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Socioeconomic Vulnerability to Ecological Changes to National Forests and Grasslands in the Southwest

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Abstract

The flow of ecosystem services derived from forests and grasslands in the Southwestern United States may change in the future. People and communities may be vulnerable if they are exposed, are sensitive, and have limited ability to adapt to ecological changes. Geospatial descriptions of ecosystem services, projected climate-related ecological changes, and socioeconomic conditions are used to assess socioeconomic vulnerability to changes in the provision of ecosystem services by national forests and grasslands in the Southwest. Vulnerability is uneven in the Southwest due to varying projected effects of climate on forest ecosystem services, and different levels of exposure, sensitivity, and adaptive capacity of people in the region.

Keywords: ecosystem services, socioeconomic vulnerability, economic contribution, national forests and grasslands

Cover photo: Desert and scrub vegetation encroaching into what was historically semi-desert grassland in southern New Mexico (credit: F. Jack Triepke, USDA Forest Service).

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Executive Summary

Ecological changes have the potential to alter the provision of ecosystem services from national forests and grasslands in the Southwestern Region (comprising Arizona, New Mexico, and parts of Texas and Oklahoma) of the Forest Service, U.S. Department of Agriculture. People and communities who derive benefits from ecosystem services will be affected to varying degrees depending on their exposure, sensitivity, and capacity to adapt to ecological changes.

This report describes an assessment of socioeconomic vulnerability to changes to ecosystems within national forests and grasslands in the Southwest. The assessment examines:

- Where in the region climate-related ecological changes are expected to alter the provision of ecosystem services and potentially interact with existing ecological stressors,
- Who in the region is more or less dependent on ecosystem services provided by national forests and grasslands in the region, and
- Where socioeconomic conditions are more or less conducive to adaptation to ecological changes.

This assessment has been integrated with a previous assessment of Southwestern ecosystems that considered vulnerability based on the disparity between the characteristic climate envelope for each ecosystem type, and future climate predictions at the year 2090 (Triepke et al. 2014). Socioeconomic vulnerability of people and communities in the Southwest is determined by the degree of exposure, sensitivity, and capacity to adapt to changes in the provision of ecosystem services derived from national forests and grasslands.

Exposure

Exposure to ecological changes is assessed by pairing projections of climate-induced vegetative change with geospatial descriptions of existing disturbances and stressors (primarily wildfire hazard and insects and disease) and the supply of selected ecosystem services (outdoor recreation, forage for livestock, forest products, and surface water supply). Although variation exists between ranger districts within a forest, the forests with the lowest average exposure are Carson, Prescott, Santa Fe, and Gila National Forests. Highest average exposure is found in Kaibab and Lincoln National Forests.

Sensitivity

Sensitivity to ecological changes is assessed by examining which areas in the region currently experience economic contributions and benefits related to ecosystem services provided by national forests and grasslands. An input-output (I-O) model—which estimates production relationships among economic sectors within a region or economy—is used to describe the current market economic contributions of three types of national forest and grassland activities that may be exposed to ecological changes: outdoor recreation, livestock grazing, and forest products. Results indicate that about 10,000 full- and part-time jobs and $270 million in labor income in the region are derived from sensitive national forest and grassland activities annually. Although a small share of the Southwest's regional economy, sensitive activities account for between 1.0 and 1.5 percent of employment and income in some areas. Benefits derived from other ecosystem services provided by national forests and grasslands—such as water supply for residential and commercial activities, firewood for home heating, and cultural and spiritual uses—are discussed in qualitative terms.

Adaptive Capacity

The assessment of adaptive capacity examines socioeconomic characteristics that may be associated with the ability of people to adapt to ecological changes. Conducted at the county level, the analysis summarizes several socioeconomic characteristics into index measures of relative adaptive capacity. The index values suggest that on average adaptive capacity is highest for national forests that are close to larger metropolitan areas, and lowest for forests that are more isolated from other economic activities.

Management Implications

National forests and grasslands present a unique setting to examine socioeconomic vulnerability because the provision of ecosystem services from these lands is affected, in part, by management decisions made by a public entity (the Forest Service). This may provide public land managers with the opportunity to adapt to projected ecological changes by adjusting management plans and activities to avoid negative effects and take advantage of opportunities associated with climate-related changes to public lands. The assessment results can be used by managers to inform forest planning efforts under the 2012 Planning Rule and to satisfy requirements of the Climate Change Scorecard. Results can be used in a variety of ways, including evaluations of tradeoffs, structured decisionmaking, and participatory decisionmaking. (Forest-level summaries of vulnerability are provided in the Appendix.)

Although the assessment does not endeavor to determine the benefits and costs of specific regional management activities and forest plans to respond to climate change, the results may be useful for prioritizing future activities and understanding which communities in the region may be more or less affected by ecological changes to forests and grasslands.

Contents

Chapter 1: Introduction

Healthy, well-functioning ecosystems produce a variety of life-fulfilling goods and services, known collectively as “ecosystem services.” Ecosystem services are defined as the components of nature, directly enjoyed, consumed, or used to yield human well-being (Boyd and Banzhaf 2007; Daily 1997) Although some authors maintain a distinction between ecosystem goods (i.e., tangible products) and services (i.e., the results of ecosystem processes that enhance things of value) (Brown et al. 2007), we will generally refer to them collectively as “ecosystem services,” and distinguish between the two categories as necessary. These services are essential to fulfilling basic human needs, including food, clean water and air, natural fibers and wood products, the regulation of pests and diseases, and recreation opportunities. Personal well-being derived from these services includes safety, the basic materials for a viable livelihood, health, social and cultural relations, and freedom and choice (McMichael et al. 2005: 45). The flow of ecosystem services facilitates social and economic vitality and contributes to the general well-being of people and households.

Communities across the Southwest (hereafter, “the region”) rely on ecosystem services to support the social and economic livelihoods of their people. Yet forest and grassland ecosystems are likely to be altered due to a changing climate (IPCC 2007: 14). As climate change alters ecosystem functions, the type and amount of ecosystem services provided by forests and grasslands will also change (Alig et al. 2011).

Research in the Southwest suggests that the climate in the region will continue to grow more variable (Gutzler 2013; Overpeck et al. 2013). Increased climate variability is anticipated to cause an increase in the occurrence and intensity of weather-related hazards (e.g., floods, droughts, heat waves, intense storms) and environmental disturbances (e.g., wildfires, pest infestations, invasive species). Changing hazard patterns and disturbance regimes will alter the natural landscape in the Southwest and change the quality and quantity of ecosystem services. The magnitude and types of changes to the provision of ecosystem services depend on the sensitivity of various ecological, social, and economic systems (Gallopin 2006; Luers 2005).

Managers of forests and grasslands face a daunting task in developing land management plans under a changing climate and changing socioeconomic conditions. Although a changing climate and its effects on ecosystem services will have broad impacts, not all people and communities will be equally affected (IPCC 2007: 12). A number of factors may determine the extent to which people are vulnerable to changes in a forest or grassland, including: proximity to the forest or grassland, reliance on ecosystem services, level of use of outdoor recreation opportunities, and exposure to natural hazards that are related to the ecosystem. Further, people and communities have different capacities to adapt to changes in supply of ecosystem services, mitigate potential negative effects, and take advantage of potential opportunities related to climate change.

This study seeks to better understand the vulnerability of people and communities to climate-related forest and grassland changes in the Southwest. The analyses in this report are designed to provide information to managers to assist in the forest and grassland planning process, particularly in light of the 2012 Planning Rule (USDA Forest Service 2012b). Although this study is not designed to provide detailed analyses of the socioeconomic impacts of specific planned activities, the results can be used to understand how climate change may alter the benefits people derive from forests and grasslands in the future, develop land management direction, help assess tradeoffs, and set management priorities.

This study addresses the following general research questions:

1. What are the roles of ecosystem services in local and regional economies and in community well-being in the Southwest?
2. What are the potential effects on economic outcomes and community well-being of changes in ecosystem services, and how do they vary across the region?
3. How can management actions be implemented to mitigate potential negative impacts of climate change on vulnerable human populations, and take advantage of potential positive impacts?

The study serves as a complement to a previous assessment of the vulnerability of major upland ecosystems of Arizona and New Mexico (Triepke et al. 2014). Based on the anticipated influence of climate change to vegetative site potential, ecosystem vulnerability was assessed and rated according to the departure of future climate from the climate envelope of a given ecosystem type at a given location. The socioeconomic assessment uses the ecological assessment results to indicate how projected changes to ecosystems may affect ecosystem services that are important for people and communities in the Southwest.

Defining Vulnerability

This assessment of vulnerability is concerned with identifying communities and geographic areas where ecological changes to forests or grasslands have the potential to adversely affect human well-being. People who are at greater risk of changes in well-being are considered more vulnerable to ecological changes.

A working definition of vulnerability used by the Intergovernmental Panel on Climate Change (IPCC) can be adapted for the purposes of this study: The degree to which people or communities are susceptible to, and unable to cope with, adverse effects of climate-related ecosystem changes. The vulnerability of people and communities is a function of the character, magnitude, and rate of ecosystem changes to which they are exposed, as well as their sensitivity and capacity to adapt to ecosystem changes (adapted from IPCC [2007]).

This definition of vulnerability is useful for assessing the degree to which people are susceptible to climate-related ecological changes in the Southwest because it encompasses the three components of vulnerability: exposure, sensitivity, and adaptive capacity. Exposure is the degree to which stressors or disturbances alter the provision of ecosystem services; sensitivity is the magnitude of change in well-being given a change in the provision of ecosystem services, and adaptive capacity is the ability of social and ecological systems to adjust to changes to mitigate potential damages, take advantage of opportunities, or cope with consequences (McCarthy 2001). In Chapter 2, these concepts are used to develop a conceptual model to describe socioeconomic vulnerability and inform the development of assessment measures.

Study Scope

People and communities will experience the effects of ecological change through numerous pathways. Only a subset of these will be relevant to public land management in the Southwest. The scope of this study is designed to offer insight on how people are likely to experience the effects of ecological changes to national forests and grasslands in the Southwest. To provide the most relevant information to managers at the regional and forest unit level, the study scope is limited along three dimensions: The source of change to ecosystem services, the geographic extent where those effects are experienced, and the set of relevant ecosystem services.

Sources of Change: Ecological Changes to National Forests and Grasslands Due to Climate Change

Forests and grasslands in the region may be subject to many forces of change in the future (USDA Forest Service 2012a), and climate change will affect natural resources across ownerships and jurisdictions. The scope of this study is meant to provide insight on the management implications of ecological changes to national forests and grasslands. In this study, only the effects of climate change on ecosystem services derived from lands managed by the Forest Service in the agency's Southwestern Region (Arizona, New Mexico, and parts of Texas and Oklahoma) (fig. 1.1) are considered.

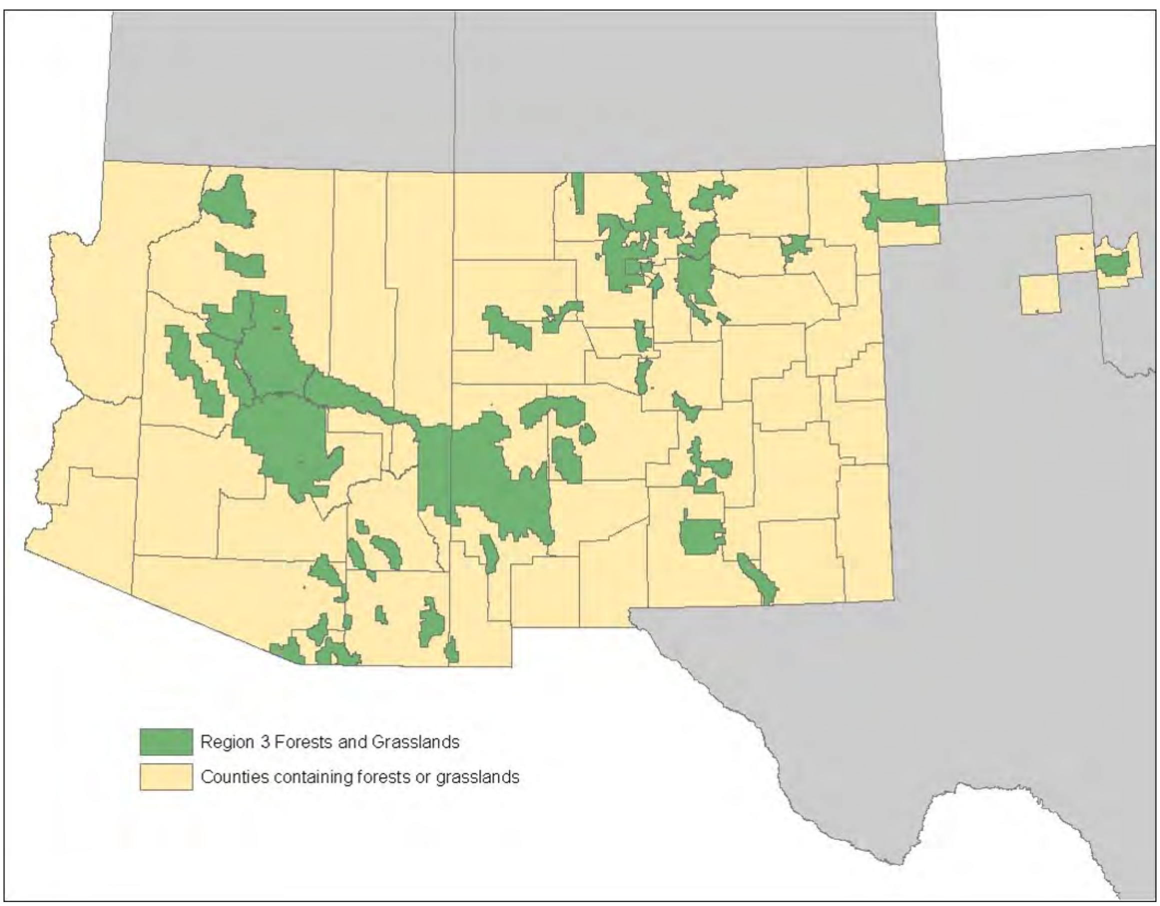


Figure 1.1—National forests and grasslands in the Southwestern Region (Forest Service Region 3).

Climate change may affect ecosystem services through multiple pathways. In some cases, changes in ecosystem services are directly related to variations and changes in temperature and precipitation. For example, changes in precipitation patterns can affect recreation opportunities for skiing (Irland et al. 2001) and fishing (Morris and Walls 2009). Other goods and services are related to climate impacts on soil conditions and the distribution of plant and animal communities (Huntley 1991; Kardol et al. 2011; Root et al. 2003). Disturbance regimes are also important, including interactions among disturbances that are related to climate change (Dale et al. 2001) and relationships between disturbances and vegetation (see Morris and Walls [2009] for a review). These pathways may in many cases be interrelated, and the provision of a given ecosystem service may be subject to changes through multiple pathways.

Of the many pathways by which climate change may affect the provision of ecosystem goods and services by national forests and grasslands, four primary pathways can be identified (fig. 1.2):

- Climate change directly affects the provision of ecosystem goods and services;
- Climate change increases the likelihood of vegetative change on the landscape, which alters the provision of goods and services that rely on the existing vegetative community;

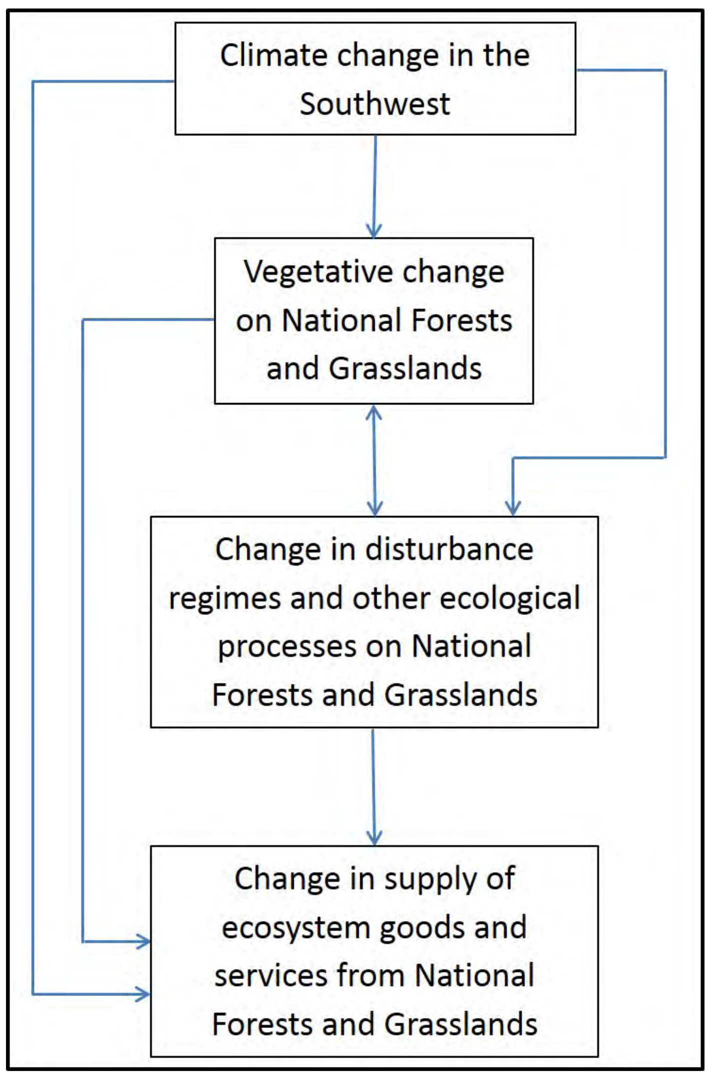


Figure 1.2—Relationships between climate change and the supply of ecosystem goods and services.

