to this is the presence of some research infrastructure and equipment. While timber harvesting and motorized travel is prohibited, oil and gas leasing is allowed if deemed feasible to extract. The intent to specially categorize research areas, according to the ARNF Forest Plan, is to “provide for conservation of representative, or particularly rare and narrowly distributed, ecological settings or components. [The research natural areas] help ensure conservation of ecosystems or ecosystem components that may provide important functions ensuring the overall sustainability of larger landscapes. Human influences on the ecological processes are limited to the degree possible, but are sometimes evident. Types of human use vary, but generally are not intensive. Travel is generally nonmotorized. Some of these areas help provide a ‘natural’ benchmark to compare with areas that are intensively managed for a particular objective” (USDA Forest Service, 1997a, pp. 326). These areas play an important part of effectively managing resources with a warming climate.

On the ARNF, there are twelve existing or proposed RNAs (as of 1997). They vary in size from 386 acres to 18,312 acres and cover a wide range of ecological characteristics. Some RNAs are located within designated wilderness areas and are distinguishable by the general lack of trail systems present in most wilderness areas.

**The Forest Plan: Chapter Four**

Monitoring and evaluation of the Forest Plan and its goals and objectives occurs
at all levels of management. According to the ARNF Forest Plan, “monitoring and evaluation are separate, sequential activities” required to “determine how well objectives have been met and how closely management standards and guidelines have been applied.” Monitoring is the collection of pertinent observational and measurable data, and evaluation is the analysis of the data. Once analyzed, decisions can be made as to whether the goals are being met and recommendations for revisions—if appropriate—can be made.

This chapter of the Plan lays out a framework for managers monitoring resources and judging success of management goals and objectives. Recommended questions for managers to refer to on a consistent time cycle are provided (See Fig. 3-B below) and the ARNF prepares an annual report on monitoring and evaluation of the forest goals and objectives.

**Annual Monitoring and Evaluation Report**

This report published by each forest annually to review the progress made towards meeting the goals laid forth in the Forest Plan highlights emerging issues facing the forest. It also recommends necessary changes to forest goals as well as monitoring and evaluation methodologies designed to reach the goals. The report attempts to answer management questions like those posed in Figure (2-B) above, and if it is decided the goals are not on track for success or have clearly failed, recommendations will be made as to how to better focus efforts to achieve management goals.
As an example, the most recent ARNF Monitoring and Evaluation Report (fiscal year 2006) shows how efforts to restore and improve terrestrial habitat for threatened, endangered, and sensitive species (TES species) have seen mixed results to date. The guiding questions for biodiversity protection can be seen in Figure (3-C) below.
The report found that despite some successful projects to restore terrestrial habitat, the forest is not on track to meet management goals as stipulated in the ARNF Forest Plan. Figure (3-D) below depicts how progress towards reaching TES species habitat improvement goals is falling short. The goal in the ARNF Forest Plan was to achieve ~4,800 acres of habitat improvement, especially for TES species over the course of the 1996-2007 Forest Plan period. The Forest is not on track to reach this goal. The monitoring and evaluation report recommends that managers continue species-level projects such as restoring riparian areas, the translocation of native cutthroat fish into unoccupied streams, and better control of off-road motorized travel in TES species habitat. The preparers of the ARNF Monitoring and Evaluation Report found that “given the high emphasis for biological diversity committed to in the Forest Plan, increased effort in this area is appropriate” (USDA Forest Service, 2006).
3.4.2 Description and Methodology: Alpine Ecosystems on the Arapaho-Roosevelt National Forest: Indian Peaks Wilderness Area

An alpine ecosystem can be defined as “the biotic zone on mountains above the natural limit of tree establishment dominated by herbaceous plants” (Bowman, 2001, pp. 4). Alpine ecosystems are characterized by a harsh climate with low average temperatures, high sustained-wind velocities, relatively little annual precipitation, and generally dry soils, all of which impose significant stresses on alpine biota. The
landscapes are incredibly spatially heterogeneous because of small and large-scale topographic relief differences as a result of the mountainous terrain (ibid.). This allows for differential snow cover through much of the year, which has effects on species composition and richness.

The alpine environment was selected as a focus of this paper because of its highly unique ecological characteristics and because changes in climate often manifest in alpine ecosystems earlier than some other environments. It is possible to measure changes to ecosystems relatively easily as there are generally fewer species residing in the alpine. Also, many ecological interactions such as the relationship between nitrogen cycling trends and plant growth rates have clearly delineated causal relationships. Additionally, because of harsh conditions, many alpine ecosystems lack any human infrastructure and provide the best example of a pristine natural environment. Finally, the alpine ecosystem is a proxy for climatic changes as the presence of seasonal snowpack—the total cumulative depth of surface snow—can amplify climate signals, and many species rely on a narrowly regulated atmospheric composition, and as such, when atmospheric compositions change, species-level alterations to ecosystem structures are evident (Williams et al. 2002).

In this section, I will outline the principal threats to ARNF alpine ecosystems posed by climate change, and especially to the Indian Peaks Wilderness Area (IPWA). First, however, I will provide some basic background information about the case study site, the IPWA in order to put climatic changes on the ARNF into context.
The Indian Peaks Wilderness Area

The IPWA is within the Indian Peaks Wilderness Geographic Area, which includes the 76,586 acres designated as wilderness by Congress (roughly 5% of the total ARNF acreage and 0.04% of the total USFS acreage), as well as a non-wilderness area devoted to research conducted through the Niwot Ridge Long-Term Ecological Research Site (NWT-LTER), which is part of a global network of research sites funded in part by the National Science Foundation and coordinated by researchers at the University of Colorado at Boulder. The area devoted to research infrastructure is ecologically similar to the IPWA, and many of the non-intrusive, non-mechanized NWT-LTER research programs are carried out within the boundaries of the IPWA. The NWT-LTER is abutted by the IPWA on three sides (see Figure 3-E below). The wilderness area also shares the southern boundary of Rocky Mountain National Park.

The IPWA is characterized by high peaks, glacial lakes, high mountain meadows, and exposed ridges with elevations ranging between 9,800 to 13,502 feet, which results in harsh climatic conditions for much of the year. The IPWA straddles the continental divide and feeds several major watersheds (See Figure 3-F below). Despite its rough terrain, the IPWA is within close proximity to major urban centers such as Boulder and Denver, Colorado. It sees very high visitor-use numbers, and as a result, the ARNF has mandated a required over-night permit system to monitor use on areas of high-stress. One area (the Four Lakes Backcountry Zone) has been designated fragile and over-used, which has resulted in the ARNF prohibiting overnight camping during summer months in order to “to ensure that wilderness values and physical resources are not being compromised” (USDA Forest Service 1997a, pp. 67).
Figure 3-E) Map showing the IPWA, outlined in red, and the NWT-LTER site adjacent to the IPWA. The green shading represents forested areas and the white shading represents alpine areas. Also, notice the scale. While the area is not exceedingly large compared with other wilderness areas, the rough topography creates many micro-climates. See Figure 3F below. Author’s Figure.
While the IPWA sees high use, the use is generally contained within specific corridors on existing NFS system trails. Much of the wilderness area is considered “effective habitat” for species living within the management area. Effective habitat is judged based on the density or roads and trails and therefore the relationship between human interactions with the natural world. Approximately 77% of the IPWA is considered to be effective habitat—as compared with the forest average of 67%. Some
other wilderness areas on the ARNF score higher (such as Neota Wilderness area, which is judged to be 95% effective for species habitat), but considering the popularity of recreation in the IPWA, the travel corridors do a relatively good job isolating areas of use on the IPWA (USDA Forest Service, 1997a). While the ARNF has outlined specific recreation-based management prescriptions to protect resources, there is no mention of managing the IPWA in the face of emerging issues such as climate change in the ARNF Forest Plan.

Principal Threats to the Indian Peaks Wilderness Area Ecosystems

As discussed in Chapter Two, NFS ecosystems are experiencing climatic changes that can be captured in general trends, such as warmer average temperatures and decreased snowpack levels. However, the localized effects of climate change are of special importance when formulating management prescriptions at the Forest level. The local effects can sometimes buck general trends because of unique characteristics such as the existence of microclimates as a result of mountainous topography and differential snowcover in many alpine areas as is the case in the IPWA (See Figure 3H below).

There are three principal threats to the IPWA alpine ecosystem. The first threat is changes in snowpack with a decreasing trend but with extremely variable localized effects. The second threat takes the form of altered ecological interactions—both plant-nutrient relations and floral-faunal relations—affecting species composition and richness and threatening biodiversity. The third threat is decreased water quality and quantity in many ARNF alpine ecosystems. Recreation, in addition to climate change poses a serious threat to the health of alpine ecosystems; however, the ARNF has already outlined
specific measures to mitigate the effects of recreation on ecosystems and it remains an established focus of ARNF managers. While recreation is an important aspect of effective resource management, it will not be the focus of this paper.

**Changes to Snowcover**

The first threat to IPWA alpine ecosystems is simple but dramatic. Changes in snowcover depth and extent will affect species composition and ecosystem functions. Distribution of snow in the alpine zone is extremely differential, and as a result, it is the most important determinant of landscape-level biotic variation (Bowman et al. 2002; Billings, 1973). Some areas remain covered in snow year-round, while adjacent areas may be free of snow due to uneven topography and wind patterns. This “creates a mosaic of growing season lengths and soil moistures that strongly affects species composition and the functional attributes of communities” (Bowman et al. 2002; Walker et al. 1993).

When climate variation changes the total annual snowfall, as well as the timing of the snowfall and the duration of snowcover into summer months, many species that rely on strict snow position, depth, and timing will be negatively impacted. The nature of the local snowpack can potentially alter patterns of alpine plant productivity and composition by affecting growing season duration, soil moisture levels, soil chemistry, and the thermal characteristics of the soil (Litaor et al. 2008). A study by Litaor et al. 2008 in the Niwot Ridge area bordering the IPWA evaluated the snow-plant growth interactions by modeling the interrelationships of snow depth, snow water equivalent (how wet the snow is), snow melting rate, and soil moisture. Litaor et al. 2008 found that “species
richness…was significantly correlated with snow depth and soil moisture,” highlighting the importance of snowpack levels and the climatic drivers of snowfall patterns.

Historical records suggest that snowpack varies each year, but climate change is likely to provide seasonal snowpack changes that fall outside of natural variation (Ingersoll et al. 2007). Snowmelt timing is arriving earlier in the year for most of the western US including the IPWA (Stewart, 2009; Stewart et al. 2004), and this affects the growing season duration and primary production. Additionally, as Ingersoll et al. (2007) found, changes in snow chemistry is probable with warmer temperatures and decreased precipitation, which may also affect species composition.