- Climate change alters disturbance regimes (e.g., fire, insects) that are important ecological processes for ecosystem goods and services;
- Climate change increases the likelihood of vegetative change on the landscape, which alters disturbance regimes that are important for ecosystem goods and services.

Alternatively, climate change can directly alter disturbance regimes, which can result in changes in vegetation and the provision of goods and services. (Note in figure 1.2 that the connection between vegetative change and disturbances can flow in either direction.)

Geographic Scope: Socioeconomic Impacts in the Southwest

The geographic scope of all benefits derived from Southwestern forests and grasslands can range from onsite enjoyment of a particular recreation opportunity to contributions to global climate change mitigation through carbon sequestration. Some benefits from forest and grassland ecosystem goods and services accrue across State and international boundaries (e.g., provision of surface water to Mexico in the Rio Grande; regulation of smoke from wildfires on Southwestern forests migrating across multiple States). Other benefits and impacts of ecosystem services are likely to accrue only within the region.

National or global impacts are not included in this study. Although ecosystem services derived from national forests and grasslands in the Southwest potentially contribute to the well-being of people beyond this geographic area, it is likely that the largest and immediate impacts will be felt by people living close to the lands where changes are taking place.

Relevant Ecosystem Goods and Services Supplied by National Forests and Grasslands

Ecosystem services that are supplied by national forests and grasslands in the Southwest and that may be affected by climate-related ecological changes (table 1) range from tangible goods (e.g., water for consumptive use, biomass for wood products, forage for livestock), to services used *in situ* (e.g., recreation site access), to non-use values (e.g., valuing the existence of natural features). These ecosystem goods and services also vary in their relationship to markets. In some cases goods and services are tied closely to market transactions, whereas others may confer benefits with little to no market activity. The list of relevant ecosystem services is limited to those affected by one of the climate pathways (fig. 1.2) described earlier; for example, the provision of minerals is an ecosystem good provided by national forests in the Southwest, but it is not likely to be affected by climate change.

Study Outline

An assessment of socioeconomic vulnerability proceeds by conducting a regional analysis of each of the three components of vulnerability—exposure, sensitivity, and adaptive capacity. These three analyses are then combined to identify areas within the region that exhibit high, moderate, and low vulnerability to ecosystem changes. A broad

Table 1—Ecosystem goods and services relevant for national forests and grasslands in the Southwest.

Ecosystem good or service	Description	Pathways that may affect provision	Scope of beneficiaries
Water supply	Municipal, agricultural, commercial, and in-stream uses	Direct – Reduced precipitation and increased temperatures Disturbance regimes – Increased incidence and severity of wildfires and erosion events	Within region; onsite; downstream users (e.g., Texas and Mexico)
Recreation opportunities	Site access and availability for onsite recreation opportunities	Direct – Reduced snowpack for skiing Vegetative vulnerability – Suitable habitat for game mammals, fish Disturbance regimes – Degradation or enhancement of sites due to wildfire	Benefits derived onsite, but could accrue to local and non-local beneficiaries
Forage for livestock	Forage availability and quality on National Forest lands appropriate for grazing	Vegetative vulnerability – Changes in range or extent of suitable forage Disturbance regimes – Incidence and severity of invasive plants	Onsite use by within-region livestock operations
Forest products – commercial use	Commercial timber and biomass, wood for personal use, food and forage for personal use	Vegetative vulnerability – Changes in range and extent of certain plant species Disturbance regimes – Increased bark beetle mortality; increased incidence and severity of wildfire	Wood product market participants, ranging from local to global
Forest products – personal use	Fuelwood, food and forage	Vegetative vulnerability – Changes in range and extent of certain plant species Disturbance regimes – Increased bark beetle mortality; increased incidence and severity of wildfire	Mostly residents within the region, particularly those close to forests
Air quality	Forests as a source (dust, smoke) and a sink for emissions	Disturbance regimes – Increased smoke from wildfires	Local and regional residents within regional airshed
Climate regulation	Forests as a carbon sink and carbon sequestration option	Vegetative vulnerability – Reduced biomass/carbon sequestration Disturbance regimes – Increased emissions from wildfire; loss of biomass due to bark beetle mortality	Global
Biodiversity and non-use species	Plant and animal genetic resources; non-use values for plant and animal species (e.g., cultural, spiritual, and existence values); biomass input for forest products and recreation opportunities	Direct – Loss of aquatic habitat due to reduced surface water flows; change in climate conditions for certain species Vegetative vulnerability – Change in range or extent of habitat Disturbance regimes – Wildfire; invasive plants; bark beetle mortality	Values accrue to residents within and outside the region
Spiritual, cultural, and historic significance	Sites, species, and landscape characteristics that hold spiritual, cultural, or historic value	Vegetative vulnerability – Change in range or extent of plants or habitat for animals for cultural and spiritual uses Disturbance regimes – Damage to cultural sites from wildfire	Spiritual site users (within region); residents within and outside the region with cultural and historic ties to forests in the region
Offsite amenities	Viewsheds and landscape characteristics that hold aesthetic value that can be enjoyed offsite	Vegetative vulnerability – Change in vegetative composition of land adjacent to private properties Disturbance regimes – Effects of wildfire on desirable viewsheds	Residents adjacent or close to forests

outline of the research design is described next, with specific details for each analysis described in the following chapters of the report.

Chapter 2 outlines the conceptual model developed to link changes in the provision of ecosystem goods and services to household well-being and vulnerability. Based on household production models, this model shows how potential changes in the quality or quantity of goods and services that are provided by ecosystems in the Southwest may affect the well-being of households across the region, and how these changes relate to vulnerability.

Chapter 3 assesses how climate-related ecological changes may affect the provision of ecosystem services that support well-being in the region. An analysis of the likelihood of climate-related vegetative change within the region's national forests and grasslands is used to identify areas where climate change is likely to alter the composition of natural landscapes (Triepke et al. 2014). Geospatial data describing forest disturbances (such as fire and tree insect infestations) and uses of ecosystem services (such as municipal watersheds and livestock grazing allotments) are paired with the vegetative assessment to identify areas that may also be exposed to climate-sensitive ecological stressors and that are critical for providing benefits from ecosystem services.

Chapter 4 provides an analysis of regional economic dependence on ecosystem services derived from national forests and grasslands in the region. Subregional economic contribution models are created for each forest unit (the administrative unit for each of the 11 national forests and grasslands in the region) based on county-level data from an input-output model; each model is a grouping of counties where direct expenditures from a given national forest are likely to occur. The models are used to calculate the indirect and induced contribution—that is, multiplier effects—of direct expenditures to generating income and employment in each subregional area.

Chapter 5 uses socioeconomic data to assess which areas in the region may have a greater or lesser density of households that can adapt to changes in the provision of ecosystem services. Building on a household production model of well-being, a set of socioeconomic indicators is summarized to indicate relative adaptive capacity across counties in the region. The county-level summaries of adaptive capacity are compared with the economic contribution analysis and the ecosystem services assessment.

The final chapter of the report discusses how management actions at the national forest unit level may relate to socioeconomic vulnerability. A set of management approaches is reviewed to highlight opportunities for mitigating negative impacts and enhancing positive impacts on well-being of climate-related changes. The broad results of the study are also discussed in relation to the 2012 Planning Rule and how managers may be able to incorporate an understanding of socioeconomic vulnerability into land management planning activities. Results for each forest unit are summarized in the Appendix.

Chapter 2: Conceptual Model and Methods for Assessing Socioeconomic Vulnerability

Definitions of vulnerability and its components say little about how and why individuals or communities may be vulnerable. In order for these definitions to be functional for assessment purposes, a conceptual model is developed to link changes to ecosystem services and household well-being to the concept of vulnerability. An assessment method is then developed to relate observations of ecological, social, and economic characteristics of households in the Southwest to the factors that affect vulnerability.

A Household Production Model of Vulnerability

The goal of this assessment is to identify people and communities who may be susceptible to or unable to cope with adverse effects of climate-related ecological changes in the Southwest. The term "adverse effects" is interpreted as negative impacts of climate-related forest or grassland changes on household well-being or utility. However, the assessment method is designed to accommodate both negative and positive impacts on well-being. Examples of positive impacts on well-being are increased productivity of forage for livestock, or increased availability of certain recreation sites. A household that is considered vulnerable is more likely to experience a relatively larger reduction in well-being if a climate-related change occurs to a forest or grassland, and is less able to mitigate reductions in well-being through adaptive action.

It is also useful to differentiate between marginal changes in well-being, and changes that can be identified as a discrete "adverse effect." For example, smoke from a wildfire may cause some people to alter daily activities and run air conditioner units more frequently, which may reduce well-being. Other people with greater exposure or sensitivity to smoke may suffer increased disease or death as a result of cardiovascular and respiratory health problems. Although many people will be made worse off due to smoke, the latter group is considered more vulnerable than the former because morbidity and mortality represent a distinct departure of well-being from the status quo.

Discrete thresholds of well-being are an important concept for vulnerability assessments (see, for example, Luers 2005; Adger 2006; Nelson et al. 2007). For assessment purposes, vulnerable people and communities are those who are more likely to cross discrete thresholds of well-being that indicate a significant departure of well-being from the status quo. Thresholds associated with discrete outcomes (e.g., visits to the hospital, or evacuation of homes due to the threat of wildfire) that are observable or potentially observable are more readily quantifiable in an assessment than are marginal changes.

Climate-related changes to ecosystem services are assumed to affect well-being through a household production function. A household production approach to ecosystem services has been used in a variety of contexts. Household production models can describe the role of environmental inputs in recreation decisions (Bockstael and McConnell 1981; Freeman et al. 2014), and are the foundation for estimating values for nonmarketed ecosystem services (Barbier 2000). Versions of the model have also been used to examine how forest products are used as natural insurance in developing countries (Pattanayak and Sills 2001; Völker and Waibel 2010), and how households in

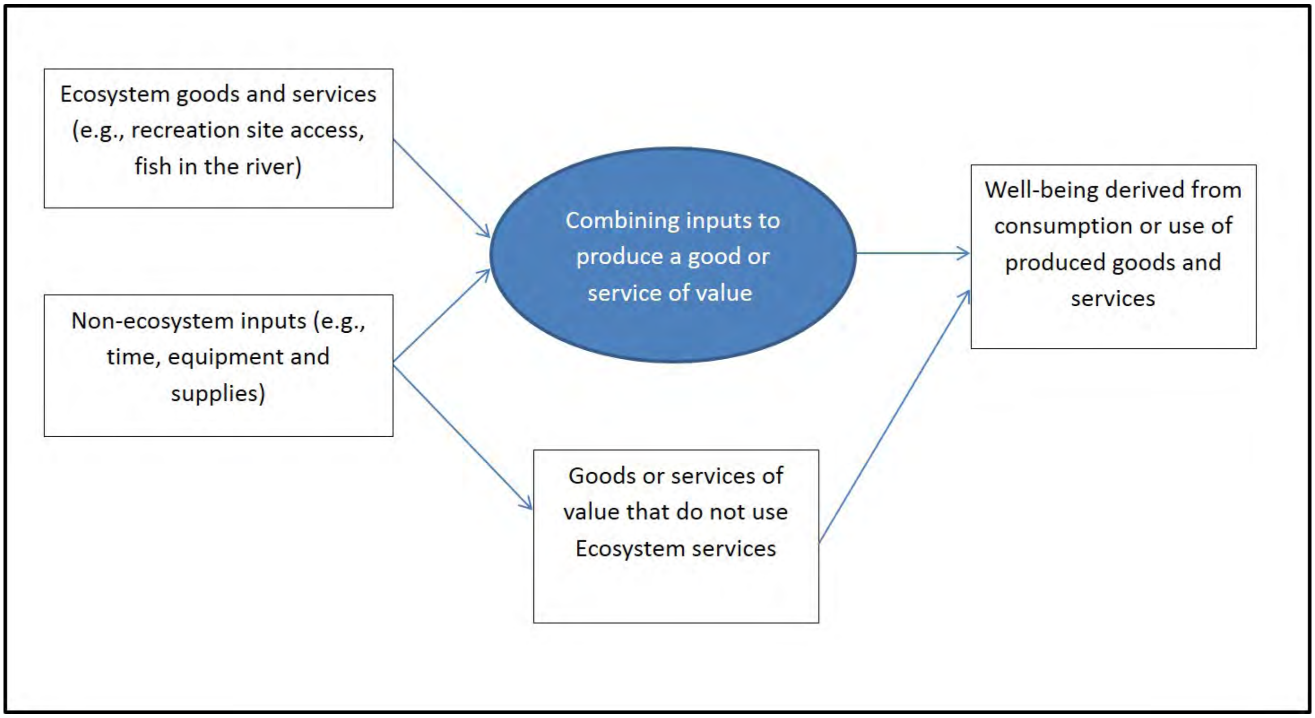


Figure 2.1—Household production model for ecosystem goods and services.

developing countries rely on ecosystem goods and services to adapt to climate change (e.g., Fisher 2004; Fisher et al. 2010; Pramova et al. 2012).

Ecosystem services are used as inputs to yield goods and services that households value (fig. 2.1). For example, fish in a forest stream are an input for producing a recreational fishing day, which may have value expressed in some households' utility functions. Other inputs in the production process may include fishing gear and tackle, time, transportation, and access to the recreation site.

A household production model recognizes that ecosystem services used as inputs may exhibit a range of values under climate change scenarios. As the provision of ecosystem services changes in the future, the ability of households to produce well-being and the likelihood of well-being falling below a discrete threshold will change (fig. 2.2). Increases in well-being (e.g., due to improved productivity of livestock forage) are interpreted as a reduction in the likelihood of crossing a well-being threshold and thus as a reduction in vulnerability. Conversely, decreases in well-being (e.g., decreases in productivity of livestock forage that necessitate purchases of supplemental forage) are interpreted as increasing the likelihood of crossing a well-being threshold and thus increasing vulnerability.

The components of socioeconomic vulnerability—exposure, sensitivity, and adaptive capacity—can be described in terms of how each relates to changes in household well-being and the likelihood of well-being falling below a threshold level given a change in ecosystem services. Each component is discussed in turn. Greater vulnerability is characterized by exposure to the risk of degraded ecosystem services, dependence on ecosystem services that support well-being, limited substitutability between ecosystem service inputs and other production inputs, and inelastic demand for ecosystem goods and services (fig. 2.3).

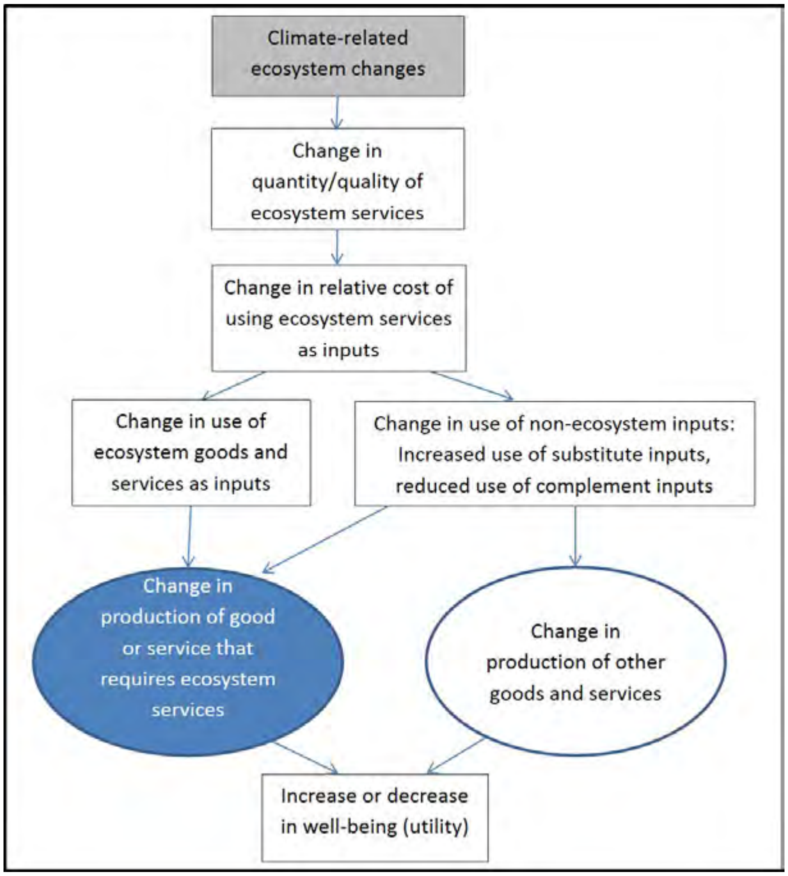


Figure 2.2—Changes in household production in the event of climate-related ecological changes.

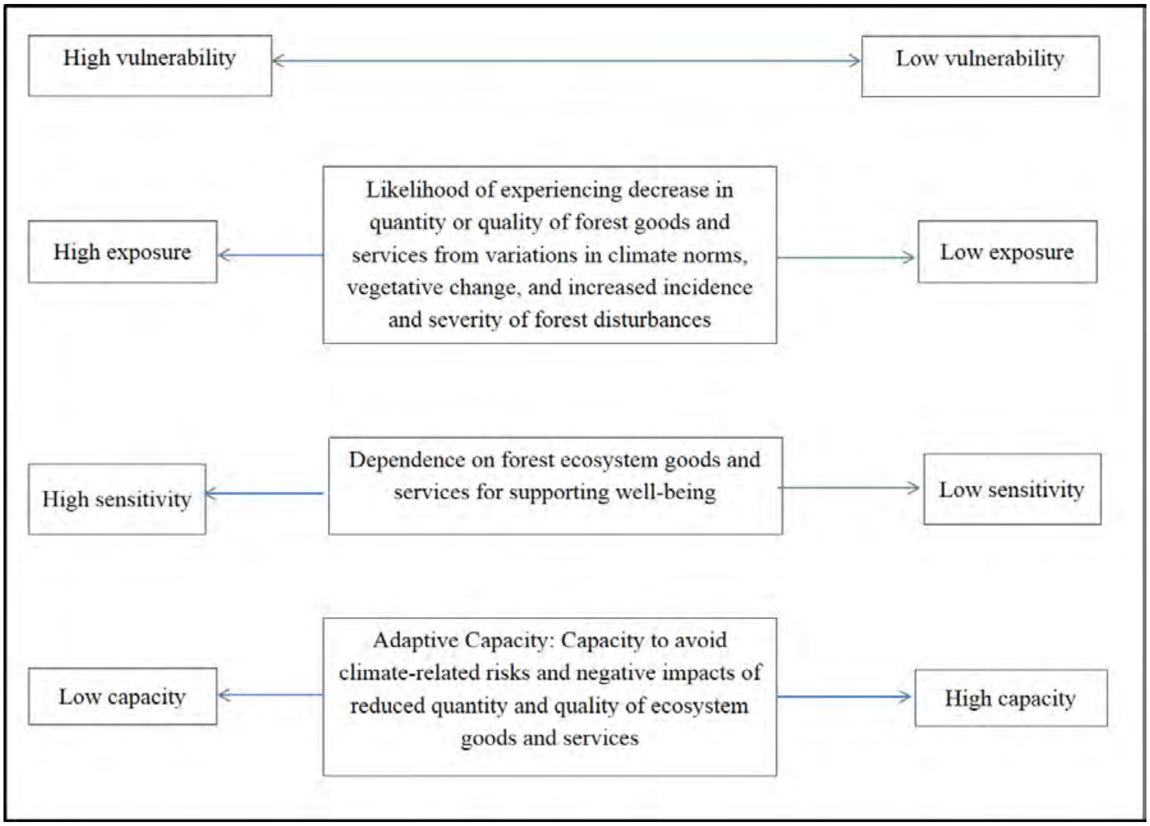


Figure 2.3—Components of socioeconomic vulnerability.

Exposure

In a household production model, exposure captures the likelihood and magnitude of a change in the quantity or quality of ecosystem services. Exposure to ecological change effects on the provision of ecosystem services is a combination of two elements: The likelihood of ecosystems experiencing climate-related changes, and the magnitude of ecological effects associated with climatic changes (Gallopin 2006; Luers 2005). The magnitude and types of change in the provision of ecosystem services depend on relationships between ecological, social, and economic systems (Gallopin 2003; Luers 2005).

Ecological changes that affect exposure are considered exogenous to individual household or community decisions. For example, the extent of expansion in bark beetle-related tree mortality under climate change in a given area is assumed to be a result of climatic, ecological, and economic forces, and not influenced by individual household decisions. However, different households may make decisions (e.g., where to live) that affect their exposure to climate-related risks.

Sensitivity

In the context of a household production model, sensitivity can be described as the degree to which households depend on ecosystem services to support well-being. Greater forest dependence implies that a given reduction in forest ecosystem service provision will have a greater effect on well-being, and result in a greater likelihood of well-being falling below a threshold.

Measuring ecosystem dependence may be difficult in some cases because household links to ecosystem services are often unobserved, particularly for non-use relationships (e.g., spiritual, cultural, and heritage values). For resource-use links (e.g., commercial resource development, forest product gathering, recreation), observations of forest product uses can allow for inferences about relationships that determine well-being. Examples of studies of these inferred connections are Fisher (2004), Fisher et al. (2010), Pattanayak and Sills (2001), and Völker and Waibel (2010).

Adaptive Capacity

Adaptive capacity encompasses the ability to engage in activities that either alter the risk of experiencing ecological changes or change dependence on ecosystem services (Murphy et al. 2015; Smit and Wandel 2006). In a household production model, adaptive capacity describes the degree to which households can alter the allocation of inputs to mitigate a decrease in well-being in response to an exogenous decrease in the quantity or quality of ecosystem services.

Households may adapt in several ways. For risks defined by geographic location (e.g., risk of wildfire), households may migrate to lower-exposure locations. Households may also make investments to reduce exposure to climate risks (e.g., installing central air conditioning, or investing in more efficient irrigation equipment), or make changes to consumption patterns to substitute non-ecosystem goods and services for goods and services derived from ecosystems in the Southwest.

The ability to make such changes is likely not to be uniform across households in the Southwest. Adaptive capacity can vary based on the economic resources, technology, information and skills, infrastructure, institutions, and equity within Southwestern communities (McCarthy 2001). Adaptive capacity may be related to income and wealth and various forms of human and social capital, including knowledge, skills, abilities, and access to support networks. Health status, education, and traditional knowledge may also be important factors contributing to a household's ability to adapt to changing ecological conditions (Smit and Wandel 2006).

Method for Assessing Socioeconomic Vulnerability

Despite widespread interest in ecosystem services, their link to human well-being is less well understood (Yang et al. 2015). The goal of an assessment of vulnerability is to identify households, communities, or other entities (e.g., counties) that are close to a vulnerability threshold and are relatively likely to cross a threshold. For example, a vulnerability assessment may attempt to identify which households in a coastal area are likely to experience a severe disruption from a hurricane due to exposure to coastal flooding, lack of insurance, and limited available community support resources. Adger (2006) describes a generalized class of vulnerability measures that compares well-being of observational units relative to a known threshold. However, well-being is usually unobservable, and thresholds may be unobservable as well.

Multiple methods exist to assess socioeconomic vulnerability depending on the underlying conceptual framework used to describe and define vulnerability, ranging from data-intensive quantitative approaches, to detailed case studies, to scenario building and participatory approaches that involve consultations with multiple stakeholders (Fischer et al. 2013; Murphy et al. 2015). Further, the types of information gathered by using a selected assessment method may fall into two general categories: (1) Profile information, which describes the characteristics of a community; and (2) process information, which describes how people in communities are related and interact (Fischer et al. 2013). This conceptual framework most closely resembles an "outcome-oriented" framework of vulnerability described in Murphy et al. (2015), which focuses attention on discrete exposure units (i.e., households) and the potential impacts of threats (i.e., climate-related changes to forest ecosystems).

The assessment method applied in this study is a modified version of a method used by Thornton et al. (2008) and Emerich and Cutter (2011). The modified version applied here is composed of three steps: (1) assessment of the likelihood of vegetative change as an indicator of changing ecological conditions, (2) assessment of economic dependence on ecosystem services, and (3) assessment of socioeconomic factors related to adaptive capacity. This method corresponds to a combination of methods described in Murphy et al. (2015), primarily the "dose-response" and "indices and indicators" methods.

Step 1—Likelihood of Vegetative Changes as an Indicator of Climate-Related Ecological Change

An important aspect of assessing vulnerability is determining where climate-related changes to ecosystems are more and less likely to affect the provision of ecosystem services. The approach taken here is to examine the location of potential changes in the

Southwest by conducting a fine-scale analysis of likely vegetative change due to projected climatic changes in the region.

Triepke et al. (2014) have used a fine-scale approach to examine how projected shifts in the distribution of temperature and precipitation may affect the pattern of vegetation currently on the landscape. This approach relies on comparing the historical range of climate variables associated with different vegetation types with projected ranges of climate variables across the region. Areas at high risk of vegetative change are those where the projected range of climate variables is unlikely to support the existing vegetative theme in that area. In this study we examined where projected climate-related vegetative change intersected with geospatial information on the occurrence and severity of ecological disturbances, including wildfire and tree mortality due to insects and disease. This intersection can indicate where ecological changes are likely and may exacerbate existing ecological stressors.

Exposure was assessed by identifying areas important for the provision of selected ecosystem services—recreation opportunities, forage for livestock, forest products, and surface water—using geospatial, administrative, and survey data. High exposure to climate-related changes to ecosystem services is defined as the intersection of high likelihood of vegetative change, the presence of disturbance hazards, and importance for the provision of ecosystem services.

Two caveats are necessary to put the exposure analysis in context. First, the analysis does not directly model potential changes in the provision of ecosystem services. Rather, likely changes in vegetation and natural resource availability are used as an indicator of where changes in ecosystem service provision are likely to occur. Second, the underlying assessment of ecosystems in the Southwest identified only the likelihood of vegetative change, not what type of vegetation is likely to replace the current state. Nor did the vegetative analysis identify the type and magnitude of ecosystem services that will flow from the area in the future. For example, the analysis does not incorporate potential changes in vegetative productivity independent of changes in vegetation type. However, the provision of ecosystem services is dependent on the underlying ecosystem functions that result in different types of vegetative cover, as well as the type of vegetation itself. Thus, projected changes in vegetation can at least indicate areas where the provision of ecosystem services is likely to change.

Step 2—Economic Dependence on Ecosystem Services

Households in the Southwest may depend on ecosystem services to support well-being in many ways. They may receive income from markets for products, use natural areas for recreation, or gather forest products for personal use, among others. This study considers dependence in two ways: economic contributions that can be measured through market transactions of ecosystem services, and reliance on ecosystem services that are not closely linked to market transactions.

The economic contribution analysis approach identifies how much economic activity (measured in employment and income) in the region can be attributed to expenditures that are related to ecosystem services flowing from national forests and grasslands. Relevant ecosystem services include provision of timber and wood products, forage for livestock, and recreation opportunities. Provision of these three resources accounts for the majority of market transactions involving ecosystem services that are provided by national forests and grasslands in the Southwest.

Economic contributions were calculated from economic relationships specified in a set of regional economic models using IMPLAN (IMPLAN 2013). The contribution analysis indicates the current economic link between ecosystem services provided by national forests and grasslands and subregional economies where those services have the greatest market impact. For each national forest and grassland in the region, a set of counties was identified where firms and households make expenditures derived from forest and grassland activities. These counties were defined as a subregional forest-related economy for each national forest and grassland. By using the relationships between economic sectors in IMPLAN, the contribution of forest and grasslands expenditures (indirect, and induced employment and income) was calculated for each subregional economy. Contributions were calculated for three categories of ecosystem services: recreation, rangeland, and timber and wood products.

People in the Southwest also depend on ecosystem services to support well-being in ways that are not fully captured by employment and income contributions of forest- and grasslands-related transactions. For example, the economic contribution analysis can indicate how changes in recreation opportunities may affect people in the region whose employment and income depend on recreation expenditures. Yet it does not account for the effect on well-being for people engaged in recreation.

Ecosystem services have a range of connection to market transactions, including some with limited or no connection to market transactions, such as the supply of surface water by forests, offsite amenities enjoyed by nearby residents, firewood and other forest products gathered for personal use, and cultural and spiritual values. Regionwide data describing the demand and supply of these services vary; sensitivity to changes in these services is discussed qualitatively and supplemented by descriptive data when possible.

Step 3—Socioeconomic Indicators Related to Adaptive Capacity

Adaptive capacity describes the ability of households or communities to avoid negative impacts from ecological changes. Although many of the adaptations that people can engage in are observable, the capacity or ability to engage in adaptations may be difficult to observe before they occur. This study examined household characteristics that are commonly associated with adaptive capacity, and used these characteristics to identify geographic areas that may have a greater capacity to withstand a negative change to ecosystem services and avoid reductions in well-being.

A set of socioeconomic characteristics was identified that can be related to the conceptual model of adaptive capacity. Data were drawn primarily from those reported at the county level in the U.S. Census. The characteristics were summarized by using indexing methods to generate indicators that describe average differences between counties in socioeconomic characteristics associated with adaptive capacity. Counties with greater adaptive capacity were defined as those with higher values of socioeconomic indicators relative to other counties in the Southwest.

A potential shortcoming of index summarization methods is that they can over-emphasize socioeconomic demographic characteristics that are easy to observe, and deemphasize other more subtle factors that contribute to vulnerability, such as institutional capacity, community, and social capital (Kelly and Adger 2000). This may limit conclusions about adaptive capacity that can be drawn from the indices as they are developed here because they only reflect differences in socioeconomic status. Indices can be helpful for generating a descriptive profile of different communities; other approaches, such as case studies and participatory community engagement (Fischer et al. 2013) or in-depth interviews and focus groups (Paveglio et al. 2015), may be needed to gather information on social processes and identify different types of communities that may respond differently to ecological changes.

Unit of Analysis

In order to be relevant for land management planning efforts within the Southwestern Region, the primary unit of analysis for the vulnerability assessment is defined by the 11 national forest and grassland administrative units within the region. The goal of the assessment is to provide socioeconomic vulnerability information for each management unit that can assist in developing unitwide management plans and prioritizing responses to climate change within each unit.

Data used in the assessments are available at a variety of spatial scales and reporting units: fine-scale geospatial representations of vegetation, watersheds, rasterized outputs from ecological models, subunits of national forests and grasslands (such as ranger districts and grazing allotments), and groupings of counties. Although the primary unit of analysis is relatively coarse, in some cases it is feasible to report assessment results at finer scales to provide additional detail about geographic variations within a management unit or to assist with planning for subunits.

Chapter 3: Climate-Related Changes to Ecosystem Services in the Southwest

Communities in the Southwest depend on national forests and grasslands for the provision of a variety of ecosystem services. The provision of these ecosystem services depends on climatic and landscape conditions that support a variety of biological functions and processes. A changing climate may alter existing biological functions and processes, and thus the existing supply of ecosystem services derived from forests and grasslands. Climate change may also intensify natural and anthropogenic disturbances that threaten the provision of ecosystem services provided by the region's forests and grasslands.

This chapter assesses risk to the provision of ecosystem services from Southwestern forests and grasslands due to projected climatic changes. Forest areas that provide several types of ecosystem services are identified by using geospatial data. The likelihood of changes to the provision of these ecosystem services is based on climate projections and the likelihood of vegetative change.

Four broad categories of ecosystem services are identified here: forage for livestock (grazing), municipal water supply, timber products, and outdoor recreation opportunities. Geospatial data describing the uses or potential provision of these ecosystem services are used to identify areas managed by the Forest Service that are important for supplying ecosystem services. Other ecosystem services, such as cultural and spiritual opportunities, and risks to their provision due to climate change are also discussed. However, comprehensive regionwide datasets describing the geographic extent of these services were not available.

This chapter first describes an ecological assessment of the likelihood of vegetative change due to climate change across the region and its relationship to prominent disturbance regimes. Existing uses or provision of ecosystem services is then examined relative to vegetative change and current disturbance regimes. These discussions build our contextual understanding of climate change, disturbance regimes, and the dependence of communities on ecosystem services provided by national forests and grasslands in the Southwest.