**Atmospheric Impact on Ecosystem Interactions**

The second principal threat to the IPWA alpine ecosystem is the alteration of both plant-nutrient and floral-faunal relations as a result of changes to atmospheric composition. Carbon dioxide (CO$_2$) concentrations have been measured in several locations in the NWT-LTER since the 1960s. Data show that CO$_2$ concentrations have increased from 322 parts per million (ppm) in 1968 to over 365ppm as of 1998, which is a significant increase in a short time period, and is similar to both global trends and other high-altitude records (Sievering, 2001). Additionally, the other most significant element interacting with ecological processes in the IPWA alpine environment, nitrogen (N), is also increasing. The rate of N deposition, especially the wet deposition rate—deposited in the form of snow and rain—is important to the IPWA alpine ecosystem and has been shown to be increasing in recent decades (ibid.). Pollution from the Front Range of Colorado is also contributing to increased N deposition. The end result is altered soil
chemistry, microbial life systems and nutrient-plant relations (Monson et al. 2001; Seastedt, 2001).

According to Suding et al. (2006), “extensive observational and experimental evidence shows that plant species diversity declines with resource enhancement” such as N deposition. “Net primary production is increasing globally because of anthropogenic N deposition, altered precipitation regimes and longer growing seasons,” all of which are evident in the IPWA. In addition to N deposition levels, warmer temperatures have increased primary production in the IPWA (Walker et al. 2006), and as a result, ecological interactions are changing (Williams et al. 2002).

Since plant diversity is decreasing overall in the alpine ecosystem as a result of anthropogenic changes to atmospheric composition, changes will be seen through all trophic levels. Phenologic patterns are shifting with an increased growing-season as spring comes earlier in the year resulting in increased primary production. Yet, while overall plant production is increasing, some species such as mosses and lichens are decreasing in biomass. Diversity of plant communities and the evenness of distribution are being altered (Walker et al. 2006) affecting herbivores and their predators.

Some species such as the yellow-bellied marmot (Marmota flaviventris) may benefit, that is increase population levels, as a result of longer growing seasons. At the same time, species such as the American pika (Ochotona princeps) are threatened by climate change and are facing population declines (Beever et al. 2003).
Diminished Water Quality and Quantity

The third principal threat to the IPWA is diminished water quality and quantity. Historically, water systems in the alpine ecosystem have less plant diversity compared with many lower-elevation systems because they “lack the habitat and seasonal diversity that characterize lakes with greater temperature, nutrient, and microtopographical ranges” (Bowman et al. 2002). However, with a warmer climate, an increased length of growing-season, and decreased snowpack, many of these alpine water systems will be altered and may be re-characterized to look and behave like lower-elevation systems.

For example, with projected decreases in the time the ground is covered with snow, more sunlight will enter water systems and alter oxygen levels, increase water temperatures, and affect transparency resulting in increased primary production. Additionally, with peak spring run-off occurring earlier in the year (Stewart et al. 2004) there is a decrease in discharge in streams and rivers in late summer and early autumn. As a result, the waters are shallower and more susceptible to temperature changes. Greater seasonal variation in temperature and other parameters allows for potential algal growth. Overall, water systems will face compositional changes and water quality will be affected (Williams and Caine, 2001). It is also expected that further N deposition increases will lead to more eutrophic water systems and eventually the systems may acidify (Baron et al. 2000). Figures (3-G) and (3-H) below show the Boulder Creek headwaters and the Green Lakes, which are being studied to understand interactions between N deposition, changes in snowpack, and acidification of lakes.

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31 See Chapter Two, Section 1.1 for more details on water quality effects.
32 Episodic acidification has already been observed in alpine lakes within the NWT LTER adjacent to the IPWA. See Williams and Caine, 2001.
Figure 3-G) Map showing the IPWA, outlined in red, and the NWT-LTER site adjacent to the IPWA. Researchers are currently studying the Green Lakes—a series of glacial lakes exhibiting classic alpine lake characteristics—to determine the interactions between climate change and water chemistry (Williams and Caine, 2001).

Author’s figure.
Water quantity issues, especially the timing of discharges and total discharge from water systems in the IPWA are important, not only for species in the ecosystem, but also for the millions of people who rely on the water directly downstream in Colorado’s urban centers. While alpine areas only cover 4% of Colorado’s land area, they provide over 20% of the state’s streamflow, and they are vital to providing late-summer flows when lower elevations face periods of low precipitation (Williams and Caine, 2001).
There are three main threats to the IPWA and its alpine ecosystem. The threats will take the form of changes in snowcover distribution, depth, and duration, altered nutrient-floral and floral-faunal interactions as a result of chemical changes in atmosphere and in alpine soil, and decreasing water quality and quantity. Climate change will affect each community within the alpine ecosystem differently, but it is clear that changes are occurring and alpine ecosystems will likely continue to change as the planet warms.

### 3.5 Conclusion

I have chosen several frames of analysis through which one can begin to see where reformation is necessary within the USFS management structures if resource managers are to successfully assist ecosystems in adapting to climate change. The Arapaho-Roosevelt National Forest (ARNF) management plan was examined in order to see where new language is required to encourage managers to incorporate climate change into policy planning, implementation, and monitoring. Additionally, I chose to look specifically at alpine ecosystems because climate change has already begun to alter ecosystems interactions and many of these changes are quantifiable. Finally, I chose to use designated wilderness, specifically Indian Peaks Wilderness Area (IPWA) on the ARNF, as a frame of analysis because wilderness areas require a special set of parameters to manage effectively in the face of climate change. Wilderness, and the unique position of resources within wilderness areas, will be the focus of Appendix 1.

The purpose of this chapter was two-fold. First, I examined the constraints on efficacious incorporation of climate change into existing USFS management structures.
These constraints are visible both in the way planning processes lack sufficient flexibility to account for the scale and complexity of climate change, as well as in the lack of clear and strong communication throughout the agency’s management levels—from the top-down and from the bottom-up—on how to handle climate change. Also, a lack of adequate motivation for managers to act proactively to address climate change remains a central hindrance to sustaining healthy ecosystems in the face of climate change.

The second purpose of this chapter was to disseminate the most appropriate avenues for initial implementation of a new management framework that can effectively incorporate climate change into policy procedures and USFS actions. I chose a forest-level analysis because the responsibilities and management reach of a National Forest are large, but not so large as to raise the potential for implementation failure. A regional-level and national-level analysis is necessary. However, starting at the forest-level balances the feasibility of implementation with tangible, relatively short-term results.

Additionally, the alpine ecosystem and designated wilderness areas were chosen as a frame of analysis because alpine ecosystems are thought to be proxies of atmospheric change and climate change is already affecting ecosystem functions, and services. Wilderness areas have special protections and require unique consideration when deciding on the best methods for climate change incorporation into USFS management. This point is explored in Appendix 1.

The next chapter will introduce the necessary tools to revise the current USFS management framework. These tools will then be applied to the Arapahoe-Roosevelt National Forest Plan in Chapter 5, which will draw on the frames of analysis from this
chapter and address some of the principal shortcomings of the current structure. The goal will be to better-incentivize effective resource management and ensure that maintained ecosystem functions and services are the top priority for resource managers as they confront climate change.
Chapter 4:
Tools to Revise
4.1 Introduction

I have established the predominant threat to National Forest System (NFS) ecosystems posed by climate change (Chapter Two). I have also highlighted the principal constraints on effective resource management in the face of climate change as a result of systemic constraints embedded within US Forest Service (USFS) management structures (Chapter Three). I will now elucidate what tools must be employed to apply revisions to current USFS management structures. These tools will lay the foundation for a reformed management framework that will move the USFS closer to effective resource management in a time of drastic and uncertain environmental change.

Climate change not only poses an unprecedented threat to sustained effective ecosystem management by USFS resource managers, but it also poses a critical threat to the USFS management structure itself. The tools presented in this chapter will be applied to the forest-level of the USFS management structure to balance the feasibility of implementation and tangible results. I begin by introducing some key ideas inherent in broad theoretical ecological management paradigms, which will be infused into USFS structural changes. I explore the theory and practical application of an ecosystem-based management approach called adaptive management (AM) and its role in a new USFS management framework. Resource managers already employ many aspects of AM, but efforts must be more concerted, and some aspects of AM must be re-established in importance and application. While AM will act as a foundation for the new framework, it is in no way a panacea. As a result, I include a discussion of other necessary tools USFS
managers must adopt, including the role of more institutionalized collaboration and appropriate stakeholder engagement throughout all levels of the USFS organization.

Section 4.2 introduces the fundamental theory within the adaptive management ecological management paradigm as well as variations on AM that contribute important additions to foundational AM theory. Section 4.3 explores the practical application of AM and its various offshoots. Section 4.4 augments the lessons that can be drawn from AM with multi-dimensional collaboration as well as enhanced stakeholder engagement in management planning and implementation processes. Section 4.5 concludes the chapter.

4.2 Adaptive Management: Theory and Application

A new “ecosystem management,” or “ecosystem-based management (EBM)” approach to resource management was developed in the early 1990s for resource managers, policymakers, and scientists to more effectively address large ecological issues (Grumbine, 1994). Advocates called for a more holistic incorporation of “ecological, socioeconomic, and institutional considerations” where each is given equal roles and management responses are “not dominated by any one concern” (Groom et al. 2005, pp. 471). Some aspects of the EBM approach were developed much earlier. Elementary ecological management concepts—such as the idea that management needs of an ecosystem often cross jurisdictional or public-private land boundaries (Wright and Thompson, 1935)—were understood by scientists and resource managers prior to the 1990s. However, with a presidentially appointed Interagency Ecosystem Management Task Force established in 1995, the ecosystem-based management approach was codified as the underlying driver of policy planning and implementation processes for agencies
such as the USFS (Groom et al. 2005). Important contributions to the EBM approach came from the adaptive management approach to resource management, which has roots that stretch back much further than the presidential task force.

First with an article in 1973 and in more explicit detail with the 1978 book *Adaptive Environmental Assessment and Management* C.S. Holling proposed a new ecological management approach for resource managers. His foundational ideas have been refined and further developed by resource managers and scholars since the idea was conceptualized, however the fundamental message has remained the same. Foundational AM theory states that effective resource management can only occur when managers engage in iterative and systematic experimentation with management techniques to increase comprehension about the natural systems and their complex interactions (Holling, 1973 and 1978). A learning-by-doing approach to resource management is necessary to confront complex issues because of the existence of a vast uncertainty about ecological interactions in the natural world.

The paradigm emphasizes proactive management actions rather than conventional reactive responses to issues. Uncertainty about future changes to ecosystems are embraced rather than denied. Management is considered a dynamic continuous process as opposed to the conventional conception of resource management where a clear beginning and ending to planning and projects exists, and where management success is only attained when a project is completed and attention can move elsewhere. Unfortunately, many resource management issues, especially those related to climate change, do not have a clear beginning and ending. It is not possible to “finish” a management project
because of the interrelatedness of management issues. Management must therefore be conceived of as a continuous process.

In this section, I outline the foundational theories of adaptive management and subsequent variations on the underlying AM principles. Then, I discuss the practical application of AM techniques, as well as the primary hurdles to effective AM application. Adaptive management is a useful framework for USFS managers to apply to management planning and policy prescriptions. However, while AM provides necessary mechanisms to approach the threats posed by climate change, the scale of the issue is such that it will not be possible to look to AM as the only solution to managing resources in the face of climate change.