Projected Forest and Rangeland Ecosystem Changes

The provision of ecosystem services by national forests and grasslands depends on complex interactions among climatic conditions (i.e., patterns of temperature and precipitation), site-specific conditions, ecological processes and disturbances, plant communities, wildlife populations, and human activities. Detailed modeling of how the provision of ecosystem services may change in the future is challenged by multiple interacting systems and a lack of available data at appropriate scales. But broad-scale assessments of changes in conditions that affect ecosystem services can indicate the direction and magnitude of potential changes, if not the precise nature of ecosystem services, in the future.

Broad-scale assessments suggest that climate change may have significant impacts on ecosystems in the Southwest (e.g., Cole 2010; Comer et al. 2012; Enquist and Gori

2008; Bagne and Finch 2012; Friggens et al. 2013; Rehfeldt et al. 2012). Exposure of ecosystem services to climate-related changes suggests that climate change has the potential to greatly alter well-being of people and communities in the region. Average annual temperatures are expected to increase by between 2.5 and 5.5 ºF by 2070, with potential for greater increases by the end of the century (Garfin et al. 2014). Higher temperatures, particularly in summer, are likely to lead to a more arid future in the Southwest (Seager et al. 2007) and increase the severity and extent of drought conditions (Gutzler and Robbins 2010). Mountain snowpack is expected to decrease due to greater incidence of precipitation falling as rain (McCabe and Wolock 1999), resulting in earlier spring runoff and lower streamflow (Garfin et al. 2014; Gutzler 2013). However, uncertainty remains about future climatic conditions and climate-related ecological change.

General relationships between climatic changes and ecosystem service provision provide some insight on potential socioeconomic impacts of ecological change. A change in temperature is itself sufficient to drive ecological changes (Williams et al. 2013) (see Friggens et al. 2013 for a review). Drought and heat stress can lead to increased tree mortality (Williams et al. 2010) and create feedback mechanisms with other ecosystem processes (e.g., insects and wildfire) (Allen et al. 2010). Decreases in snowpack are likely to have negative impacts on ecosystem services that directly rely on snow (e.g., winter recreation) and streamflows (e.g., surface water for irrigation).

A shortcoming of climate and ecosystem assessments at the regionwide scale is that it can be difficult to draw inferences about effects to ecosystem services at the subregional level. In particular, uncertainty about future conditions, about ecological responses to climate change, and about human adaptation to changing ecological conditions within a region combine to make it difficult to predict vulnerability with precision. But local assessments of climate impacts may be critical to management and planning (Williams et al. 2010).

Ecosystem Vulnerability—Analysis of the Likelihood of Vegetative Change

The method used by Triepke et al. (2014) to assess potential climate-related changes to ecosystems on national forests and grasslands relied on downscaled climatological projections paired with spatially detailed ecological data on the distribution of ecosystem types across the region. By segmenting national forest and grassland area into individual plant communities and assessing the climatic conditions that support each community, downscaled climate projections were used to predict vegetative change at a fine spatial resolution.

Each segment was assigned to 1 of 31 ecological response units (ERUs) identified for major upland ecosystems in the Southwest (Wahlberg et al. 2016) (table 2). Individual segments were also assigned likelihood of change ratings based on the departure of future climatic conditions from climatic conditions that support current vegetation (see box 1 for a description of data, climate models, emissions scenarios, and methods used to develop the ratings). Segments where future climatic conditions are projected to diverge significantly from the climate envelope of their respective ecosystem type were rated at higher likelihood of vegetative change. If future conditions were

Table 2—Ecological response units (ERUs) for major upland ecosystems of the Southwest.

Ecological response unit	ERU subclass	ERU code	System type
Spruce-Fir Forest		SFF	forest
	Spruce-Fir – Lower	SFM	forest
	Spruce-Fir – Upper	SFP	forest
Bristlecone Pine		BP	forest
Mixed Conifer with Aspen		MCW	forest
Mixed Conifer – Frequent Fire		MCD	forest
Ponderosa Pine Forest		PPF	forest
	Ponderosa Pine/Bunchgrass	PPG	forest
	Ponderosa Pine/Gambel Oak	PPO	forest
Ponderosa Pine – Evergreen Oak		PPE	forest
Pinyon-Juniper [PJ] Sagebrush		PJS	woodland
PJ Evergreen Shrub		PJC	woodland
PJ Woodland		PJO	woodland
	PJ Woodland – Cold	PJOc	woodland
	PJ Woodland – Mild	PJOm	woodland
PJ Grass		PJG	woodland
	PJ Grass – Cold Temp	PJGc	woodland
	PJ Grass – High-Sun Precip, Mild	PJGmHS	woodland
	PJ Grass – Low-Sun Precip, Mild	PJGmLS	woodland
Juniper Grass			woodland
	Juniper Grass – Cold	JUGc	woodland
	Juniper Grass – High-Sun Precip, Mild	JUGmHS	woodland
	Juniper Grass – Low-Sun Precip, Mild	JUGmLS	woodland
Madrean Encinal Woodland		MEW	woodland
Madrean Pine-Oak Woodland		MPO	woodland
Montane/Subalpine Grassland		MSG	grassland
Colorado Plateau/Great Basin Grassland		CPGB	grassland
Semi-Desert Grassland	High-Sun Precip	SDGhs	grassland
	Low-Sun Precip	SDGls	grassland
	Piedmont Grassland	PFG	grassland
	Foothill Grassland	FHG	grassland
	Semi-Desert Lowland Grassland (also called Chihuahuan Semi-Desert Grassland)	SDLG	grassland
	Sandy Plains Grassland (also called Chihuahuan Sandy Plains Grassland)	SPG	grassland
Alpine and Tundra		ALP	shrubland/mixed
Mountain Mahogany Mixed Shrubland		MMS	shrubland
Gambel Oak Shrubland		GAMB	shrubland
Sagebrush Shrubland		SAGE	shrubland

Table 2—*Continued.*

Ecological response unit	ERU subclass	ERU code	System type
Interior Chaparral		IC	shrubland
Sand Sheet Shrubland		SSHR	shrubland
Intermountain Salt Scrub		ISS	shrubland
Sonora-Mojave Mixed Salt Desert Scrub		SDS	shrubland
Chihuahuan Salt Desert Scrub		CSDS	shrubland
Chihuahuan Desert Scrub		CDS	shrubland
Mojave-Sonoran Desert Scrub		MSDS	shrubland
Sandsage		SAND	shrubland
Shinnery Oak (Black Kettle National Grasslands)		SHIN	Great Plains
Mixed-Grass Prairie		MGP	Great Plains
Shortgrass Prairie		SGP	Great Plains

projected to be similar to conditions supporting current potential vegetation, the likelihood of vegetative change was rated as low. Results for each plant community segment were then aggregated to subregional scales.

The downscaled assessments of likelihood of vegetative change are useful for identifying areas that may be susceptible to climate impacts that can affect the provision of ecosystem services. The ecosystem assessment did not explicitly model how climate change (or climate-induced vegetative change) affects ecosystem functions and the provision of goods and services. Rather, it can aid in describing the probability of ecological change and, for our purposes, potential effects to the supply of ecosystem services.

An advantage of this approach is that it provides a spatially detailed assessment that covers nearly the entire region. Further, because the ecological assessment is tied to vegetation, it provides an important link to climate-induced change for ecosystem services that primarily rely on particular vegetation types (e.g., timber products and forage for livestock). Disadvantages of this approach include limited ability to make inferences about ecological functions in the future and the magnitude of potential change in provision of specific ecosystem services. For example, the hydrological functions are correlated with the distribution of vegetation types on the landscape (Stephenson 1998); the likelihood of vegetative change assessment can identify areas where hydrological functions are more likely to be affected by climate-related changes to vegetation, but it cannot predict how those functions will change or the magnitude of change.

The effects of climate change on vegetation may vary geographically across the region (fig. 3.1). Overall, about 45 percent of area within national forests and grasslands in the region is at high or very high likelihood of vegetative change due to climate change, representing over 8 million acres. Some areas, such as in the Carson National Forest in northern New Mexico and in the Gila and Apache-Sitgreaves National Forests along the border between Arizona and New Mexico, exhibit relatively low likelihood of climate-induced vegetative change. Yet national forests in central Arizona (the Tonto) and northern Arizona (the Kaibab) show a higher proportion of area with high or very high likelihood of vegetative change.

BOX 1—An Ecosystem Approach to Assessing the Likelihood of Climate-Induced Vegetative Change

The assessment of likelihood of vegetative change relies on a correlative modeling approach to develop climate envelopes for individual ecosystem types. The correlative modeling approach is based on finding a range of climatic conditions (i.e., the climate envelope) that is correlated with the existence of ecosystem types on the landscape. Projections of future climatic conditions can then be compared to the climate envelope for each ecosystem type to determine where on the landscape the future climate may induce changes in the composition, structure, and processes of ecosystems. The development of an analysis of vegetative change rating is described in the following steps, with detailed description of methods available in Triepke et al. (2014):

1. The landscape across the region was stratified into ecological response units (ERUs) (see table 2), representing recognizable ecosystem types that repeat across the landscape.
2. Based on topographical data, the landscape was segmented into base-level polygons that have similar energy patterns, as an inference of site vegetation potential and natural disturbance regimes. Each segment was assigned to an ERU.
3. Discriminant analysis was used to associate climate variables with the existence of each ERU on the landscape; the results of the analysis indicate the climate variables from which to develop climate envelopes for each ERU, along with the explanatory value used to weight each variable. The climate envelope describes the range of climatic conditions associated with the existence of each ERU under current climatic conditions prior to about 1990. The climate variables used to describe the climate envelopes are mean annual temperature, mean annual precipitation, degree days greater than 5 ºC (9 ºF) within the frost-free period, degree days less than 0 ºC based on mean minimum monthly temperature, mean temperature in the warmest month, and mean temperature in the coldest month.
4. Downscaled climate model outputs from the Rocky Mountain Research Station’s laboratory in Moscow, Idaho, were used to project climate variables into the future (year 2090) at the 90-m^2 (970-ft^2) spatial resolution. The downscaled outputs are then associated with each ERU polygon on the landscape.
5. For each landscape polygon, future climate from the CGCM3 global circulation model (GCM) under the A1B emissions scenario was compared to the climate envelope for the relevant ERU, with each climate variable weighted by its explanatory value. A likelihood of vegetative change rating was given to each polygon based on departure of future climate from the climate envelope of the given ecosystem type. Low likelihood represents 2 standard deviations (s.d.) or less of climate envelope mean; moderate likelihood represents between 2 and 3 s.d.; high likelihood, between 3 and 4 s.d.; and very high likelihood, greater than 4 s.d. from the envelope mean.
6. Uncertainty in the likelihood of vegetative change rating is reported for each polygon based on agreement of ratings from three GCMs (CGCM3, HADCM3, and GFDLCM21), each of which yields slightly different projections under a given emissions scenario. Low uncertainty was assigned if all three GCMs yield the same likelihood rating for a given polygon under the A2 emissions scenario, moderate uncertainty was assigned if two of the three GCMs yield the same likelihood rating, and high uncertainty was assigned if none of the three GCMs agree on the likelihood rating. Likelihood of change ratings for each ERU are used for tabulation and reporting only when uncertainty is low or moderate.

Note: The A1B emissions scenario is used to report likelihood of vegetative change because it represents a commonly used mid-range emissions scenario (Gutzler and Robbins 2010). However, scenario outputs are not available for all GCMs. To develop the uncertainty ratings, the A2 scenario was used because the downscaled data for that scenario were available for multiple GCMs for comparison. See Triepke et al. (2014) for more details on model and scenario selections.

Summarizing likelihood of vegetative change by administrative units can indicate where managers may expect to encounter climate impacts (fig. 3.2). Ranger districts exhibit considerable variation in potential climate-induced vegetative change, from as little as 5 percent to almost 90 percent of the area at high or very high likelihood of vegetative change. The degree of uncertainty associated with climate change projections also varies by administrative unit. Several ranger districts have more than 20 percent of area where vegetative change is highly uncertain, in other words, where the climate models do not agree on the likelihood of change.

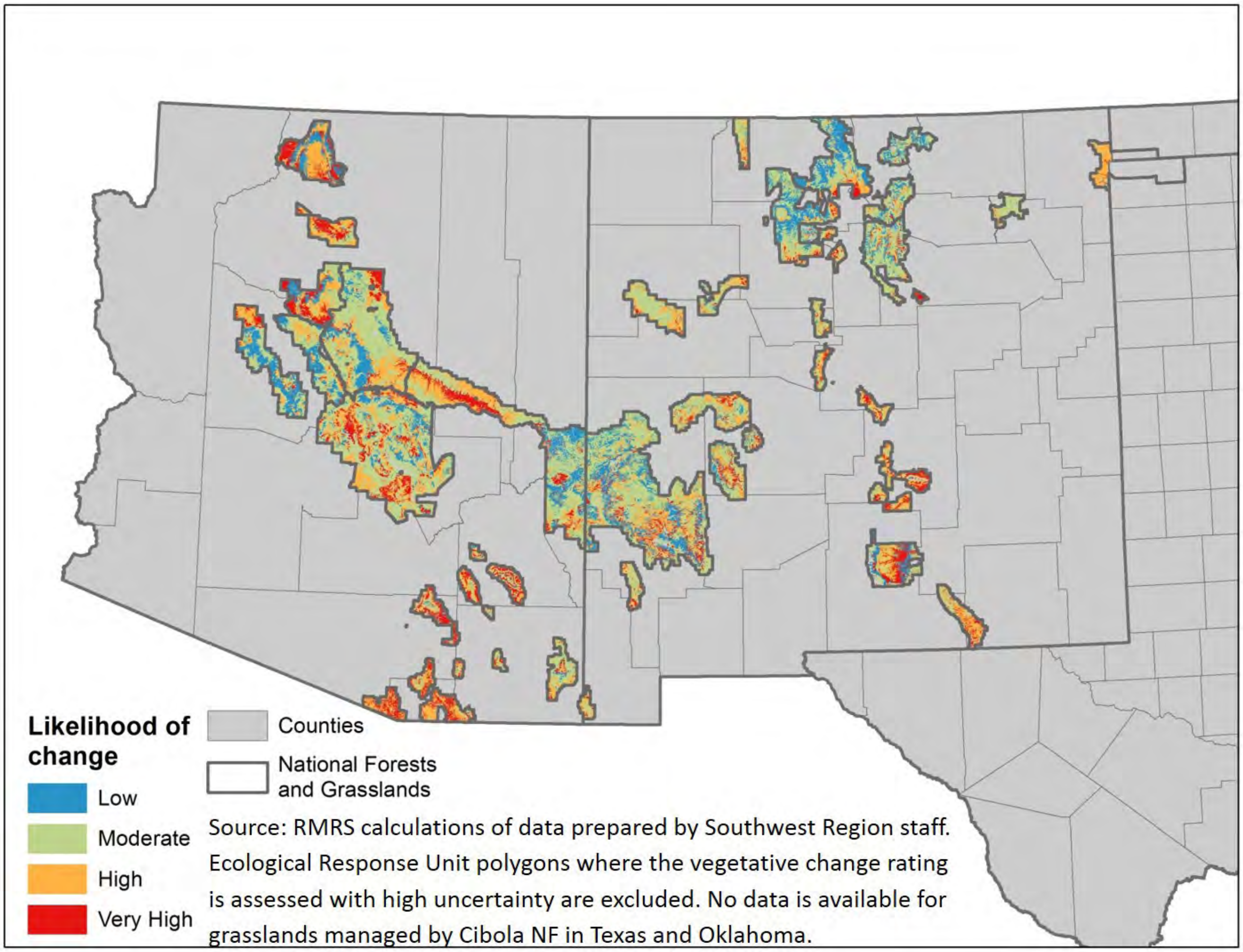


Figure 3.1—Likelihood of vegetative change on national forests and grasslands in the Forest Service Southwestern Region. Orange and red areas are where projected future climatic conditions are likely to fall outside of the range of conditions that support current vegetation types. Green and blue areas are where projected future climatic conditions are within the range of conditions that support current vegetation. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

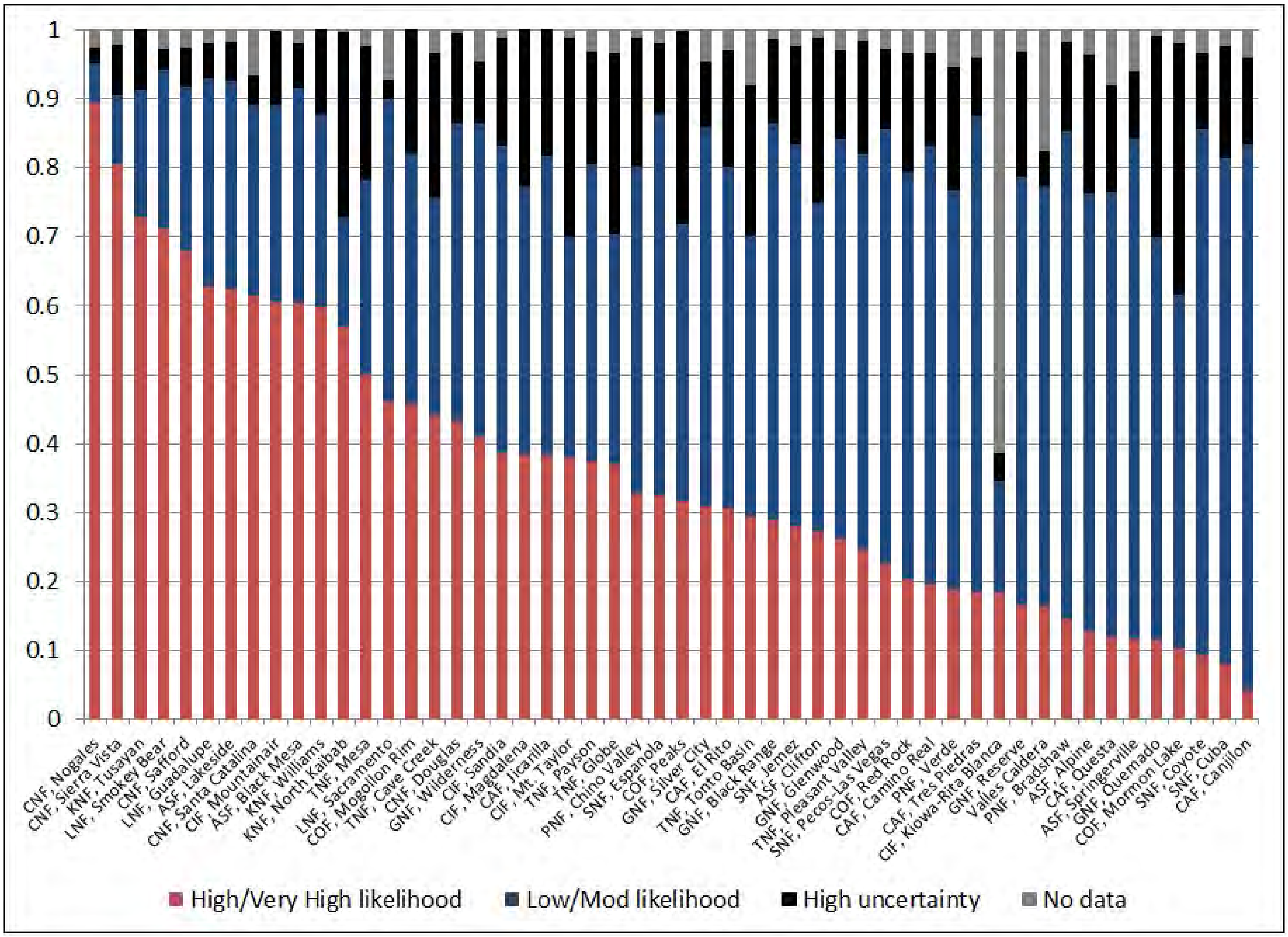


Figure 3.2—Share of ranger district area in the Forest Service Southwestern Region in likelihood of vegetative change categories, and in high uncertainty. Bars to the left of the chart (taller red portions) indicate a higher proportion of area in each ranger district where vegetative change due to climate change is more likely. Bars to the right indicate ranger districts where a greater proportion of area has low or moderate likelihood of changing vegetation types due to climate change. The height of the black portion of each bar indicates the proportion of ranger district area where projections of vegetative change are uncertain. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

Disturbance Regimes

The landscape and communities that contain Southwestern Region forests and grasslands are subject to natural and anthropogenic disturbance. Climate change is likely to interact with forest and grassland disturbances to cause ecological changes, although much remains to be studied about relationships between climate change and disturbances (Dale et al. 2000). Interactions among disturbances, which may be exacerbated under climate change scenarios, can cause major ecological transitions (Allen 2007). Understanding the potential ecological transitions can aid in identifying how ecosystem services may be affected by climate-induced changes to disturbance regimes.

Several types of disturbances are important in the Southwest and may be affected by climatic changes to forests and grasslands, including wildfire, insects and disease, floods, erosion and landslides, and noxious and invasive plants. To assess the potential for climate change to interact with disturbances and affect ecosystem service provision, the areal extent and severity of disturbance regimes is summarized for national forest

Table 3—Description and summaries of variables used in the exposure analysis.

Variable	Description	Number of obs.	Mean	Min	Max
vrisk	Share of area rated high or very high likelihood of vegetative change, by ranger district	52	0.43	0.05	0.94
WHP	Share of area rated high or very high wildfire hazard potential, by ranger district	52	0.40	0.02	0.82
IMDR	Insect and disease mortality risk; share of area greater than 25% projected percent basal area loss of trees, by ranger district	52	0.11	0.0	0.44
vrisk_RMU	Share of area rated high or very high likelihood of vegetative change, by range management unit	1,005	0.46	0.0	1.0
grazing_exposure_RMU	Exposure of animal unit months (AUMs) to high or very high likelihood of vegetative change, by range management unit	1,005	713	0	15,269
AUM_RMU	Number of permitted AUMs, by range management unit	1,005	1,994	5	22,464
grazing_exposure_RD	Exposure of AUMs to high or very high likelihood of vegetative change, by ranger district	50	18,893	0	84,365
water_exposure_HUC	Index of exposure of watersheds important for surface drinking water to vegetative changes, by 12-digit Hydrologic Unit Code (HUC) watershed	1,712	7.76	0	89
vrisk_HUC	Share of area rated high or very high likelihood of vegetative change, by12-digit HUC watersheds	1,712	0.46	0	1
IMP_HUC	Importance rating of 12-digit HUC watersheds for surface drinking water	1,712	19.7	0	89
water_exposure_RD	Index of exposure of watersheds, by ranger district	52	9.45	0.19	37.0

units and ranger districts. These summaries provide a current snapshot of areas within the region where ecosystem service provision may be stressed by disturbances. The disturbance summaries are then overlaid with summaries of the likelihood of vegetative change described in the previous section to gauge the relative stress that climate change will exert on plant communities. Detailed geospatial data are available for current wildfire hazard (Fire Modeling Institute 2014) and risk of tree mortality due to insects and disease (Krist et al. 2014). Other disturbances are discussed qualitatively due to a lack of comprehensive geospatial data for the region. Eleven variables were used in the exposure analyses (table 3).

Wildfire

Wildfire is an endemic ecosystem process in the Southwest, and plays an important role in shaping ecosystem functions on national forests and grasslands. Wildfire has the potential to directly affect people as a hazard that threatens communities and critical infrastructure (e.g., power distribution lines), and is also a factor that affects the provision of several ecosystem services.

Wildfire directly impacts provision of timber and rangeland services and the availability and desirability of recreation opportunities. Fire also has direct and indirect effects—both positive and negative—on a range of nonmarket values provided by forests (Venn and Calkin 2011). High-severity wildfire tends to degrade most ecosystem services and valued assets, and is particularly damaging for air quality, municipal watersheds, and built structures (Thompson et al. 2011). Critical species habitat, air quality, and moderate- to high-density development are at greatest risk of being degraded by fire, but fire-adapted ecosystems are expected to experience positive effects from fire overall (Thompson et al. 2011).

Climate change is likely to alter wildfire regimes in the Southwest due to higher temperatures and earlier spring snowmelt and runoff (Dale et al. 2001; Westerling et al. 2006), resulting in greater wildfire activity (Flannigan et al. 2000; Littell et al. 2009). Climate effects on vegetation may exacerbate wildfire risk through increased tree mortality due to warming and extreme fire behavior, water deficits, and drought stress (van Mantgem et al. 2009; Williams et al. 2010), although long-term effects may vary with changes in vegetation and fuel availability in the future. Due to the rapid response of fire regimes to climatic changes, climate effects on wildfire may overwhelm other direct effects on vegetation and species (Flannigan et al. 2000), and wildfire may act as a trigger for type conversion to another ERU or novel system.

Wildfire hazard is assessed for each forest unit and ranger district by examining the current likelihood and conditional severity of wildfires on national forests and grasslands by using the Wildfire Hazard Potential (WHP) geospatial data developed by the Forest Service's Rocky Mountain Research Station, Fire Modeling Institute (Fire Modeling Institute 2014). WHP describes areas where wildfires are likely to occur that would be difficult for suppression activities to contain. High-hazard areas identified by WHP are characterized by relatively high likelihood of wildfire occurring and burning at high intensities that tend to be damaging for ecosystem services and functions (Fire Modeling Institute 2014). The WHP geospatial data are a continuous scale calculated at a 270-m^2 (2,900-ft^2) resolution; the continuous measure for each pixel is then classified into five hazard categories: Very low, low, moderate, high, and very high.

Wildfire hazard potential is summarized for each national forest ranger district by calculating the share of area in each district where wildfire hazard is classified as high or very high (fig. 3.3). Ranger districts in the region vary widely in the share of area exposed to high or very high wildfire hazard potential, from less than 2 percent (Jicarilla Ranger District in the Carson National Forest) to over 80 percent (Mogollon Rim Ranger District in the Coconino National Forest). However, most ranger districts have less than half of their area categorized as high or very high hazard.

Wildfire hazard potential provides a current snapshot of areas in the region that may be affected by severe wildfires. These areas may be more or less exposed to climate-related changes to vegetation that can alter fire regimes in the future. Wildfire hazard and likelihood of vegetative change are not strongly correlated with each other (correlation coefficient = –0.15). Geographically overlaying the two indicators can help identify specific districts that may be of greater concern due to both wildfire and climate change-related hazards. Three ranger districts have more than 50 percent of area at high or very high wildfire hazard and high or very high likelihood of vegetative change (fig. 3.4). Most of the remaining districts are of less concern, with less than 50 percent of area rated as high or very high wildfire hazard and less than 50 percent of area rated at high or very high likelihood of vegetative change.

The lower (lb) and upper bound (ub) of areal intersection of wildfire hazard potential and likelihood of vegetative change (vrisk) are calculated as:

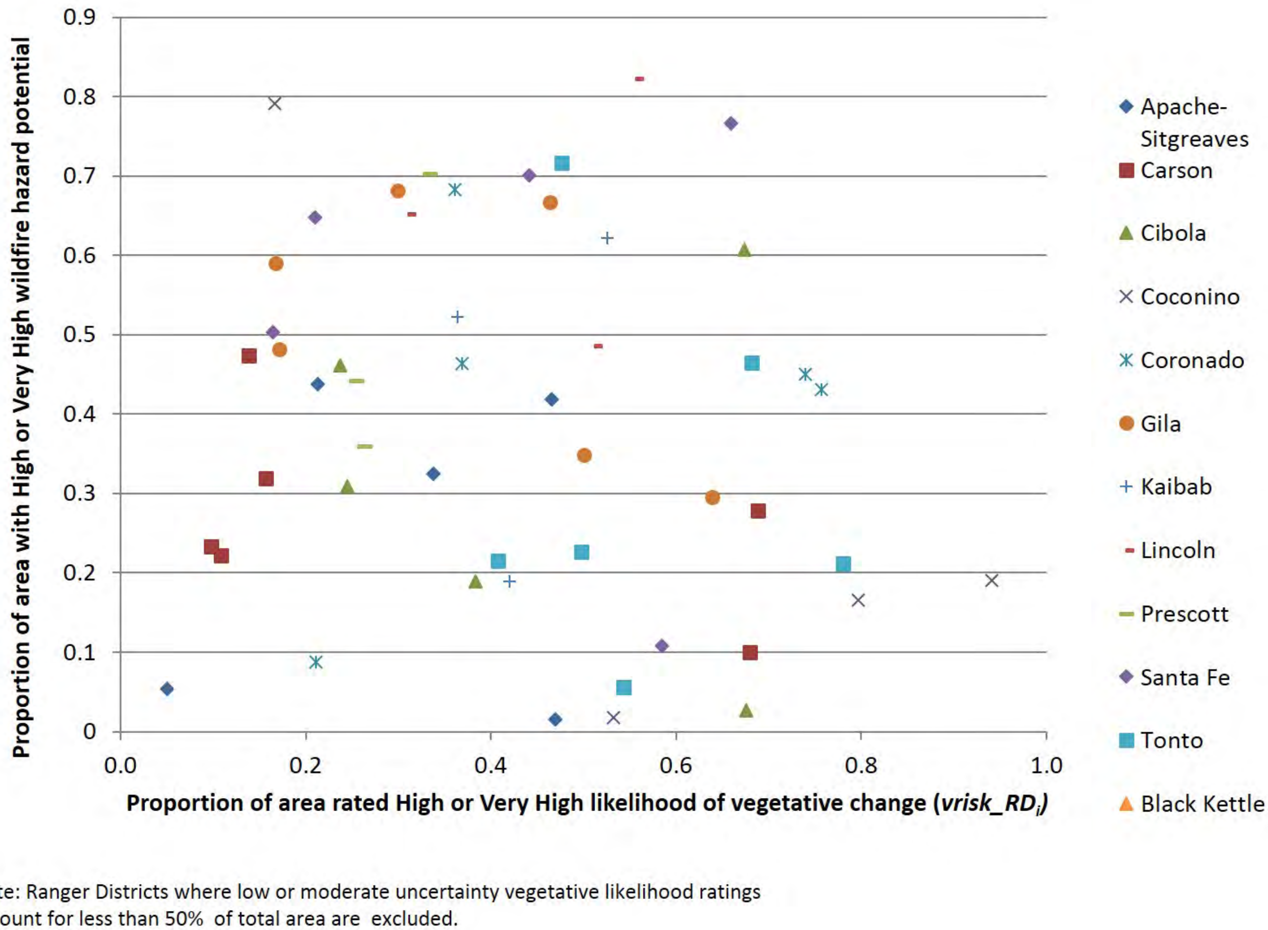
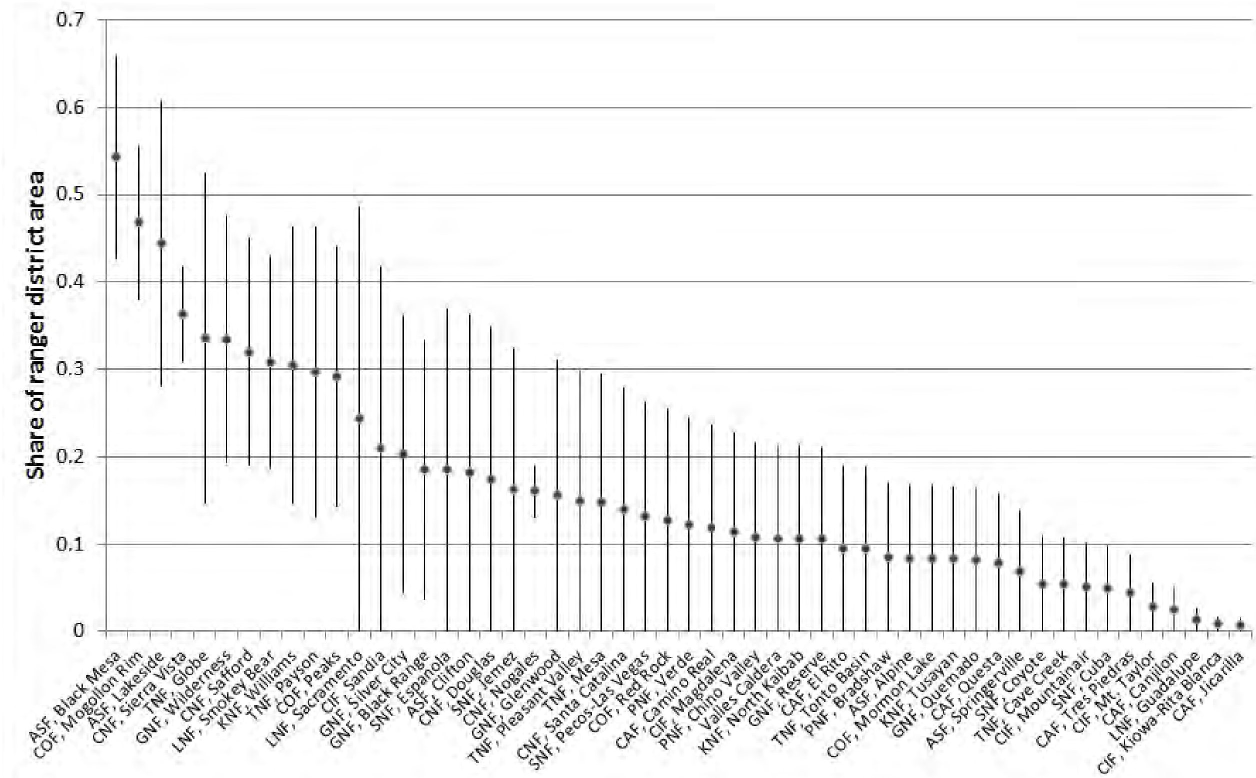


Figure 3.3—Scatter plot of climate-related likelihood of vegetative change and wildfire hazard potential in the Forest Service Southwestern Region, by national forest or grassland and ranger district. Points moving to the right and up indicate increasing share of ranger district area that is at high or very high likelihood of seeing vegetative changes and increasing share of area that is at high or very high current wildfire potential. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

$$lb_{WHP,vrisk} = \max[0, -(1 - WHP - vrisk)]$$
$$ub_{WHP,vrisk} = \min[WHP,vrisk]$$

The assessment of wildfire hazard and likelihood of vegetative change is nonspatially explicit in that the two variables are summarized independently for each ranger district. Additionally, the effect of climate on wildfire hazard has not been assessed, and the interactions between changes in wildfire hazard and vegetative changes require more detailed modeling. However, the range of areal intersection can indicate which ranger districts are more or less likely to be at risk of both high wildfire hazard and climate-induced vegetative change. Most ranger districts have a maximum possible spatial intersection between wildfire hazard and vegetative change of less than 40 percent of total district area, and may have no intersection depending on the spatial pattern of each variable. Twelve ranger districts have a maximum possible spatial interaction greater than 40 percent, and all but one of these ranger districts have a minimum possible spatial interaction of at least 15 percent.