4.2.1 Adaptive Management: Foundational Theory and Modern Variations

Embracing the uncertainty about how ecological systems will change in the future—both dependent and independent of human actions—forms the basis of adaptive management.\(^{33}\) As C.S. Holling (1978) writes, “however intensively and extensively data are collected, however much we know of how the system functions, the domain of our knowledge of specific ecological and social systems is small when compared to that of our ignorance” (Holling, 1978, pp. 7). In other words, we can and must endeavor to increase our knowledge about the deeply layered interactions between ecological variables. However, the complexity of the natural world is beyond confined human comprehension. AM allows avoidance of counter-productive measures at the large,
system-scale through collaboration and by striving to increase the knowledge-base of the natural world with the acceptance of a permanent and unavoidable difference between our understanding of ecological interactions and those interactions themselves.

**Key Concepts and Distinctions**

Before applying the concepts inherent in adaptive management, it is necessary to define some principal concepts. Within the context of AM, I will define *uncertainty* as follows: There exists a certitude of future ecosystem changes, constant and/or sporadic, exogenous and/or endogenous, expected and/or unexpected, dependent on or independent of human actions, but whose specific outcomes vary from mostly to completely unknowable to resource managers in the present. Additionally, *complexity* as it will be used in the context of AM must be clarified. Complex systems must be considered beyond the bounds of human knowledge. Like uncertainty, we must conceive of complexity through a limited, finite human comprehension of characteristics of individual systems and relationships between systems. We must simplify the systems in order to create effective management plans, but overly simplistic models lack credibility (Holling, 1978), so finding a balance between simplicity and effectiveness is essential.

A central distinguishing factor between adaptive management and other ecological management paradigms is the definition of ecological *resilience*, which necessitates a discussion of ecological equilibria. The conception of equilibrium in natural systems is especially important when deciding how to effectively manage

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34 For principal resilience theorists, see Holling, 1996; Gunderson, 1999 and; Gunderson and Pritchard, 2002.
ecosystems, and AM differs from other socio-ecological approaches to resource management. Parallels have been drawn between conventional ecological management and conventional economics (Gunderson et al. 2002; Holling, 1996) where there is a belief that a singular and exclusive equilibrium state exists in an economic or ecological system.

However, adaptive management promotes the idea that systems do not naturally maintain a single equilibrium. Holling (1996) uses the phrase *engineering resilience* to characterize the traditional conception of ecological equilibria. It purports that ecological systems tend to exist close to a stable steady state when human actions are not affecting the systems. “*Engineering resilience*, then, is the speed of return to the steady state following a perturbation” (Gunderson et al. 2002, pp. 4). This notion of resilience does not, according to AM theorists, capture the true behavior and tendencies of ecological systems.

Rather, *ecological resilience* (Holling, 1996) “emphasizes conditions far from any stable steady state, where instabilities can shift or flip a system into another regime of behavior” (Gunderson et al. 2002, pp. 4). In other words, the system enters another stable domain with new unique characteristics (Holling, 1973). There are, therefore, potentially multiple equilibria within one system, or there can be an equilibrium that is characterized by wide ranges of natural variation and exogenous and endogenous shocks that create a very heterogeneous quality within the system. Heterogeneity, according to AM, is beneficial to the health of an ecosystem and should be desired (Rogers, 2003; Stalamans et al. 2001). There is a threshold, however, where shocks will be too great to be absorbed by the system and will cause the system to undergo a complete re-characterization. So, in
this case, ecological resilience “is measured by the magnitude of disturbance that can be absorbed before the system is restructured with different controlling variables and processes” (Gunderson et al. 2002, pp. 4-5).

Ecological resilience is a broader concept that attempts to fully capture the complexity inherent in natural systems. Those operating on the basis of engineering resilience tend to rely too heavily on models and a simplified, comprehensible, knowable world. “These approaches simplify the mathematics and accommodate the engineer’s drive to develop optimal designs…There is an implicit assumption that ecosystems exhibit only one equilibrium steady state or, if other operating states exist, that those states should be avoided” (Gunderson et al. 2002, pp. 5) because one equilibrium is easier to quantify and use as a target for management prescriptions.

Managing from an ecological resilience perspective puts emphases on ecosystem-scale interactions to define primary ecosystem function. The stability of an ecosystem, which should be maintained by management actions, results from the variability of critical functional variables. When this variability is reduced past a certain threshold, an ecosystem can flip from one organization to another (Gunderson et al. 2002), which can result in systemic collapse in the form of severe biodiversity loss at the regional scale or extirpation at the local scale. Thus, it is the dynamism in the system, not an inelastic static state that makes it “natural.”

Therefore, managing for ecological resilience is managing resources with the intent of maintaining or increasing the ability of the system to absorb shocks and to maintain vital functions. Adequate “resilience allows a system to withstand the failure of
management actions. Management is necessarily based upon incomplete understanding [of ecological interactions], and therefore ecological resilience allows” resources managers “the opportunity to learn and change” (Gunderson et al. 2002, pp. 6-7). It is easy to see how managers desire adequate resilience in ecological systems, but what practical steps are necessary to achieve adequate resilience? This will be considered in Section 4.2.2.

A final distinction that can be made is between passive adaptive management and active (or experimental) adaptive management. Both Anderson et al. (2003) and Gregory et al. (2006) find that adaptive management can take several unique forms. One is usually more advantageous than the other depending on funding and personnel resources or other institutional constraints. Passive adaptive management plans use available information to form management prescriptions from the start and then stipulate “future decision points where feedback and new information are analyzed” and incorporated into the plan (Anderson et al. 2003, pp. 205). This allows for flexibility of management structures depending on changing conditions, but it also encourages immediate action on an issue.

Whereas, Active (or experimental) adaptive management systematically experiments with various management options in “different places or at different times to test hypotheses about the system and management options as quickly as possible” (Anderson et al. 2003 pp. 5). The plan will outline a “learning period” on a five or ten year scale. Once the experimental learning period is completed, results are reviewed and the best management practices are applied more broadly throughout all applicable levels of management (Anderson et al. 2003).
Evolution and Transformations of Adaptive Management

There have been a number of ecological management paradigms that have been conceptualized within a broad AM framework but which often offer more explicit details how theory can be translated into practice. I will touch on the important aspects of several pertinent evolved products of AM to draw-out a more holistic management approach that can be applied to climate change and the USFS.

Other AM theorists, such as Kai Lee, have taken fundamental aspects of AM expanded upon them. First, according to Lee (1993), “adaptive management is ecosystemic rather than jurisdictional” (Lee, 1993, pp. 62), which is a necessary feature of any management paradigm in the face of climate change. AM focuses on holistic ecosystem function requiring managers to be rooted in inductive rather than deductive theory formation and policy prescription. Jurisdictional boundaries must be dismantled to ensure that management decisions are based upon ecosystem boundaries instead of political boundaries. This has been a central focus for those advocating for an ecosystem-based management approach, but efforts to date have not been sufficient.

Second, we must manage at the population- or ecosystem-level; the focus cannot be only on individuals within a given ecosystem. Lee argues that failures at the individual species-level need to be tolerated because risk-taking is necessary to maintain holistic ecosystem health. However, what individual species is lost remains important to holistic ecosystem function, because dominant and keystone species, for example, are more important to maintaining ecosystem function than other secondary species. Third, the management time-scale must be based on biological generation rather than business
cycles or a term of office (Lee, 1993 and 1999). There must be continuity in the type, structure, and timeframe of management prescriptions to ensure effective management policies.

Researchers such as Colfer (2005) and Buck et al. (2001) have utilized basic AM principles and attached them to collaborative management approaches and stakeholder engagement as a means for effective resource management. Adaptive collaborative management (ACM) takes the learning-by-doing idea and applies it to all stakeholders—beyond managers—and encourages participatory learning-by-doing of local communities and the public at large. Fostered involvement in policy planning and implementation ensures a long-term commitment to effective resource management. Buck et al. (2001) point to four major themes of the ACM strategy that “(1) proceeds in a learning process mode rather than according to a universal a priori blueprint; (2) considers errors, mistakes, and failures not in normative terms but as normal occurrences resulting from policy experiments; (3) engages both local and nonlocal stakeholders in a participatory process of goal setting, planning, management experimentation, and evaluation; (4) utilizes a variety of methods to generate knowledge that keeps pace with ecosystem change resulting naturally or from expanding human activity.”

Savory (1988) applied the ideas of “holism” (Smuts, 1926) to resource management, which he calls holistic resource management (HRM). Savory (1988) finds that scientists and managers are failing to perceive of the breadth of the natural world and all its intricately complex systems. Looking only at the “parts of the machine” is insufficient to harmonize ecological integrity and human benefits from ecological services because we fail to observe the “dynamic interrelationships that constitute its
being. Isolate any part, and neither what you have taken nor what you have left behind remains what it was when all was one” (Savory, 1988, pp. 26). Humans are living within the ultimate global experiment. It is not possible to remove humans and human-thought processes—inherently causing biases—from management decisions. Managers cannot fully control all variables if humans are part of the larger experiment.

This notion seems elementary, but the feasibility of a constant holistic view of the natural world is difficult when managers are faced with site-specific tasks and professional specialization in a narrow field. Yet, it remains important to consider the larger picture when prescribing any management policy, and collaboration is the key to achieving this. Climate change intensifies the interrelationships inherent between ecological variables. We must look both at individual interactions as well as system interactions to understand the effects of climate change on the natural world. Holistic resource management is necessary in the face of climate change because it reminds resource managers that micro-scaled analyses comprise larger macro-scaled trends and that both must be fully appreciated.

Another variation of adaptive management is integrated natural resource management (INRM), which provides a more anthropocentric view on managing resources for continued ecological services. The mechanism to achieve sustained natural resource stocks is through a multi-disciplinary collaborative approach. The aim, of INRM is “to integrate several disciplines and involve different stakeholders operating in their own subsystems across different spatial and temporal scales. These approaches focus on identifying management strategies for sustaining natural resource stocks and

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35 See Campbell and Sayer (2003) for an overview of INRM and various applications.
flows of goods and services as well as their underlying ecological processes” (Lal et al. 2002, online only, no page numbers).

Collaboration is necessary to prevent one perspective or discipline from dominating resource management decisions at the detriment to health of the system as a whole. For example, in a district on a national forest that has a strong timber industry, there could be a tendency to focus management decisions on maximum sustainable yields, which might be an efficacious management decision insofar as silviculturalists (tree scientists) are concerned, but the emphasis on timber could distract from other issues the district may be facing. The district might have a strong forest-science specialization but may lack a specialization in another necessary input to holistic ecosystem health such as the presence of a soil scientist or a social scientist analyzing different aspects of forest health and management. Interdisciplinary collaboration creates a more complete fabric from which to manage resources for holistic health and lessens the possibility of a major threat to ecosystem health going unnoticed. Despite the fact that INRM is based on a strictly anthropocentric management perspective, it still provides a useful conception of effective management for ecosystems more broadly.

The various evolved and modernized applications of AM outlined above create a fuller picture of the possible structural changes that can be applied to the USFS management framework in the face of climate change. I will draw out the appropriate aspects of each paradigm listed above (including AM itself) to apply to the ARNF Forest Plan in Section 4.4.
4.3 Practical Application of Adaptive Management and Sub-Paradigms

Adaptive management is cyclical in form and practice. The application of adaptive management to USFS management structures will require the adoption and maintenance of a continuous cycle of goal setting, data collection, analysis, monitoring and evaluation, and goal adjustment (See Figure 4-A below). Policies must be continually evaluated on soundness and utility and revised accordingly. The iterative processes of evaluation of existing goals, the incorporation of new findings, and the adjustment of goals—as well as the mechanisms needed to achieve those goals—pose challenges to overworked USFS resource managers facing tightly mandated funding. However, practical application of AM is possible if managers are encouraged and given incentives to design creative and cost-effective experiments to decipher the best adoptable management practices.

Application of fundamental AM theory will be largely the responsibility of high-level resource managers and policymakers providing incentive to lower-level managers to incorporate systematic and iterative experimental management techniques into existing duties. To accommodate for AM incorporation, collaboration between managers and specific delegation of tasks is necessary to promote the cyclical processes within AM.
Many USFS managers claim that basic adaptive management already underlies management decisions they make (Stankey et al. 2003) because the USFS mission is to manage resources sustainably. However, even if management decisions do incorporate aspects of AM, such as an emphasis on evaluation and monitoring, the full cyclical AM process has not been made explicit enough. Specialization and delegation of tasks within a collaborative framework is the most obvious path to overcome the hurdle of practical application of AM theory, which often has vague language. Specific delegation of
assessment responsibilities will be based on the skill-set of the manager: scientists begin collection and analysis of data, and at the same time, managers must initiate conversations with stakeholders and formulate background investigations into how user conflicts are likely to arise. They must stipulate specific goals that work to achieve the overarching goal: maintaining the health, functions, and services of NFS ecosystems. A landscape-level focus must then be delegated and categorized into local-level analyses. Local management goals must complement regional goals and care must be taken to ensure counter-productive actions are avoided throughout the process. For example, one local goal could conflict with a goal of an adjacent management area and as a result nullify the forward progression of management prescriptions. For this reason, clear communication throughout the collaborative process is necessary.

Deciding how to utilize passive vs. active adaptive management will depend on institutional constraints such as funding limitations and political opposition. With regards to USFS incorporation of AM, I propose that reformation of existing management structures must be based on both passive and active AM whereby a learning period is designed and a systematic experimentation framework is created (active). At the same time, AM techniques are implemented immediately (passive) founded on baseline datasets in existence for many basic aspects of NFS ecosystems such as water quality or phenology changes in sub-alpine forests.

An initial reformation of the USFS management structure will apply passive adaptive management. For effects of climate change already evident within NFS ecosystems, there must be immediate incorporation of AM into existing management plans at the local level in order to act expeditiously and prevent climate change-related
issues from growing out of control. Provisions, such as redefining the ways in which funding allocation is stipulated, must be created to enable fast response times. In the active AM stage of reform, larger management structures will be updated. Support for anticipatory actions will be embedded within the reformed management plans in order to bring attention to larger and longer-term issues. This will ensure issues that are likely to arise sometime in the near future, but whose effects are not of imminent concern or not sufficiently understood are still acknowledged in planning processes. One example could be the effects on alpine floral composition from the loss of permanent snow or glacier cover in certain areas. Research and systematic experimentation will be initiated immediately, and in a five- or ten-year period, the results will be incorporated into management plans and policies will be prescribed and goals readjusted.

Practical application of AM will require incentives for managers to shift management emphases away from conventional foci and most likely take on additional work. However, resisting AM incorporation will have dire consequences for managing resources effectively and meeting principal USFS management goals in a warming world. Making AM practical will require a concerted effort to establish and maintain collaborative relationships with all stakeholders, which will be the subject of the next section.

4.3.1 Concluding Thoughts on Adaptive Management

Adaptive management proposes many pertinent conceptions of effective resource management and while problems can arise when translating AM theory into practice (see Section 4.5) the foundational ideas must be incorporated into USFS management
structures. The goal of AM is to increase ecological resilience in ecosystems to avoid collapse of the system. This must be achieved through systematic, iterative experimentation to increase our knowledge of ecological variable interactions and foster a learn-by-doing approach to resource management. As data are collected and interactions are more clearly understood, managers can incorporate new information into management plans and therefore encourage flexible management plans based on changes occurring within ecosystems rather than on operation within predetermined organizational constraints. The complexity and uncertainty of future ecosystem changes are seen as an opportunity to learn and make anticipatory management decisions in the future, as opposed to conventional management frameworks, which rely on responsive actions and which fail to effectively address complex issues such as climate change.

Climate change poses new threats to ecosystems that may not be familiar to scientists and resource managers. AM provides a means of addressing such a wide-scale issue and must be embraced by managers throughout the USFS. The next section will build on AM to create a more comprehensive approach to effectively managing ecosystems in the face of climate change.

4.4 Collaboration and Stakeholder Engagement

Working in unison with adaptive management, concerted efforts promoting long-term collaboration are necessary for effective management of NFS ecosystems in the face of climate change. Collaboration, in this context, covers several things. First, collaboration refers to the sharing of and unhindered access to technical know-how, raw and analyzed data sets, research infrastructure such as specialized software or weather...
stations, and collection and analysis of field observations by stakeholders on the changes to ecosystem structure or health. Second, collaboration also brings together various stakeholders to participate in setting management goals and sharing responsibility for implementation of policies. It encourages partnerships and initiates dialogue between individuals to find solutions to ecological challenges. The goal of collaboration is to bring together varied specialties and expertise to form a coherent multi-disciplinary approach to resource management.

*Multi-dimensional collaboration (MDC)*, which encourages communication between high-level policymakers and lower-level managers in an attempt to share a wide range of perspectives concerning the effects of climate change on management processes, must be emphasized and fostered by the USFS. At the same time, MDC focuses on collaboration between the USFS and other institutions contributing to ecosystem management such as state divisions of wildlife and university research centers. Multi-dimensional collaboration refers to the inclusion of a wide range of diverse perspectives to find creative solutions to the complex issues posed by climate change. I use the term *multi-dimensional collaboration* to signify the importance of diversity in collaborative efforts—both in expertise and in motivating reasons for engaging in collaboration. MDC is multi-planar and multi-directional. It places the forest-level managers in the center of numerous dialogues. In a metaphorical sense, the forest-level managers are the hub of a wheel, connecting various peripheral stakeholders and providing feedback and translation between collaborative members. Their primary function is to bring together all stakeholders—from natural scientists, social scientists, policymakers to public landowners, or other individuals with a vested interest in maintaining the health of an
ecosystem—and facilitating dialogue in order to find creative ideas for effective management.

Stakeholder engagement refers to the encouragement of participatory learning-by-doing for all individuals and organizations interested in or required to monitor the health of ecosystems. A shared vision—the protection of vital ecosystem services, for example—and diverse and inclusive participation are the central parameters of effective collaborative resource management.

4.4.1 Collaboration as a Supplement, Not a Substitute

Collaboration and stakeholder engagement are centered on the fostering of shared values; they focus on networking motivated individuals and organizations to take a stake in long-term management plans to ensure ecological preservation. An extensive study by Wondolleck and Yaffee (2000b) examined the utility of institutionalized collaboration throughout various resource management processes. They found that collaborative “approaches must be treated as supplements—and not alternatives—to conventional decision making” (Wondolleck and Yaffee, 2000b, pp. 237). This is the case because it is important that senior officials retain mandated authority in order to ensure accountability for actions. However, if partnerships can be proactive and there is vested interest in a successful collaborative effort by “local champions”—be it policymakers, scientists, or members of the general public—then collaboration can result in both ecological benefits and streamlined management efforts (Imperial, 2005; Conley and Moote, 2003; Wondolleck and Yaffee, 2000b, pp. 178). If constructed successfully these collaborative efforts can extend across jurisdictional or geographic boundaries. Finally, voluntary,
deliberate professional relationships between managers are necessary for successful long-term collaborative resource management.

As most would agree, collaboration within resource management structures is not a panacea for all management issues (Imperial, 2005; Wondolleck and Yaffee, 2000a, 2000b), but it can augment key organizational processes and is necessary within all adaptive management applications. Achieving successful collaboration can be challenging, however. Many resource managers are dissuaded from engaging in strong collaborative inter- and intra-organizational relationships because if duties and responsibilities within the relationship are not delegated clearly, there is a potential for the relationship to fall into decay and eventually collapse. This can occur because collaborative management actions can incur substantial upfront costs (Imperial, 2005) and distract organizational resources from existing projects or planning processes if initiated improperly.

Wondolleck and Yaffee (2000b) outline five steps that are necessary for successful resource management collaboration. First, it is necessary to collect high quality baseline data and information on the management issue being addressed. Second, the organization—such as the USFS—and leaders of the task force initiating the collaborative approach must “mobilize and develop capable people from a spectrum of interests at an appropriate geographic scale” (Wondolleck and Yaffee, 2000b, pp. 247). Third, these individuals must be provided opportunities for interaction and incentives to find creative solutions to the issue being addressed. Encouraging creativity will result in more tangible immediate results. Fourth, the individuals must be enabled to “implement solutions in a way that mobilizes resources, shares ownership, and moves adaptively to a
future that will be characterized by changes in values and knowledge” (ibid). Therefore, it is vital to include high-level officials as well as lower-level managers in the collaborative process to give legitimacy to recommended policy adjustments. Similarly, there must be strong institutional support to ensure that adequate organizational resources are provided to set precedents that collaboration can work and will yield positive results.

4.4.2 Enhancing Avenues of Communication

With regards to climate change and NFS ecosystems, collaboration must include individuals and organizations from a wide range of disciplines and expertise. Policymakers must initiate and maintain constant discourse with research scientists—both those directly studying the effects of climate change on NFS ecosystems as well as those performing more general climate research such as climatologists and hydrologists—to remain up-to-date on expected climatic and ecosystem changes.

This will require new and strengthened relationships between USFS managers and university research centers, non-governmental organizations (NGOs) such as the Nature Conservancy, inter-governmental organizations (IGOs) such as the United Nations Environment Program, state agencies such as a state’s division of wildlife, and other federal agencies such as the US Fish and Wildlife Service (USFWS) and US Geologic Survey (USGS). Including public participation in planning processes and utilizing volunteers for observational data collection is also vital to effective resource management in the face of climate change. Strong stakeholder engagement has shown to result in sustained ecological health and has helped to build durable private-public relationships if
initiated properly with clear goal and responsibility delineation and task delegation (Theobald and Hobbs, 2003).