Note: Each bar represents the range of possible areal intersection of high - very high(h-vh) wildfire potential and h-vh likelihood of vegetative change; the bottom of the bar is the minimum share of area that is both h-vh wildfire potential and h-vh likelihood of vegetative change, and the top of the bar is the maximum share of area that is both h-vh wildfire potential and h-vh likelihood of vegetative change. The point represents the mid-point or expected areal intersection.

Figure 3.4—Potential areal intersection of high or very high wildfire hazard and high or very high likelihood of vegetative change in the Forest Service Southwestern Region, by ranger district. Ranger districts to the left of the chart have a greater proportion of area that is likely both to see vegetative changes and to have high current wildfire potential. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

Insects and Disease

Forest insects and disease can have a positive or negative effect on forest health, although severe outbreaks can result in damaging effects to forests (Moser et al. 2009; Tkacz et al. 2008). Tree damage and mortality from insects and disease may change ecological functions and values derived from forests (Chornesky et al. 2005), and can degrade public and private benefits provided by forests (Holmes et al. 2008). For example, diseased and dead trees reduce aesthetic values of forests that accrue to nearby homeowners (Huggett et al. 2008). The economic costs associated with insects and disease can be substantial depending on the location, spatial scale, and type of outbreak (Ayres and Lombardero 2000).

Insect and disease mortality risk (IDMR) in the Southwest is summarized by using data that describe the projected percent basal area loss (PBAL) due to mortality from insects and disease from the National Insect and Disease Forest Risk Assessment (Krist et al. 2014). These data indicate geospatial locations where, based on current forest conditions and without remediation, 25 percent or more of standing live basal area greater than 1 inch in diameter would be likely to die over the next 15 years due to insects and diseases. PBAL data are in raster format at a 240-m^2 (2,600-ft^2) resolution. Each pixel in the raster data is given a PBAL rating between 0 and 100, corresponding to the PBAL projected for trees in that pixel. The percentage of area with at least 25 percent projected PBAL is reported for each forest unit and ranger district (which is the same threshold used by Krist et al. 2014 to identify areas at risk of uncharacteristic tree mortality). The PBAL raster data cover "treed land," which includes all areas with a measurable tree presence; not all national forest and grassland areas contain treed land. The percentage area with at least 25 percent PBAL is calculated using the total treed land within the forest unit or ranger district as the denominator, and the total area with at least 25 percent PBAL as the numerator.

Climate may affect insect and disease outbreaks through multiple pathways, including (1) a direct effect of temperature and precipitation change on insect and disease activity, (2) indirect effects of climate on plant physiology and natural defenses, and (3) indirect effects of climate on natural competitors and enemies (Ayres and Lombardero 2000). Effects of climate on insect and disease spread are ambiguous, depending on interannual variations in temperature, precipitation, and effects on competitors and natural defenses against insect and disease spread (Dale et al. 2001). However, ranger districts with a relatively high share of area that is at risk of insect- and disease-related mortality and climate-induced vegetative change can be interpreted as having greater exposure to an existing stressor (insects and disease) and greater stress on vegetation from climate.

Most forests and districts have less than 20 percent of area at high risk of insect and disease mortality. A few ranger districts, mostly concentrated in northern New Mexico in the Santa Fe and the Carson National Forests, have between 25 and 45 percent of area at high insect and disease mortality risk (fig. 3.5). Overall, there is a negative correlation at the ranger district level between the likelihood of vegetative change and insect and disease mortality risk (correlation coefficient = –0.45); almost all of the ranger districts with greater than 50 percent of area at high or very high vegetative risk have relatively low mortality risk (<15 percent). Conversely, only one district (Sacramento Ranger District in the Lincoln National Forest) has high mortality risk on more than 20 percent of its acreage and at least 50 percent of its area at high or very high likelihood of vegetative change.

Summarized at the ranger district level, comparisons of insect and disease mortality and likelihood of vegetative change do not account for spatial intersections of the two variables; it is possible for most ranger districts that very little area is at high likelihood of both insect and disease mortality and vegetative change due to climate change (fig. 3.6). The lower and upper bound of areal intersection of high insect and disease mortality risk and high likelihood of vegetative change are calculated as:

$$lb_{IDMR,vrisk} = \max[0, -(1 - IDMR - vrisk)]$$
$$ub_{IDMR,vrisk} = \min[IDMR, vrisk]$$

Overall, most ranger districts have relatively low likelihood of experiencing both insect and disease risk and climate-induced vegetative change. Six ranger districts have potential areal intersection greater than 20 percent of total area; five of these are in either the Carson or the Santa Fe National Forests in northern New Mexico. Most ranger

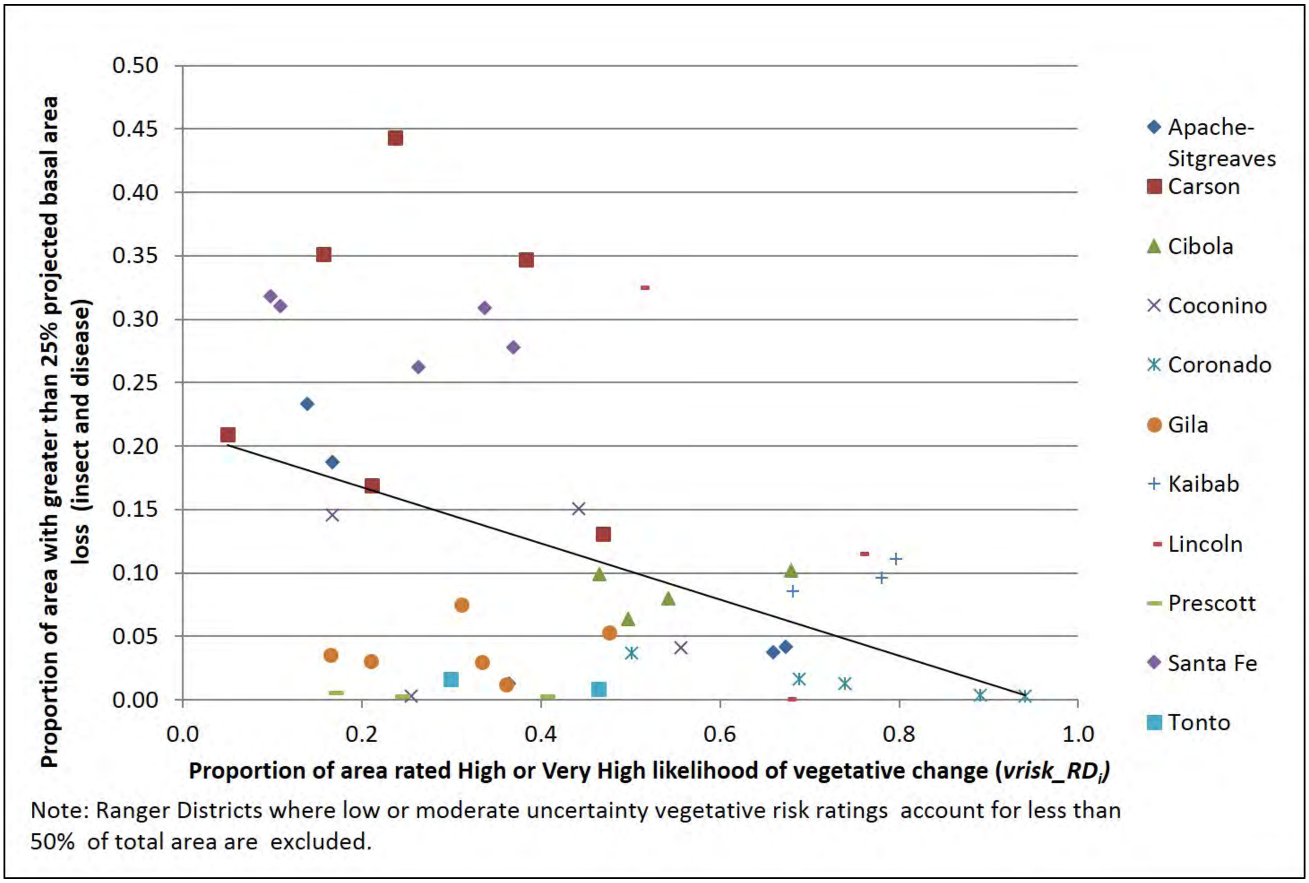


Figure 3.5—Scatter plot of climate-related likelihood of vegetative change and risk of basal area loss due to insects and disease in the Forest Service Southwestern Region, by forest and ranger district. The trend line indicates the average relationship between proportion of area with high likelihood of vegetative change and proportion of area with high projected basal area loss. The downward-sloping line indicates that ranger districts that have more land at high likelihood of vegetative change tend to have less area at risk of tree mortality due to insects and disease.

districts have a maximum areal intersection of less than 10 percent of ranger district area. However, the assessment of areal intersection of stressors does not specifically account for how climate change may interact with insect and disease risk. The insect and disease assessment does not specifically account for projected changes in climate, and under future climate and vegetative changes the risk of insects and disease potentially would be different than the current assessment indicates. The overall negative correlation between likelihood of vegetative change and mortality risk deserves further exploration, although this is beyond the scope of this assessment. For example, it would be useful to examine whether a more detailed model of insect and disease mortality that incorporates climate change would yield similar findings, or whether there is correlation between areas currently experiencing vegetative change and tree mortality.

Floods, Landslides, and Noxious and Invasive Plants

Interactions between disturbances and climate change may also have indirect effects on other hazards and disturbances, such as floods, landslides, erosion, and the spread of invasive plants. Climate change is likely to lead to changes in hydrology and the frequency and severity of floods, erosion events, and landslides (Ryan and Vose 2012). Severe and prolonged droughts are associated with severe fires and large erosion

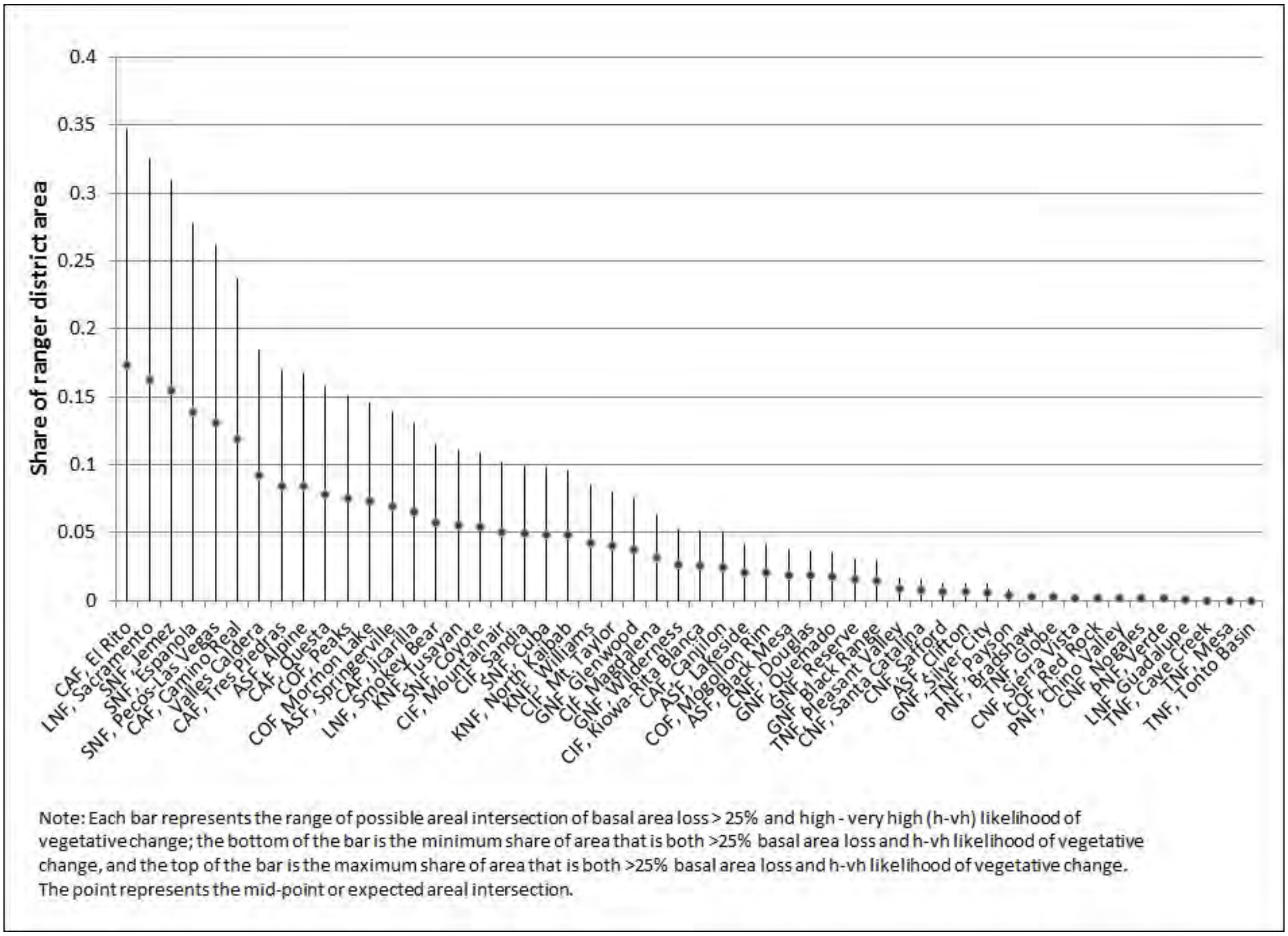


Figure 3.6—Potential areal intersection of basal area loss greater than 25 percent and high or very high likelihood of vegetative change in the Forest Service Southwestern Region, by ranger district. Ranger districts to the left of the chart have a greater proportion of area that is likely both to see vegetative changes and to have high projected tree mortality due to insects and disease. Note that because all of the bars extend to the bottom of the chart, it is possible in all ranger districts that there is no spatial overlap between high vegetative risk areas and high tree mortality areas. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

events (Pierce et al. 2004), which can result in major ecological transitions (Allen 2007). There is some evidence that climate change is associated with increased flooding risk, although several human and landscape factors also play a role and may confound the effects of a changing climate (Bronstert 2003).

The establishment and spread of invasive plants can alter fire regimes and ecosystem functions (Smith et al. 2000), affect the productivity and economic viability of rangelands that support livestock grazing (DiTomaso 2000), and reduce wildlife habitat quality (Masters and Sheley 2001). Climate change is expected to increase the establishment and spread of invasive plants, although the exact response of invasive and native plants to changing climatic and biological factors is not fully understood (Ryan and Vose 2012). Increased carbon dioxide (CO_2) concentration may favor the productivity of invasive species over native species (Smith et al. 2000), and some invasive species (e.g., cheatgrass, *Bromus tectorum*) may be promoted by higher temperatures but not necessarily increased CO_2 concentration (Blumenthal et al. 2016). Climate may affect invasive plants through several pathways, including altered opportunities for transport and introduction, changing climatic constraints (on native and invasive plants), the distribution and impact of existing invasions, and the effectiveness of control efforts (Hellmann et al. 2008). Projected declines in average productivity and increased variability in productivity (Reeves et al. 2014) also may provide opportunities for invasive species.