Collaboration and stakeholder engagement have a critical role to play in effective USFS resource management. USFS efforts to foster collaboration and public participation in the past have been met with mixed results (Imperial, 2005). Many managers carry out effective collaborative efforts with existing institutional incentive structures, but there must be a greater emphasis placed on deconstructing jurisdictional barriers within resource management agencies. Clear and concise communication from high-level managers must emphasize the need for strong inter- and intra-agency relationships. The results of experimental AM techniques must be made readily available to managers and other individuals who can take action to build resilience within ecosystems and maintain vital functions and services. Collaboration can be interpreted vaguely when applied to a federal resource management agency such as the USFS. The USFS has four distinct management levels, all of which have unique roles. The structure is designed to encourage efficient planning processes and field implementation, however, communication between each level must be clearer. Dialogue between policymakers and managers must be maintained to measure progress towards implementing effective adaptive management prescriptions.

Constructive public participation in planning and implementation of management decisions has been mired by the organizational constraints within the USFS, as discussed in Chapter 3, Section 3.2. As a result, many managers have a negative view of strong collaborative efforts with other institutions and individuals and are reluctant to utilize the potential pool of resources within concerted stakeholder engagement (Koontz et al. 2004;
Wondolleck and Yaffee, 2000b). They are overwhelmed by a potential for up-front costs such as the required time and funding commitments for public outreach and the addition of responsibility to existing workloads. Also, many managers are wary of the potential for failure. In fostering collaborative efforts, they are spreading out the potential of failures in goal achievement to a greater number of people (Wondolleck and Yaffee, 2000b). Some believe the potential of small-scale failure spread out over numerous people will translate to total project or goal failure; if one link in the chain breaks that the entire chain will break apart. However, research has shown that these fears are mostly unfounded (ibid.). In reality, one broken link in the chain will not necessarily result in a failed project or partnership. Rather, it can be part of the learning process and strengthen partnerships and future collaborative efforts. When specific precautions—regular review of the relevance of goals, for example—are taken by leaders of collaborative efforts, the benefits of collaboration outweigh the costs. Again, clear communication and delegation of tasks is necessary for successful multi-disciplinary collaboration.

4.5 Conclusion

The role of multi-dimensional collaboration and stakeholder engagement is vital to successfully managing NFS ecosystems in the face of climate change. Implementing adaptive management techniques requires clear communication between managers and other stakeholders on mechanisms for achieving management goals. Productive and lasting relationships—both between individuals and between institutions—are necessary and should be prioritized by USFS managers. Collaborative efforts build on a foundation
of adaptive management techniques and one requires the other to achieve effective management.

In this chapter, I have provided both the theoretical and practical applications of adaptive management (AM) and introduced multi-dimensional collaboration and its role in the USFS management structure. Additionally, I argued for increasing stakeholder engagement to break through jurisdictional boundaries between other federal and state agencies as well as private landowners. Also, I provided mechanisms designed to overcome principal organizational constraints within the USFS. It is imperative these tools are applied to forest-level management structures to ensure ecosystems are managed effectively. Specific application of these tools will be the focus of the next chapter.
Chapter 5:

Applications and Revisions
5.1 Introduction

In this chapter, I utilize key concepts presented in previous chapters to recommend revisions to the Arapaho-Roosevelt National Forest (ARNF) Forest Plan. These revisions lay a foundation for US Forest Service (USFS) resource managers to more effectively manage ecosystems in the face of climate change. The previous chapter introduced necessary tools managers must employ as threats to ecosystem functions and services become clear. These tools include the more specific application of adaptive management (AM) techniques as well as the implementation of what I term *multi-dimensional collaboration* and stakeholder engagement.

The analysis in this chapter leads to the conclusion that the continued reliance on a management framework designed on the basis of responding to issues after they arise is insufficient in the face of rapid climate change. Instead, I advocate an approach of proactively confronting emerging resource management issues. It is necessary for the USFS to reform their current management framework in order to better incorporate the challenges posed by climate change into policy prescriptions and management plans.

In this chapter, I propose revisions based on each step of the adaptive management cycle outlined in the previous chapter (See Figure 4A). There are six vital steps in the AM cycle; each step coincides with revisions to the current management structure on the ARNF. Additionally, I apply changes based on the need for more effective and extensive collaborative efforts between all stakeholders. The principal revisions proposed below include the creation of a forest-level climate change task force, adjustments to the review period for management goals, better incorporation of
volunteers and other stakeholders in data collection and ecosystem monitoring programs, the expansion of research natural areas (RNAs), and creating a framework for specific delegation of tasks to harmonize collaborative efforts.

I also discuss the principal impediments to the proposed changes outlined in this chapter. I argue that despite such impediments, it remains critical that the USFS adopt these revisions. The complexity of the issue of climate change and the organizational constraints on USFS management will not be fixed overnight, but there are initial steps that can be taken immediately to ensure that management policies reflect a concerted effort to achieve effective resource management and achieve tangible results. Finally, I discuss these proposed revisions in the larger context of climate change and USFS resource management. I emphasize the importance of prioritizing climate change as the most pressing and consequential issue facing the USFS.

Section 5.2 facilitates the application of the new framework to the ARNF Forest Plan. In Section 5.3, I provide a discussion of the principal impediments to the widespread dissemination of this new framework and the justification for implementation despite these impediments. Section 5.4 extrapolates the results of this paper to broader contexts. It also summarizes the lessons that can be learned from the scope of analysis presented here and the motivating questions underlying this paper. Further research is needed to augment the lessons that can be drawn from this analysis.

5.2 Changes to the Arapaho-Roosevelt National Forest Management Plan: A Revised Forest Plan

Changes to the language and managerial emphases within the Arapaho-Roosevelt National Forests (ARNF) Forest Plan are necessary to effectively manage its ecosystems
in the face of climate change. These revisions must incentivize resource managers to incorporate adaptive management (AM) into USFS policy planning and implementation. The changes must also encourage a stricter interpretation of overarching USFS mission statements and the laws governing USFS management activity. Policies must specifically address climate change and language must be made more explicit.

The ARNF Forest Plan outlines principal management issues and desired directions for USFS managers to follow. The Plan is updated every 10-15 years. The ARNF Plan was last updated in 1997 when effects of climate change were less visible in National Forest System (NFS) ecosystems. Vital changes to the Plan include more explicit language highlighting the importance of climate change to ecosystem health, the need for adaptive management underlying each decision made on the ARNF, and a framework for encouraging multi-dimensional collaboration.

5.2.1 Emphasizing Each Step of the Adaptive Management Cycle

In this section, I incorporate each step of the adaptive management cycle (See Figure 5-A below) into the ARNF. All steps are inextricably linked in purpose and function, however it is necessary to highlight each individually before considering them as a whole. The first step in the AM cycle is goal setting. Goal setting for desired ecological conditions exists within the current ARNF Forest Plan, however current structures of goal setting will not suffice when confronting climate change and incorporating AM into USFS management. This is the case because under the current USFS goal setting procedures, lower-level managers lack sufficiently clear direction and guidance from senior managers. Communication between managers must be made more
explicit with regards to climate change, especially as managers are expected to draft goals for their respective management unit.

**Figure 5-A)** Modified from Stankey et al. 2006: Reprinted from Chapter 4. The management cycle inherent in adaptive management. This figure highlights the continuity and iterative processes required to encourage a flexible management structure needed in the face of climate change. There are six principal steps outlined in the AM cycle.

Therefore, to improve goal-setting procedures, the ARNF must create a forest-level climate change task force whose purpose will be to review ecological threats and formulate recommendations on policy prescriptions at the forest- and district-level. Each district will have a representative on the task force. This individual should have a science background (i.e. the district wildlife biologist) and be able to express the concerns and perspectives of their respective district. This task force will synthesize findings by
research conducted on the ARNF and create policy proposals for forest-level managers. They will also provide approval for experimental management techniques performed on the ARNF when questions of multiple-use conflicts may arise. The task force will be responsible for proposing goals and ensuring those goals are reviewed on a consistent basis. I propose that primary goals be reviewed every two years, instead of the normal five or ten year period that most management goals in the ARNF Forest Plan are reviewed. The dynamism inherent in climate change requires constant updates to goals and the mechanisms designed to achieve those goals.

Natural variation in ecological systems has the potential to challenge perceptions of goal achievement, especially as systems are undergoing drastic alterations from climate change. A two-year review period could—as a result of natural variability—make it difficult to decipher ecosystem health trends. However, a short review period will ensure drastic ecosystem alterations do not go unnoticed. This would lessen the risk for consequential positive feedback loops or small-scale collapses in ecosystem integrity because actions can be taken before the issue grows to large to confront effectively. Constant review and tests of relevance for both management goals as well as the means to achieving those goals is necessary as ecosystems face far-reaching alterations. Larger, longer-term management goals will retain a five or ten year review period to account for the long time scales associated with the effects of climate change and the long-term commitment on climate change as an emphasis for USFS managers.

The second step in the adaptive management cycle is data collection. Since data are lacking on local trends in ecosystem responses to climate change and baseline data are needed to mark future changes, I propose a forest-level program that utilizes
volunteers and private partnerships to collect observational data on key aspects of NFS ecosystems. The data collected will be used to establish baseline information on species composition, richness, and extent. Each district should hire an individual who will be a volunteer-coordinator and science technician responsible for overseeing data collection projects on his or her district. This technician will then collate all the raw observational data and distribute them to scientists at the forest-level. These scientists will analyze the datasets and use them as a basis for making decisions on management experiments and policy recommendations. Meta-analyses can be performed on datasets from the entire forest to decipher forest-wide trends in changing ecological interactions. These results will be utilized by the forest-level climate change task force to guide policy planning processes.

The Colorado Division of Wildlife already collects data on species populations in this manner; volunteers perform basic tasks and generate purely observational data that is not the result of perfectly designed and controlled scientific experiment, but which can still show trends and establish a baseline of ecosystem composition and behavior. Involving the public in data collection establishes a closer relationship to NFS resources and this could help build a constituency for effective management. Large observational datasets will create more work for analysts, but are necessary to establish trends in ecosystem changes, and instead of a complete reliance on the small number of trained ecologists in a district to collect baseline data, interested members of the public can be utilized. The model used by the Colorado Division of Wildlife must be applied and expanded to the USFS. As an example, volunteers could measure the elevation of current treeline to establish if and by how much treeline is moving uphill as a result of warmer
temperatures and longer growing seasons. The ARNF can utilize existing agency relationships with NGOs to collect observational data. Organizations such as Wilderness Volunteers or the Rocky Mountain Youth Corp provide volunteers the opportunity to work with agencies such as the USFS to restore habitat, construct and maintain trails, and clean high-use areas. Relationships with such organizations should be expanded to collect observational data and provide a more complete picture of changes in ARNF ecosystems.

The third step in the adaptive management cycle falls directly in line with the data collection described above. Analysis of the data must be specifically delegated to ensure efficiency and quality. The results obtained from analysis of both observational data and data derived from experimental AM techniques (see below) must be consistent and able to be extrapolated to larger spatial scales to decipher trends. The methodologies for research throughout the forest must be consistent to create larger forest-wide trends. Localized analyses are important in creating a larger mosaic of ecosystem changes, and while localized effects will be unique and often hard to extrapolate to the forest-level, it remains necessary to establish general trends within ecosystems in order to provide justification for policy creation and direction to lower-level managers. This will require concerted collaboration between analysts and clear communication between all levels of management. It will also be important for USFS analysts to collaborate with non-agency analysts such as those working on the Niwot Ridge Long-Term Ecological Research site (NWT-LTER) and with other state (division of wildlife) and federal (US Fish and Wildlife Service) agencies to streamline analyses and maintain consistent methodology.

The fourth step in the adaptive management cycle is the evaluation of management techniques and prescribed policies and the monitoring of any impacts
management decisions have on resources. The ARNF must operate on a framework of regular and detailed evaluation of the efficacy of management decisions in the face of climate change. The mechanisms for evaluation must be made explicit in the Forest Plan. This can be achieved by reviews of primary goals every two years and detailed reviews every five or ten years. A two-year review period will ensure drastic changes to ecosystem health do not go unnoticed. Monitoring and evaluation results must be immediately incorporated into management plans and affect management actions. Engaging the public in the planning processes from the beginning will ensure the results from evaluations are incorporated quickly. If stakeholders feel as if they are included in processes from the start, post-planning process litigation will be cut down (USDA Forest Service, 2002). A shorter review period is necessary despite an obvious increase in workload. Monitoring of resources can coincide with data collection on ecosystem health. Data collection methodology should allow for both monitoring of ecosystem health as a result of management actions, and at the same time, measuring ecosystem health as a function of climate change.

The fifth step in the adaptive management cycle is the incorporation of new information on ecosystem changes and interactions, new technologies, results from evaluation and monitoring programs, and feedback from collaborative efforts into management planning processes. This is also an important step whereby stakeholders can feel as if their voices are being heard by USFS managers, and as such, the USFS must encourage stakeholders to provide feedback and new information on ecosystem health. As the effects of climate change become more quantifiable, it will be necessary to provide mechanisms for incorporation of new data into existing datasets. Future results
can be compared to baseline datasets to distinguish where changes are occurring. This information must affect project plans and focus the attention of managers to where it is most needed. For example, if the effects of climate change cause a drastic decline in the population of an indicator species, the information must be given to managers who can implement measures to address the decline. This again shows the importance of shorter review periods and the promotion of flexibility in management emphases.

Also, the incorporation of new information must affect policymaking and management decisions to ensure that actions are taken based on the most up-to-date data and available technologies. For example, as higher-resolution ecological modeling software is developed, USFS managers must harmonize management actions with results from the most recent modeling results for a particular area. This will require concerted collaborative efforts between USFS research stations, other resource management agencies, and universities researchers to share the costs associated with new technologies and analyzing datasets.

It will be necessary to then use the new information to formulate updated and more useful policies to effectively manage ecosystems, the sixth step in the adaptive management cycle. The implementation of more relevant policy prescriptions will result from the inclusion of new information as it becomes available, and it will be the responsibility of managers to translate new management and ecosystem needs to policymakers. Implementing updated policies must be accounted for in the Forest Plan. Mechanisms to foster efficient policy revisions should come from the forest-level climate change task force, who will review findings and recommend to forest-level managers necessary adjustments. These adjustments must be pushed through impact assessment
processes quickly, and therefore, they should be regarded as policy revisions instead of as entirely new policies to speed implementation procedures. Impact assessments serve an important purpose: to ensure negative consequences of new management actions are caught before a project is implemented, but often the impact assessment processes are cumbersome to the point that goals are compromised. Including stakeholders throughout the revision process will cut down on the potential for litigation after the impact assessment is released. Litigation lengthens impact assessment processes, so less litigation will allow for more efficient management adjustments in the face of climate change. Finally, revisions will be reviewed with other primary goals on a two-year basis and overhauls to policies—as opposed to adjustments—can be made after such reviews.

The final step in the adaptive management cycle connects back to the first step of goal setting. Primary management goals must be updated as a result of the cycle and reestablished. Then the cycle will start again in a continuous process of data collection, analysis, review, policy implementation, and policy and goal adjustment. The AM cycle is designed to promote continuity in management processes. The cycle allows for and encourages updating management techniques and goals as changes occur to both ecosystems and the way they are managed. The cycle increases the need and capacity for collaboration. With the AM cycle more clearly embedded within the ARNF Forest Plan, it is necessary to explore the means for managing ecosystems more effectively in the face of climate change.
5.2.2 A Framework for Experimentation

Once climate change is explicitly established as the predominant threat to ARNF ecosystems in the Forest Plan, specific guidance on techniques designed to maintain ecosystem integrity must be given to resource managers. The ARNF must provide mechanisms to encourage systematic iterative experiments on the forest. This must occur within three steps. First, the ARNF must expand experimental programs in the Fraser Experimental Forest (see Chapter 3, Section 3.4.1), which can generate a greater amount of baseline data on ecosystem changes. The expansion of the experimental forest program is possible without drastic funding increases if the priority is placed on research examining climate change signals such as phenology shifts and establishing key changes in ecological variable interactions. Changes in species-species interactions as well as abiotic-species interactions are vital to understanding the role of management prescriptions.

Second, research natural areas (RNAs) must be expanded. These management units provide baseline data on a number of different ecosystems within the ARNF. Scientists at the USFS Rocky Mountain Research Station (RMRS) coordinate research projects exploring key ecological processes. Expanding the RNA network must be a priority in the ARNF Forest Plan because these areas provide high quality data. Under this system, acres are set aside for research purposes only, which can mitigate the effects of other stressors on ecosystems such as recreation. Controlling for more variables will yield better data and create a more detailed picture of current and probable future changes to ecosystems. RNAs are also easier to approve and establish than new wilderness areas, which have similar research qualities, but require congressional approval and lengthy
administrative proceedings. RNAs are not designed to preserve large areas on national forests, rather, they are small (generally less than 1000 acres) and serve the specific purpose of scientific inquiry. As a result, RNAs do not generate the multiple-use tug-of-war between stakeholders that wilderness areas do. Each is important, and each serves a unique purpose.

Third, expanded partnerships between RMRS and existing ecological research stations maintained by other institutions are necessary to incorporate adaptive management into the ARNF Forest Plan. Climate change science is a popular research focus and collaboration between the RMRS and universities, for example, can lend shared fiscal resources and datasets, increasing analytical efficiency and making regional trends more easily discernable. The NWT-LTER and RMRS must work more closely and the results of this relationship—namely larger baseline datasets and a better understanding of changing ecological interactions—must be translated into policy at the forest level.

The mechanism underlying each of these expanded programs or partnerships is an emphasis on iterative experimentation with management techniques. Expanding the network of ecological research sites requires a greater number of field-going personnel collecting data and more scientists analyzing those data. More data allows for a better understanding of ecological interactions, but the most important link in this chain is creativity in experimentation and management prescriptions. Once baseline data are collected, managers must establish a list of the greatest local threats to ecosystem functions and services and sort them into a basic hierarchy. Then, hypotheses must be tested for how management options are likely to affect ecosystems—for better or
worse—to establish a framework for experimental management prescriptions. Experiments must be carried out at the local level and then examined for usefulness in achieving overarching goals and efficiency. If deemed successful, then they can be applied on larger scales and recommended for forest-level implementation. I recommend that initial data collection and experimentation occur within the alpine ecosystem where changes are already clearly discernable. Alpine ecosystems are an early-warning signal for drastic environmental change, and while we understand some important ecological interactions, there is much more to be learned in order to make useful management decisions.

Resource managers must prioritize management needs and create a hierarchy of actions designed to promote efficient responses to changing ecosystems. Millar et al. (2007) suggest that initially, a triage approach to managing resources will be required to address the effects of climate change most likely to disrupt ecosystems. Longer-term management hierarchies must also be established immediately and consistently updated as the effects of climate change on ecological interactions are more clearly understood. A list of services and functions most at risk to climate change must be formed and updated on each district. A forest-level compilation of the district lists will highlight hotspots and allocate project funding based on the assessed hierarchy of needs. The forest-level list hierarchy will delineate trends and link local and regional effects.

Mechanisms to facilitate useful revisions to the ARNF forest plan are strongly linked to the ability of resource managers to confront threats to ecosystem functions and services with creative experimental designs to increase our understanding of ecological interactions. These experiments must also be designed to ensure there are no negative
consequences associated with experimental management techniques. Therefore, iterative experiments must be controlled, a process that will require time and effort. To keep iterative experiments efficient, it is necessary to augment them with a substantial amount of observational data and concerted collaborative efforts. Collaboration, as will be discussed below, is the hub that brings the various aspects of effective resource management together in the face of climate change possible.

5.2.3 Collaboration and Stakeholder Engagement on the Arapaho-Roosevelt National Forest

A framework for multi-dimensional collaboration (see Chapter 4, Section 4.3) must be made more explicit in the ARNF Forest Plan. Collaborative efforts thus far have been mostly ad-hoc and the result of motivated individuals rather than an institutional emphasis. Forest-level managers must foster clear avenues of communication between other levels of management in the USFS. Forest-level managers are in a position to be at the center of both agency and non-agency collaborative efforts because of the management scope of the national forest (NF). A NF balances local and regional perspectives. The ARNF must utilize its position to create effective and efficient collaborative efforts. The RMRS and the scientists at the NWT-LTER are in a unique position to share know-how, and raw and analyzed data sets. Such opportunities are possible if managers and policymakers are willing and able to utilize the results of collaborative research projects. This will require them to focus on effective stakeholder engagement throughout planning processes to speed environmental impact assessments and avoid time-intensive and costly multi-use litigation. Inclusion of public and private institutions in USFS management planning is essential to effective resource management in the face of climate change.
The most fundamental revision to ARNF management is the need to create incentives for managers to collaborate. This will require dismantling institutional barriers to explicit communication and delegation of tasks. Modern technology such as Internet networking has provided the opportunity for data dissemination to occur at much lower costs and in less time. Arapaho-Roosevelt National Forest scientists must utilize shared online databases and networking potentials with all project planning and implementation processes. Delegation of tasks across jurisdictional boundaries will cut costs and yield management decisions that more effectively utilize available data and technology. Cross-jurisdictional collaborative efforts are vital to addressing the complexity and scale of climate change and these barriers must also be dismantled.

5.2.4 Concluding Thoughts on Revising the Arapaho-Roosevelt National Forest Plan

The Arapaho-Roosevelt National Forest Plan requires revision to address the threats posed by climate change. The Forest Plan sets the tone and the methodology of resource management on a NF. Without explicit inclusion of climate change into the Forest Plan, it will not be possible to effectively manage resources in a time of rapid environmental change. I argue that the ARNF must incorporate and emphasize the adaptive management cycle, multi-dimensional collaboration, and stakeholder engagement within the Forest Plan. The proposed revisions are necessary, however they will certainly present unforeseen hurdles the USFS will have to confront, which will be the subject of the next section.
5.3 Overcoming the Principal Impediments to the Proposed Revisions

The adjustments to USFS management structure outlined above are necessary in the face of rapid climate change. There are, however, basic impediments to the proposed changes that must be overcome. Despite the existence of several important impediments to the implementation of proposed changes, adjusting USFS management structures is still necessary. Steps must be taken immediately to implement the proposed changes. The greatest shortcomings of adaptive management, multi-dimensional collaboration, and encouraging increased stakeholder engagement are rooted in the scale of climate change. The other principal impediment—which is often cited as the greatest hurdle to effective actions by many federal agencies including the USFS—is insufficient government funding.