A challenge to assessing the effects of climate-related forest change on floods, landslides, erosion events, and invasive plants is a lack of regionwide data on their occurrence and severity. Further, multiple interacting factors that affect these hazards and disturbances may confound the effect of climate-related changes to forests. In general, areas at high risk of vegetative change (i.e., where the existing plant community may not be supported by the future climate), at high risk of damaging wildfires, and where insects and disease are likely to result in tree mortality are assumed to be more exposed to the risk of floods, landslides, erosion, and invasive plants. Although we do not directly assess the exposure to these hazards across the region, the next section assesses the intersection of likely vegetative change, wildfire hazard, and insect and disease mortality to identify areas in the region exposed to multiple climate-related stressors.

Intersecting Risk of Climate Change Effects and Disturbances

Combining the available geospatial data on disturbances (fire, insect and disease mortality) with the assessment of the likelihood of vegetative change provides additional insight into the areas of the region where multiple stressors may threaten the provision of ecosystem services. The expected share of area that is rated in the high or very high category of at least two of the three stressors (likelihood of vegetative change, wildfire hazard, and insect and disease mortality risk) is calculated for each ranger district (fig. 3.7).

Expected intersections are calculated by interpreting each area share as the probability that a given acre is in the high or very high category for a given stressor. Thus, the probability that a given acre is in the high or very high category for all three stressors is the product of each area share for that ranger district: $Pr(3) = vrisk \times IMDR \times WHP$. The probability of an acre being in the high or very high category for two stressors is the sum of the pairwise products of the three area shares: $Pr(2) = (vrisk \times IMDR + vrisk \times WHP + IMDR \times WHP)$.

Most ranger districts have relatively low expected area that is likely to be at high or very high risk of all three stressors; the highest value is less than 10 percent of ranger district area. Greater variation is evident for expected area affected by two stressors. Four ranger districts are expected to have at least 50 percent of area in the high or very high risk category for at least two stressors, yet about one-fifth of ranger districts are expected to have less than 10 percent of area in the high or very high risk category for at least two stressors.

Uses and Roles of Ecosystems in the Southwest

The assessment of the likelihood of vegetative change and disturbances is useful for evaluating the exposure of Southwestern forests and grasslands to climate-related changes in the provision of ecosystem services. Vegetative change and changing disturbance regimes may alter the provision of water, recreation opportunities, grazing, and

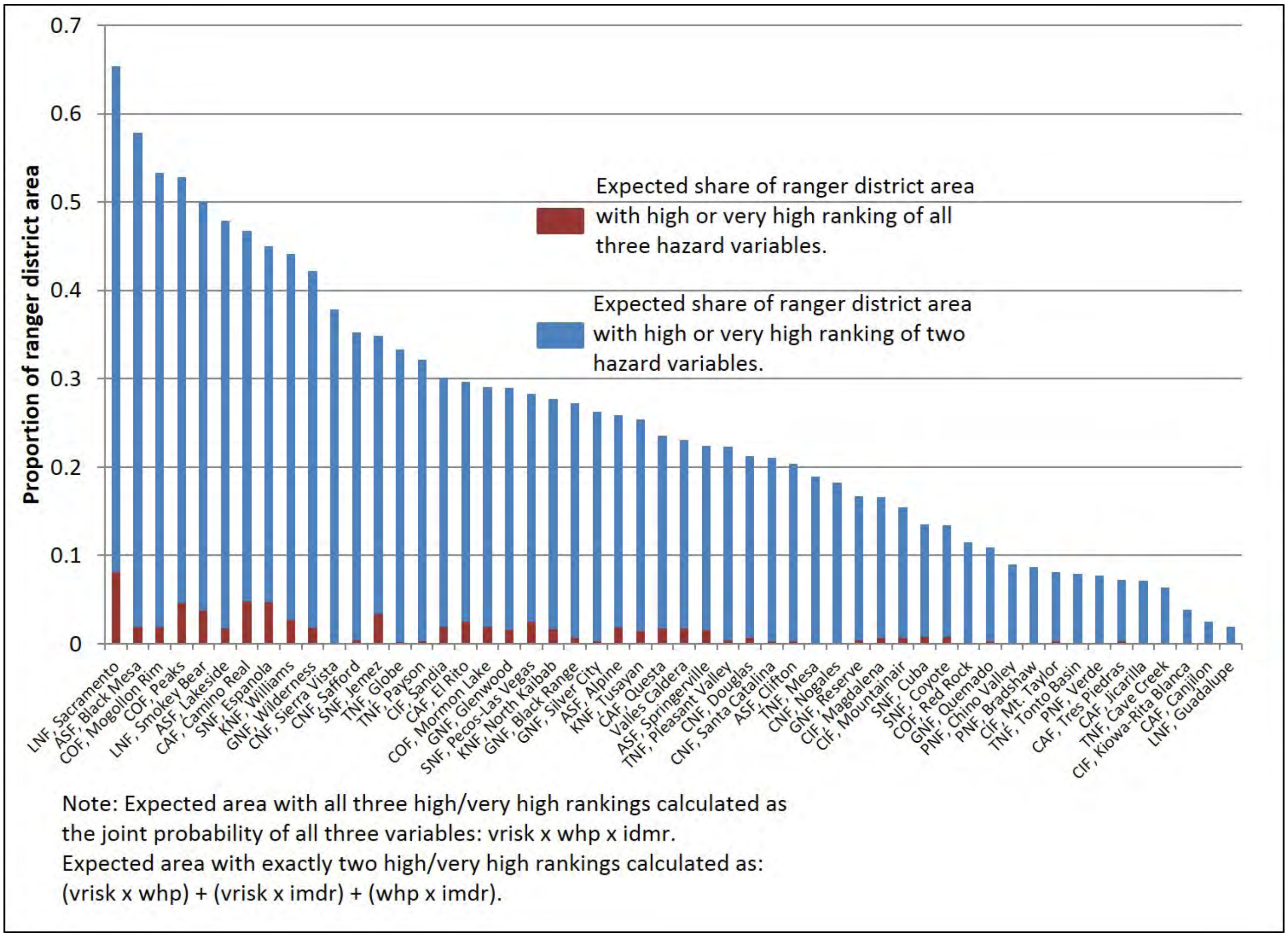


Figure 3.7—Expected intersection of likelihood of vegetative change, wildfire hazard, and insect and disease mortality risk in the Forest Service Southwestern Region, by ranger district. The height of the red bars indicates the expected proportion of area in each ranger district where all three hazard variables are rated as high or very high. The height of the blue bars indicates the expected proportion of ranger district area where at least two of the three hazard variables are rated as high or very high. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

commercial and noncommercial forest products. In turn forest regulating services (e.g., long-term storage of carbon, climate regulation, water filtration, soil stabilization) and forest supporting services (e.g., pollination, seed dispersal, nutrient cycling) can change. Forest- and grassland-supported cultural services (e.g., education, aesthetics, spiritual connection, recreation experiences, tourism opportunities) may also be affected. These relationships are broadly recognized, but spatial data (where available) can provide more detailed information on the extent of threat to many of these uses and the spatial distribution of areas that are relatively more or less exposed to climate-related changes.

Forage for Livestock

Areas available for livestock grazing cover more than 15 million acres of national forests and grasslands in the Southwest (calculated by summing the total area in range management units where livestock operators may have permits to graze livestock). Public rangelands are an important source of forage for livestock operators in the western United States. Grazing on public lands supports employment and income in local economies (discussed further in Chapter 4) and cultural traditions in Southwestern communities that date back to the earliest European settlement of the region (Atencio 2004). Rangelands also provide a variety of nongrazing ecosystem services, such as cultural heritage services, biodiversity, wildlife habitat, and offsite scenic and lifestyle amenities enjoyed by nearby residents and communities (Brown and MacLeod 2011; Havstad et al. 2007; Torell et al. 2005).

Increased CO_2 concentrations and changes in temperature and precipitation directly affect the productivity of rangelands. Increased CO_2 concentrations and longer growing seasons may increase productivity on rangelands (Baker et al. 1993), but higher temperatures and increased variability of precipitation, interactions with disturbances such as fire and invasive plants and hazards such as erosion and landslides, and increased human impacts may stress rangeland productivity in some areas (Chambers and Pellant 2008). Greater climate variability can also have an impact; for example, optimal livestock stocking rates may decline as precipitation becomes more variable (Ritten et al. 2010). In the Southwest, projections of the effects of climate change on forage quantity and cattle production indicate overall reductions in rangeland productivity and increased vulnerability of cattle production in the future (Reeves and Bagne 2016).

An assessment of the exposure of forage for livestock to climate-related forest and grassland changes relies on identifying areas that are important for livestock grazing and most at risk of vegetative change. Most of the area within national forest and grassland boundaries is part of range management units (RMUs). Vegetative risk for RMUs is summarized by joining ERU polygons and vegetative risk ratings to RMU polygons defined by the Southwestern Region. For each RMU polygon, vegetative risk is defined as the share of area that is rated at high or very high risk of vegetative change, or:

$$\text{vrisk\_RMU}_i = (\text{acres\_high}_i + \text{acres\_vhigh}_i)/\text{total\_acres}_i. \quad (1)$$

Similar to the forest- and ranger district-level summaries, both the numerator and denominator are calculated based on vegetative likelihood ratings that are of low or moderate uncertainty (see box 1 for details of the uncertainty ratings).

To examine the exposure of grazing activities to vegetative risk due to climate change, RMU vegetative risk summaries are paired with the number of permitted animal unit months (AUMs) associated with each RMU. Grazing exposure to vegetative risk is calculated as the number of permitted AUMs on an RMU (AUM_RMU_i) multiplied by the share of area at high or very high risk of vegetative change (vrisk_RMU_i, calculated from equation 1), or:

$$\text{grazing\_exposure\_RMU}_i = \text{vrisk\_RMU}_i \times \text{AUM\_RMU}_i. \quad (2)$$

Permitted AUM data are gathered from individual livestock grazing permits through the Forest Service Natural Resource Manager iWeb data management application. Each RMU may be associated with one or more livestock grazing permits, which are summed to the relevant RMU. Grazing exposure is measured by using permitted AUMs, which summarize the agreed-upon number of animals, by species, and timing of grazing allowed under the permit. In any given year a permittee may be authorized to graze more or fewer AUMs, and permittees may graze a number of AUMs that differs (generally lower) from the authorized number. Permitted AUMs are used as a measure of long-term

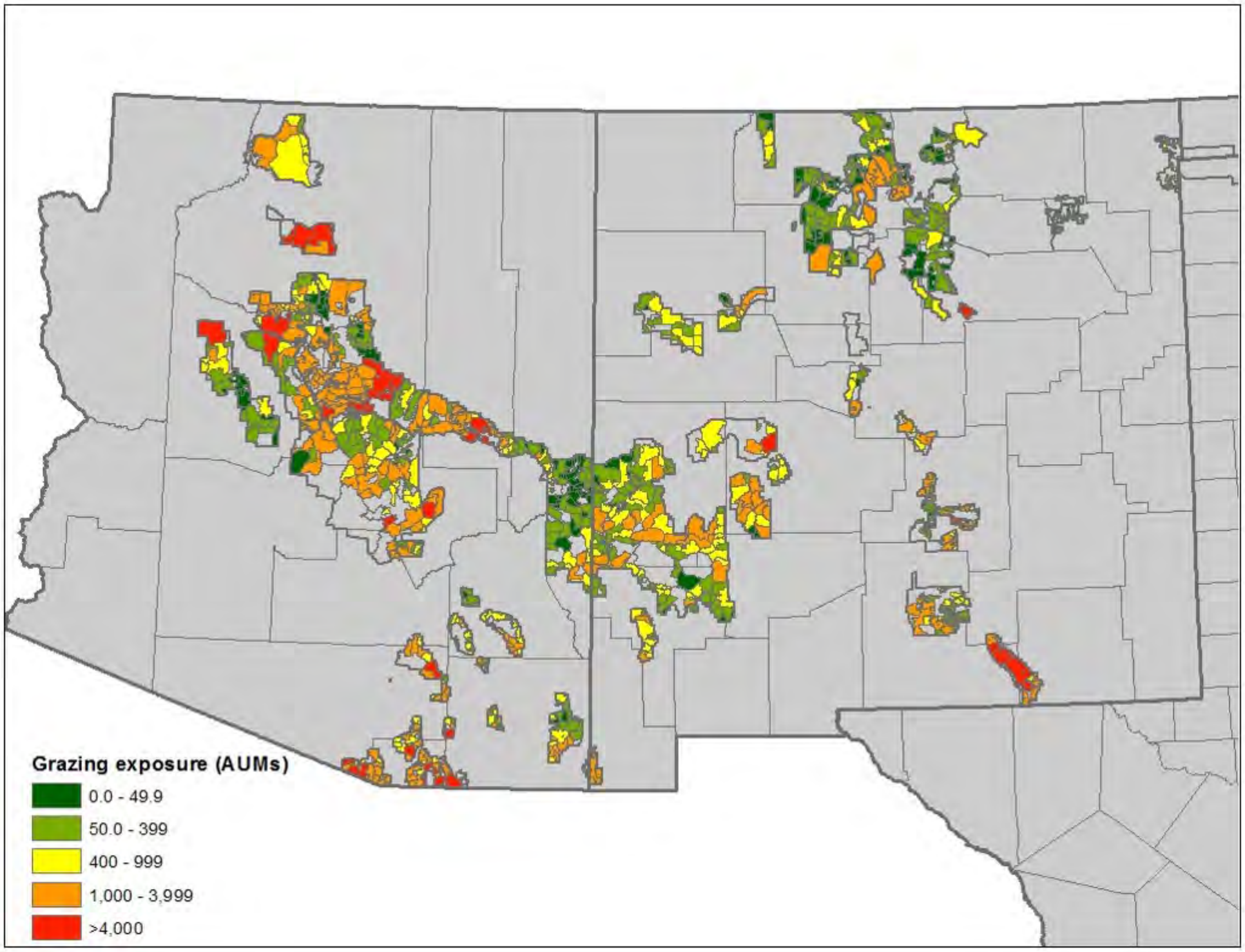


Figure 3.8—Exposure of permitted animal unit months (AUMs) to climate-induced vegetative change on national forest and grassland range management units in the Forest Service Southwestern Region. Red and orange areas indicate high grazing exposure, or areas where a large number of permitted AUMs graze on land that is rated at high or very high likelihood of vegetative change. Green areas indicate low exposure, or areas where few AUMs are permitted to graze on land rated at high or very likelihood of vegetative change.

expected carrying capacity of each RMU, even though the actual number of animals that graze an RMU may differ from the permitted number.

Total grazing exposure (fig. 3.8) amounts to more than 900,000 AUMs, or about 43 percent of all permitted AUMs in the region. However, significant variation in grazing exposure exists within the region (fig. 3.9). Although all forest and grassland units have some areas of high exposure, the Coronado in Arizona accounts for a large share (about 28 percent) of exposed AUMs in the region. Three Coronado ranger districts are among the five districts with the highest number of exposed permitted AUMs. Ranger districts on forests in northern New Mexico (the Santa Fe and the Carson) tend to have fewer exposed AUMs due to a combination of lower total numbers of permitted AUMs and lower average likelihood of vegetative change on RMUs in these forests. The finding of within-region variation in exposure is useful for interpreting broader-scale analyses of grazing vulnerability (e.g., Reeves and Bagne [2016]) that find interregional variation in vulnerability and overall higher vulnerability in the Southwest. However, the assessment

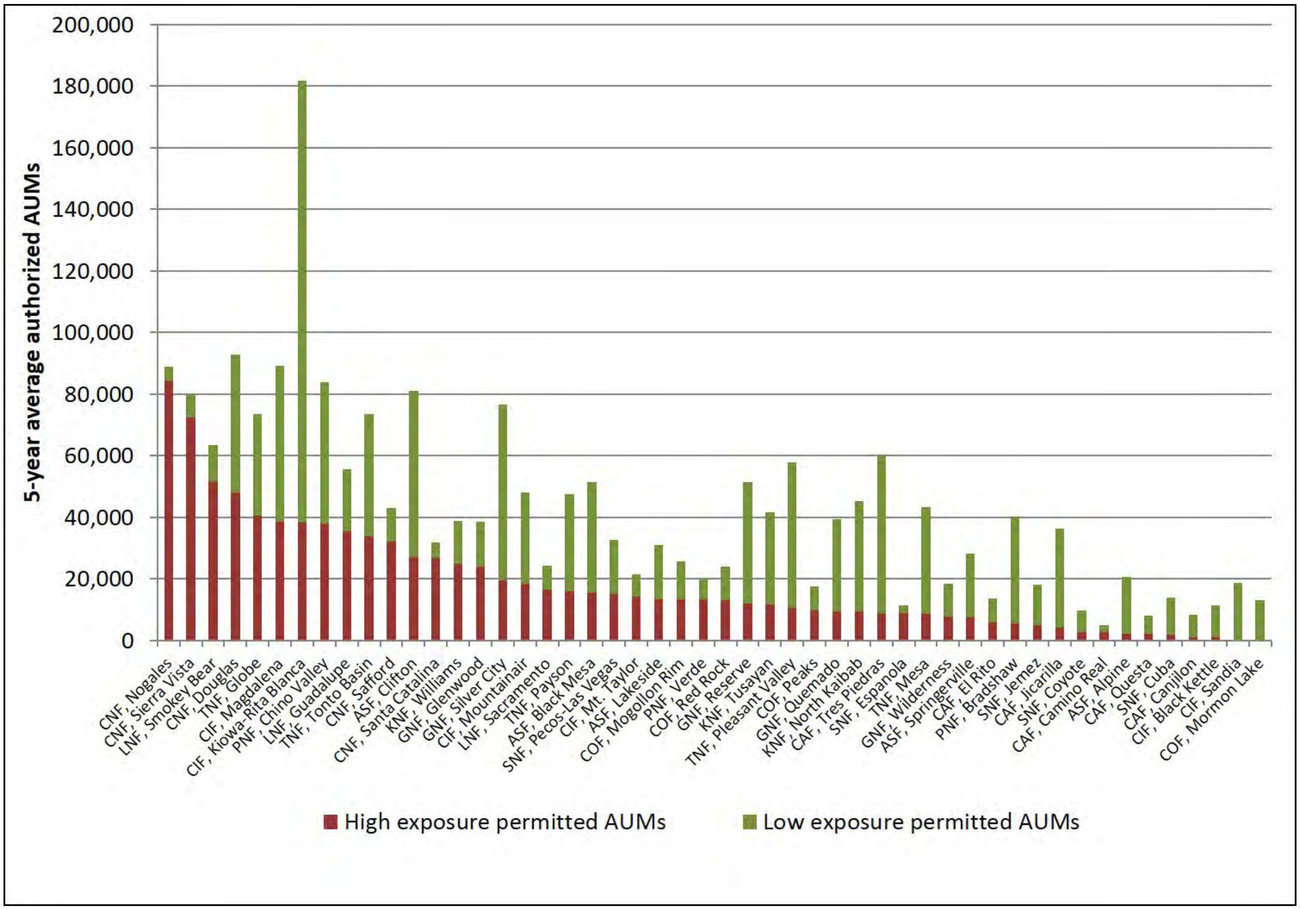


Figure 3.9—Permitted animal unit months (AUMs) on range management units with high and low exposure to vegetative change in the Forest Service Southwestern Region, by ranger district. Bar height indicates total permitted AUMs on all range management units (RMUs) managed by each ranger district. High-exposure AUMs (red bars) are calculated as the total authorized AUMs multiplied by the share of RMU area that is at high or very high likelihood of vegetative change (i.e., grazing_exposure_RMU from equation 2). For example, if 1,000 AUMs are permitted to graze on a ranger district where 50 percent of the land is rated at high or very high likelihood of vegetative change, exposed AUMs would equal 500 AUMs (1,000 × 0.5). Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

here does not account for potential changes in rangeland productivity that are not captured in the likelihood of vegetative change.

Surface Water Supply

National forests and grasslands have long been recognized as an important source of surface water for downstream users. The historical establishment of many national forests was predicated on the protection of key watersheds (Steen 2004: Chapter 2).

The combination of an arid climate in the Southwest, rapid urbanization and population growth, and a changing climate may stress water users. Recent changes in hydrology in the region are likely to have been caused by human activities, suggesting that future changes in climate will lead to reductions in water availability (Barnett et al. 2008). In general, climate change is likely to result in a transition to a drier climate with more severe droughts and reduced surface water runoff (MacDonald 2010; Seager et al. 2007), and reductions in water storage, downstream releases (e.g., to Texas and Mexico), and hydropower generation. Climate change is also likely to affect complex interactions between hydrology and indirect impacts of climate variability, including increased incidence of floods, droughts, low-flow conditions, erosion events, and landslides (Ryan and Vose 2012).

The distribution and type of vegetation are important factors that determine surface water stream flows, although the magnitude and direction of effects of changes in vegetation depend on local and regional characteristics (Ryan and Vose 2012). Vegetation has an impact on the timing, magnitude, and seasonality of runoff (Brown et al. 2005), which affect water availability for downstream surface water users.

Identification of watershed exposure to climate-related changes to national forest lands is based on the likelihood of vegetative change due to climate change and the importance of watersheds for surface water users. Likelihood of vegetative change is used as a proxy for climate impacts that may affect surface water supply. Greater likelihood of vegetative change is interpreted as an indicator of greater exposure to climate-related changes to surface water supply. However, we do not attempt to develop a detailed hydrological model of water supply responses to climatic changes, or discern whether climate-induced changes to vegetation on important watersheds is likely to increase or decrease supply in the future.

The importance of watersheds within national forest and grassland boundaries for municipal surface drinking water is summarized by using Forests-to-Faucets data from Weidner and Todd (2011). The 12-digit Hydrologic Unit Code (HUC) watershed polygons are joined to national forest and grassland boundaries, and vegetative risk ratings of ERU polygons are summarized for each HUC that intersects a national forest and grasslands area. Watersheds in Arizona and New Mexico are included, but the few watersheds associated with grasslands in Oklahoma and Texas are not included because the vegetative risk data do not cover these areas. Similar to the RMU summary and the national forest and ranger district summary, vegetative risk for each HUC is calculated as the share of area at high or very high vegetative risk. For the many 12-digit HUCs that are only partially within forest or grassland boundaries, vegetative risk is calculated by using only the ERU-level polygons that fall within the boundaries of both the 12-digit HUCs and forests or grasslands.

Importance of surface water sources for municipal drinking water is measured by using the ‘IMP’ index field in the Forests-to-Faucets data. The value of IMP for each 12-digit HUC is a standardized index value between 0 and 100 that summarizes relative mean annual water supply, the flow of water (e.g., from upstream to downstream watersheds), and water demand (i.e., of the municipality where water is eventually consumed).

Exposure of watersheds within national forests and grasslands to vegetative risk is calculated by multiplying the importance for surface drinking water (IMP_HUC) by the share of area in each HUC that is at high or very high likelihood of vegetative change, or:

$$\text{water\_exposure\_HUC}_i = \text{vrisk\_HUC}_i \times \text{IMP\_HUC}_i. \quad (3)$$

vrisk_HUC_i is calculated as:

$$\text{vrisk\_HUC}_i = {}^{(\text{acres\_high}_i + \text{acres\_vhigh}_i)}/\text{total\_acres}_i,$$

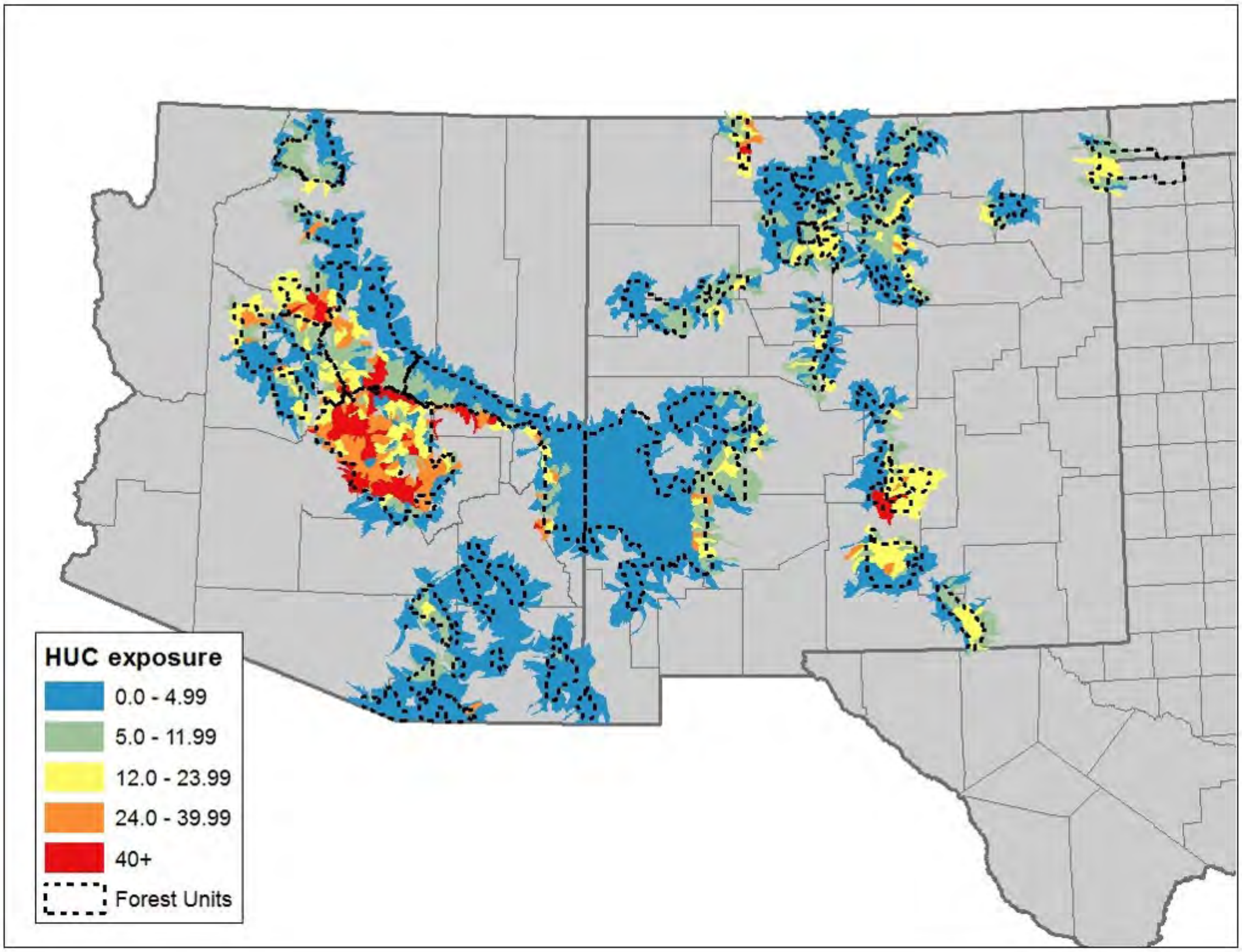


Figure 3.10—Watershed exposure to likelihood of vegetative change (water exposure HUC) in the Forest Service Southwestern Region, by 12-digit hydrologic unit code (HUC). Red and orange areas indicate important watersheds with high exposure to climate-induced vegetative change. Green and blue areas indicate important watersheds with low exposure to vegetative change.

where acres_high$_i$ and acres_vhigh$_i$ are the acreage within a given HUC that is at high and very high likelihood of vegetative change, respectively, and is the total acreage of a given HUC.

The calculation in equation 3 is consistent with the calculations of the exposure of watersheds to forest threats in Weidner and Todd (2011: equations 10 and 11), where IMP is multiplied by the percentage of area in each watershed that is forested and the percentage of area in each watershed that is highly threatened by development, insects and disease, or wildland fire. We extend this formulation by specifying vegetative risk as the threat to watershed health, and are concerned with the entire watershed area within national forest and grassland boundaries (rather than just the proportion of area that is forested) (fig. 3.10).

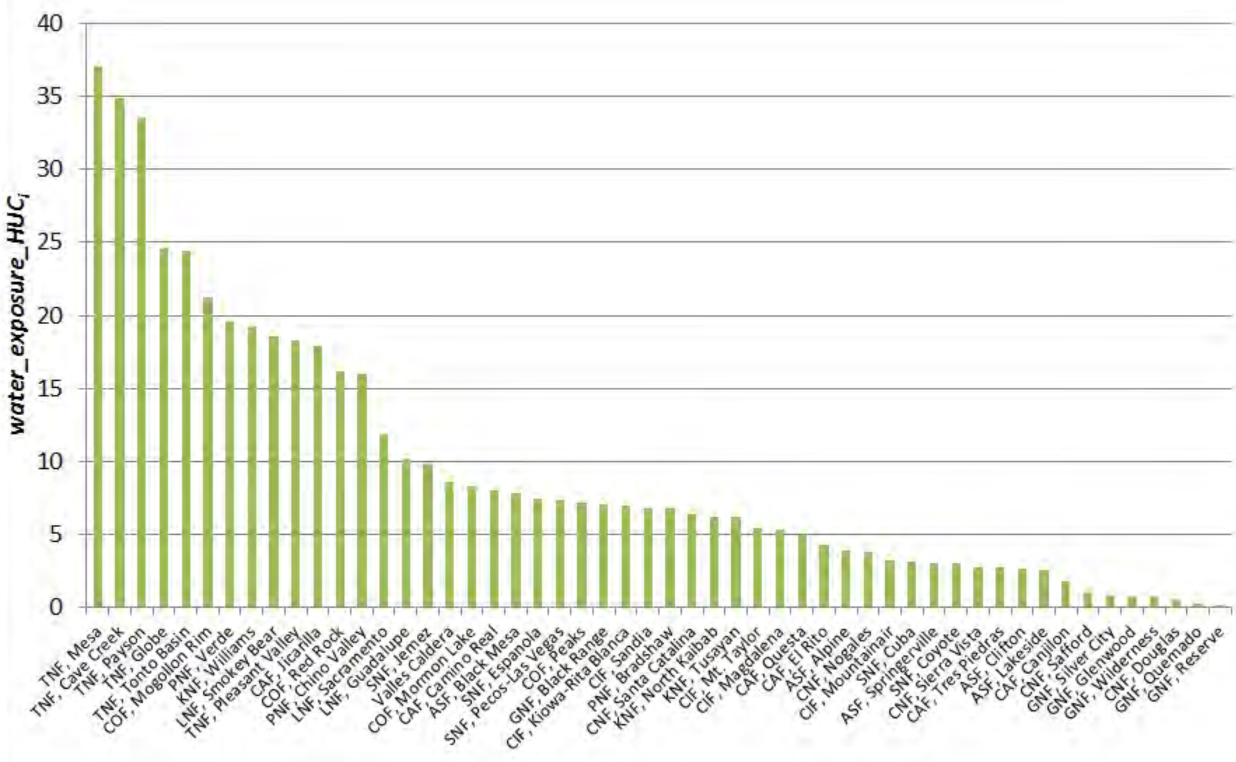
Surface drinking water exposure for each ranger district is calculated as the acre-weighted average of water_exposure_HUC$_i$ for all HUCs that intersect the relevant geographic area. For example, average water exposure for ranger district *j* is calculated as:

$$\text{water\_exposure\_RD}_j = \sum_i (a_{ij} \times \text{water\_exposure\_HUC}_{ij}),$$

where a_{ij} is the share of area in ranger district *j* that is in watershed *ij*.

Several ranger districts exhibit low average exposure to climate-related changes to municipal watersheds (fig. 3.11). Twenty ranger districts have water exposure values less than 5, indicating that watersheds within those districts exhibit some combination of relatively low importance for surface drinking water and low likelihood of climate-induced vegetative change. Several of the low-exposure ranger districts are relatively remote, including most of the districts in the Gila National Forest.

The highest-exposure ranger districts tend to be associated with surface water sources that supply the Phoenix, Arizona, metropolitan area. For example, all of the districts in the Tonto National Forest are among the 10 most exposed ranger districts, and 9 of the 10 most exposed RDs include watersheds that drain into the Salt-Verde Rivers system, which is an important surface water source for Phoenix.



Note: Ranger district averages are acre-weighted averages of HUC-12-level water_exposure_HUC for all watersheds within each ranger district. Larger values represent greater exposure of important watersheds to the likelihood of climate change -induced vegetative change.

Figure 3.11—Average exposure of watersheds to climate change-induced vegetative change in the Forest Service Southwestern Region, by ranger district. Higher bars indicate a greater exposure of important surface watersheds to climate-induced vegetative change. The index values are the product of the watershed importance index and the proportion of area rated at high or very high likelihood of vegetative change, summarized by ranger district. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

Significant variation in watershed importance and likelihood of vegetative change exists, even within ranger districts. For example, about 5 percent of watersheds are relatively important for surface drinking water but have low likelihood of climate-induced vegetative change. On the other hand, nearly 10 percent of watersheds are ranked as the lowest importance for surface drinking water (i.e., IMP_HUC = 0), but exhibit high or very high likelihood of vegetative change on at least 50 percent of land within the watershed.

Timber Products

Commercial timber production supports employment and income in local economies in the region (discussed further in Chapter 4), and