The scale of climate change is unmatched in the history of resource management. It also presents management issues of unrivaled complexity. Adaptive management operates on the principal of embracing complexity in management techniques; however the scale of climate change has the potential to overwhelm managers with such vast complexity and breadth. In previous applications of AM, managers have utilized the paradigm in confined geographic areas or with a single threat. However, isolating threats from climate change can be difficult (or impossible) and therefore, employing AM in this fashion may not work. Instead, AM must be applied at local, individual-variable scale when possible, and more evenly at larger scales, such as the forest-level.

The literature applying adaptive management to climate change is so far incipient. Finding the right scale of experimentation to obtain useful results is challenging. Also,
opponents of AM cite the difficulty of keeping costs low and the potential for political backlash for perceived failures throughout the management processes (McLain and Lee, 1996). Effective collaboration and a more holistic management perspective are necessary to overcome these challenges. Some (Bormann et al. 2007; Alan and Curtis, 2005) cite confusion over goals and the definition of success in management projects as a major problem with AM when applied at larger scales. Again, clear communication between low- and high-level managers and cross-jurisdictional delegation of tasks are necessary to overcome these hurdles.

The other principal impediment to the proposed changes to the USFS management structure outlined above is a lack of funding. While increased funding for projects to address the effects of climate change on ecosystems would be beneficial, the reality is that funding levels for project-level design and implementation are unlikely to see drastic change in coming years. The Obama Administration has signaled its intent to increase funding for the Forest Service (Lindsey, 2009), however the USFS must plan to manage ecosystems within realistic funding scenarios. Collaboration—especially with other public and private institutions—is a way to keep costs low and attain effective resource management. Costs incurred as a result of AM experimental techniques and upfront costs to collaborative efforts must be viewed in longer timescales and beyond political terms of office and appointments. Instead, costs must be considered and judged on the basis of long-term projects designed to continuously manage ecosystems on a decadal scale.

New programs and projects to address climate change will strain existing budgets, which is why collaborative efforts with private organizations are so important. The role
of volunteers on national forests will become more important when the USFS confronts the challenges posed by climate change. Increased labor resources are necessary to monitor ecosystems and implement new management techniques, but a greatly expanded USFS workforce may not be possible, requiring volunteers and partnerships with other organizations to augment the existing USFS workforce. New and unforeseen costs are certain, but the costs of inaction are likely to be much greater. The proposed changes outlined above will stress USFS budgets, but emphasizing climate change in funding allocation is a necessity. Collaboration is the main avenue to overcome funding limitations with such a widespread and complex issue.

5.3.1 Concluding thoughts on the Revised Forest Plan and the Principal Impediments to Implementation.

This section employed the tools presented in Chapter 4 to revise the Arapaho-Roosevelt National Forest Plan. I applied these tools to provide an example of the mechanisms needed to effectively manage ecosystems in the face of climate change. While there are impediments to applying these techniques to the USFS management structure, the benefits of doing so far out-weigh the costs. It is necessary for the USFS to adopt these changes immediately to confront climate change effectively. Inaction will threaten the health of vital ecosystem functions and services.

While the proposed changes are not a cure-all, they are necessary first steps. More research is needed to fully address the organizational constraints within the USFS management structure to ensure ecosystem functions and services are maintained in a time of rapid environmental change. Also, deciphering how to best open avenues of
communication between other agencies must also be examined by USFS managers and standardized for universality.

5.4 Conclusion: This Paper in a Larger Context

Broadly, this paper has accomplished four things. First, it argued that climate change poses an unprecedented and far-reaching threat to ecosystem functions and services and to the way those ecosystems are managed by the USFS (Chapter 2). Second, it examined the USFS management structure and dissected exactly where constraints to effective ecosystem management in the face of climate change exist (Chapter 3). Third, it introduced the tools—namely the more salient aspects of adaptive management as well as the specific application of multi-dimensional collaboration—that must be utilized to encourage adequate flexibility in forest-level management structures (Chapter 4). Finally, it employed these tools and created a management structure that is better equipped to facilitate effective ecosystem management as the climate is changing (Chapter 5).

The USFS has made efforts to show an investment in addressing the challenges posed by climate change,36 and a greater managerial emphasis on climate change is likely to increase as the effects become impossible to ignore. The perspective outlined in this paper was from a forest-level analysis. Implementation of revisions to management structures must occur at every level of the USFS, however. There must be a similar analysis of organizational constraints and mechanisms to overcome those constraints at the national level and regional level. District-level managers must be given specific

36 See USDA Forest Service, 2009a; 2009b; 2009c; 2009d for the most current activities of the USFS to confront climate change.
directions from managers at higher levels as well as an opportunity to provide on-the-ground input to policymakers adjusting current management structures.

Additionally, guidance must come from the Secretary of Agriculture (the USFS’s parent department), Congress, and the President on how to prioritize climate change-related management issues. This will require analyzing current budget allocations for emerging issues and adjusting them to reflect the importance of climate change in all aspects of USFS management. Increased funding is necessary. A national media campaign is also necessary. Every member of the public is a stakeholder in effective resource management, and as such, they must be educated about climate change issues and contributions they can make to agencies such as the USFS in addressing climate change.

The scope of this analysis is limited. More research is needed to expand the scope to provide a more complete picture of necessary changes to management structures of resource management agencies more broadly. In other words, additional resource management agencies—such as the National Park Service and Bureau of Land Management—must utilize a similar analysis to examine their own management structures and decide how climate change will be addressed. Then, each agency must coordinate efforts to dismantle jurisdictional hurdles in effective resource management. Similar analyses must also take place within state agencies such as natural resource departments and divisions of wildlife.

The proposed revisions in this chapter are generally applicable to other agencies, but each agency must have specifically tailored proposals to ensure changes are
appropriate. For example, the creation of a climate change task force within the agency should be something all resource management agencies initiate, however the management level most appropriate for facilitating the task force will differ between agencies because of, for example, the size of management compartments. Eventually, each level of management within resource management agencies should have some form of a climate change task force, but deciding where the initial implementation of a task force will differ depending on the agency.

The problem is clear. Climate change is likely to impair current USFS management mechanisms resulting in threatened ecosystem functions and services. This paper provides a foundational framework for adjusting USFS management structures to effectively manage ecosystems in the face of climate change. This analysis must be built upon and further refined to provide a comprehensive framework for USFS management in a time of rapid environmental change and uncertainty. As USFS managers formulate a plan for addressing climate change, I hope they will be able to use the ideas presented in this analysis to get started and begin more complex review processes.
Appendix: The Special Case of Designated Wilderness Areas
A.1 Introduction

This paper has laid a foundation for accepting the challenges to effective resource management posed by climate change and created mechanisms to overcome those challenges. The US Forest Service (USFS) is responsible for managing several categories of public lands. One of the more prominent designations is a wilderness area. These areas are protected by special laws and require different management techniques than standard USFS lands. Climate change poses unique threats to wilderness areas, both to the ecosystems within the designated wilderness areas and to the way those ecosystems are managed by the USFS.

In this appended chapter, I explore the effects of climate change on wilderness areas. It is necessary to approach the effects on wilderness ecosystems with a unique set of parameters. I shed light on what these parameters are and why the case of wilderness areas is different. I argue there are three principal perspectives managers must consider when deciding how to effectively manage wilderness ecosystems in the face of climate change. There are moral, political, and ecological concerns that pose important questions about effective management.

Section A.2 shows how wilderness areas have a unique role in the USFS management structure and require a special framework for addressing the effects of climate change. Section A.3 explores the moral questions raised by climate change and wilderness areas. It also looks at the political and ecological considerations that must be addressed by wilderness managers. Finally, I conclude in Section A.4 by showing how threats to wilderness connect with larger USFS resource management goals.
A.2 The Wilderness Designation: Obstacles and Opportunities

Congress passed the Wilderness Act in 1964, which established the National Wilderness Preservation System. The act was passed on the following principle:

In order to assure that an increasing population, accompanied by expanding settlement and growing mechanization, does not occupy and modify all areas preservation and protection in their natural condition, it is hereby declared to be the policy of the Congress to secure for the American people of present and future generations the benefits of an enduring resource of wilderness. (*Wilderness Act, 1964, Sec. 2(a]*)

Designated wilderness areas were defined explicitly in the act as such:

A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean in this chapter an area of underdeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value. (*Wilderness Act, 1964, Sec. 2(c]*)

Agencies such as the USFS were given the task of protecting designated wilderness areas from the negative effects of human actions. When considered in the context of climate change, the wilderness law has been broken. Human-induced warming of the planet is resulting in the alteration of wilderness ecosystems and disrupting the “primeval character” of wilderness (Cole and Landres, 1996). The Wilderness Act was drafted to protect ecologically, physically, and aesthetically significant or unique areas so
that “the imprint of man’s work [be] substantially unnoticeable.” Yet the burning of fossil fuels—often hundreds or thousands of miles away—is directly resulting in alterations to the “naturalness” of wilderness areas.

This begs the obvious question: what baseline is used to determine “naturalness” in wilderness areas? How do we define what “primeval character” is? Traditionally, USFS managers have attempted to maintain or restore conditions prior to westward expansion during the 19th century or prior to European arrival in the Americas. However, humans have always affected the state of ecosystems. For example, Native Americans have altered environments, albeit in different ways than Europeans arriving in the Americas (Cole et al. 2008). Native American alterations have been localized and while significant, it was not until the 20th century that landscapes were altered at the regional and global scale. In recent decades it has been clear that the dynamism inherent in ecological systems challenges any standardized formula for naturalness. Ecosystems change through time. This is clear. However, it is also clear recent changes far exceed historical variation in rate and extent (see Chapter 2). Managing for a “natural” state in wilderness areas is not the most appropriate way to maintain or restore healthy ecosystems. Instead, managers must set goals and take actions that endeavor to maintain vital ecosystem services and functions over a potentially artificial conception of “naturalness.” One scholar has written that instead of focusing on managing towards naturalness, it makes logical sense to instead manage away from degradation, which is an aim that can be found in other environmental protection policies such as the Clean Air Act (Scott, 2001).
Wilderness areas have special legal considerations, which require managers to uphold a higher standard of ecosystem protection. Local-scale human impacts on ecosystems are lessened in wilderness areas because of restrictions on the type and number of people using wilderness areas for recreation. For example, no mechanized modes of travel are permitted within wilderness areas. At the same time, wilderness ecosystems face the same impacts of global-scale issues such as climate change that non-wilderness ecosystems face.

Thus, wilderness areas provide managers the opportunity to measure the relationship and make distinctions between localized and globalized management issues (Graumlich, 2000). Specifically, wilderness areas can show how the effects of climate change interact with impacts of other management issues such as recreation on USFS ecosystems. Wilderness fulfills an important niche in the larger climate change and USFS management discussion. Deciding exactly how to confront climate change within wilderness areas, however, raises difficult moral, political, and ecological questions about naturalness and ecological protection that must be addressed. This will be the focus of the next section.

**A.3 Wilderness Areas and Climate Change: Moral, Political, and Ecological Considerations**

Wilderness areas have an important role to play in understanding the effects of climate change on National Forest System (NFS) ecosystems. They are a signal of global change and they differentiate many local and global human impacts. They are a significant part of the baseline data on less perturbed ecosystems and will help mark changes to ecosystems as a result of human actions. The special laws (principally, the
Wilderness Act) governing wilderness area management are designed to insulate some of the nation’s more unique and vital ecosystems from the impact of human actions. Climate change poses a unique set of threats to wilderness areas, which create new issues for resource managers. I will touch on the moral, political, and ecological considerations that make the discussion of climate change in wilderness areas different than other NFS ecosystems.

**A.3.1 Moral Considerations**

Moral questions arise as a result of the legislation protecting wilderness areas and the human relationship to climate change. Humans have burned enough fossil fuels to alter the composition of the atmosphere (IPCC, 2007a). As a result ecosystem functions and services are threatened. The collective actions of humans are disturbing the character of wilderness areas. The Wilderness Act provides that these areas are removed from human influences, to make certain wilderness “character” is upheld. Character is defined by ensuring “the earth and its community of life are untrammeled by man.” *Untrammeled* has intensely debated connotations (Scott, 2001). Many associate the word with “untrampled” or “unperturbed,” but the word is actually more closely related to words such as “unrestrained” and “unimpeded.” Therefore, untrammeled wilderness is wild, autonomous, and self-organizing (Cole, 2001; Turner, 1996).

It follows in either connotation of the word *untrammeled*, that the Wilderness Act has been broken. We have disrupted ecosystems as a result of drastic alteration to the atmosphere. So what can be done to address this? The only legal ramification is to manage ecosystems to their “natural” state. However, as discussed above, this requires a
definition of “naturalness” and managers must decide in what capacity and with what goals management should look like. If we take explicit management actions, we risk steering ecosystems into an artificial, human-conceived and limited notion of ecologically sustainability. Yet, if we do not actively manage we face potential risks, known and unknown. These risks range from local re-organization of ecosystem structure to an important contribution to perhaps the largest global extinction in geological history. The goal must be to maintain vital functions and services in ecosystems and this should dictate management decisions. However it is not always clear how to manage for maintained functions and services, which is what makes climate change so dangerous.

This “dilemma of intervention” (Cole et al. 2008) forces resource managers to decide when and how to actively manage ecosystems and when to let ecosystems morph and reorganize without human intervention. Landres (2004) emphasizes the balance that must be maintained when deciding how to restore a perturbed ecosystem as a result of human actions. Not restoring wilderness areas, according to Landres, “may allow natural conditions to further degrade, but taking action destroys the symbolic value of restraint and may influence natural conditions in unknown ways” (Landres, 2004, pp. 498). Climate change poses threats too large to ignore, but addressing the threats will undoubtedly further-challenge notions of wildness and naturalness.

The Wilderness Act has been broken and it is necessary to determine how to motivate managers to address the legal breach. I suggest that acting on climate change in wilderness areas—on striking a balance between managing for wildness and preventing systemic ecological collapse—requires adopting themes presented in the previous chapter; namely, fundamental ideas in adaptive management (AM), specific collaborative
partnerships, and stakeholder engagement. Managers must be given incentives to determine where this balance lies for each wilderness area and the wilderness system as a whole in order to manage wilderness effectively in the face of climate change.

This is moral issue because we have allowed human actions to affect the character of wilderness areas. With the drafting of the Wilderness Act, the US made a clear declaration to protect in perpetuity our most important ecosystems from human influences and we, as a nation, have let this vision slip. It is necessary to reestablish the significance of protecting wilderness ecosystems and reaffirm the laws designed to safeguard them from human influences.

**A.3.2 Political Considerations**

The Director of Wilderness and Wild and Scenic Rivers for the USFS, Chris Brown, has outlined a three-fold response to climate change in wilderness areas: (1) preserving the ecological systems; (2) preserving the wilderness experience and; (3) creating a wilderness constituency among the public (Brown, 2008). This response will rely heavily on collaborative efforts and forging new public-private partnerships. Preserving the ecological systems will require analyzing the feasibility of both adaptively managing ecosystems and upholding legal requirements for wilderness protection. It may be the case that certain provisions will require modification in order to maintain wilderness character in the face of climate change. For example, the installation of mechanized scientific equipment used to measure changes in ecosystems is prohibited in wilderness areas under the Wilderness Act, but managers will need to decide whether this provision should be upheld.
Preserving the wilderness experience will also require an examination of current regulation to determine if they are sufficient to preserve wildness in wilderness areas. Building a constituency, according to Brown, is necessary to encourage a greater public stake in preserving both ecological systems and the wilderness experience. Creating a constituency will ensure the effects of climate change do not go unnoticed in wilderness areas and will motivate managers to take effective actions. The issue must be made a national one. Public interest and participation in wilderness management will give the issue local and national political saliency, which will make effective management more feasible.

Another principal political consideration when discussing climate change and wilderness areas is reconciling the extent to which the wilderness system is fragmented. There are 704 wilderness areas, 419 of which are managed by the USFS (Wilderness Institute, 2009). These 419 areas total 35.5 million acres, which is roughly 20% of the total acres managed by the USFS (Landres et al. 2005). Wilderness areas are rarely connected however, and instead tend to be “islands” with non-wilderness and/or non-USFS lands surrounding them (See Figure A-A below). How do we rectify the extent to which the system is fragmented in the face of complex, widespread, and borderless issues posed by climate change?

Jurisdictional boundaries must be dismantled in order to effectively manage wilderness areas in a warming planet. Additionally, resource managers must forge partnerships with private landowners to manage ecosystems holistically. Encouraging stakeholder engagement and nationalizing the issue of climate change and wilderness areas will lessen the risk for the public-private land interface creating hurdles to effective
ecosystem management. This will not be an easy task, but localized partnerships and measures to include private landowners and the wider public in planning processes will help managers overcome this hurdle.

**Figure A-A) From Wilderness Institute, 2009.** This map depicts the wilderness system in the western US. The green areas are lands managed by the USFS. The dark green are designated wilderness areas. Wilderness areas comprise roughly 20% of the total USFS lands (Landres et al. 2005). Notice the extent to which wilderness areas are fragmented and the system unconnected.

Finally, policymakers and resource managers must decide if current levels of visitor use remains appropriate as ecological interactions change and feedback loops are created between climate related and non-climate related human impacts on wilderness ecosystems. Adjustments to the number of users or the types of users in wilderness areas may be met with backlash from affected user groups. This could have political
ramifications for USFS policymakers and will add to the multiple-use debate playing-out on many national forests. At the same time, failing to adjust recreation regulations or maximum user days, for example, could prove disastrous as the effects of climate change interact with the effects of recreation and other management issues on wilderness ecosystem services. Therefore, USFS managers must decide how to most appropriately strike a balance between preserved ecological systems and preserved wilderness experience.

**A.3.3 Ecological Considerations**

Wilderness areas are home to a multitude of important ecosystem services (Cole and Landres, 1996). They also hold incredible biodiversity, however they are threatened by climate change (Graumlich, 2000). When USFS managers design plans for retaining ecosystem functions and services within an adaptive management framework, they may look to assisted migration—where resource managers physically relocate individual species to a new area of suitable habitat—as a necessary technique. This is especially difficult with wilderness management. Under current regulations, species cannot be introduced to wilderness areas.

Many wilderness areas in the western US are located in the alpine and sub-alpine ecological zones. As the climate warms, one expected effect is an uphill migration of some species of flora to find suitable habitat. Also, species such as the American pika (Ochotona princeps) will attempt to find suitable terrain at higher elevations in the alpine zone. The pika, as a result of fragmented, mountainous topography, will have a difficult time migrating and may require human intervention for continued survival (Beever et al.
Many of the most suitable areas for pika introduction would be in wilderness areas, especially in states such as Colorado, where much of the alpine zone is designated as wilderness areas. Policymakers must decide how to address the introduction of species into wilderness areas. The matter is made more complicated because it will be hard to make a distinction between native and non-native species as the climate continues to warm. Species range shifts and changes in dispersal patterns may make it difficult to manage for “naturalness.”

The introduction of species into wilderness areas is just one ecological consideration, but important in underscoring the unique case of wilderness protection in a time of human-driven climatic change. Introducing species will require modifications to current regulation, which may be very difficult to achieve. In any scenario, a synchronization of moral, political, and ecological considerations is necessary for wilderness managers to effectively manage ecosystems in the face climate change. Wilderness areas are unique in design and function, and therefore, a unique set of parameters to address the effects of climate change on wilderness ecosystems is needed. These parameters must include an examination of current regulatory mechanisms and how changing environments will necessitate changes to wilderness management. The final section of this chapter will show how the management of wilderness areas fits within larger USFS management structures as managers confront the challenges posed by climate change.
A.4 The Role of Wilderness and Broader USFS Management Structures in a Time of Rapid Environmental Change

Wilderness areas have a unique role in the USFS management framework. Special protections present challenges and opportunities for USFS managers to effectively manage ecosystems. The fact that wilderness areas are protected from many human impacts—such as effects of motorized recreation—and yet unprotected from other human impacts—most principally climate change—place wilderness management in an important light with regards to USFS management structures. Wilderness areas are ideal laboratories for differentiating human impacts. Rich paleoecological data exist in many wilderness areas because of a relative lack of detrimental direct human influences, which has left ecosystem structures largely intact. These ecosystems can be utilized to help understand what observed effects are attributable to natural variation and which are human-caused. When combined “with adjacent, more intensely managed areas,” wilderness areas “offer settings where human alteration of ecosystems processes can be observed and, in many cases, quantified” (Graumlich, 2000, pp. 27). Wilderness areas have a pivotal role to play in measuring changes to ecosystem interactions and understanding how human actions are likely to affect ecosystems in the future.

This unique position creates an opportunity and a responsibility for USFS policymakers to ensure wilderness areas are protected and effectively managed as the planet warms over coming decades. This will require a renewed emphasis on wilderness preservation by the USFS. This will, again, necessitate the expansion of a wilderness constituency to pressure policymakers to protect new areas and strengthen existing regulatory systems to maintain vital ecosystem functions and services.
The USFS mission is to manage ecosystems sustainably to provide ecosystem services, such as clean water, to the American people and to ensure that future generations have unhindered access to those same services. The creation of the National Wilderness Preservation System signaled to the world America’s commitment to ecological protection and insulation from the ill-effects of human actions. Climate change presents a threat to wilderness ecosystems and the foundational principles of the wilderness system that must be addressed by USFS managers. The position of the wilderness system in the USFS management structure rests within the opportunities and challenges management of these resources pose. Tough choices must be made as to how much of an active management role the USFS should take in attempting to maintain wilderness character and uphold legal parameters protecting wilderness areas.
References:


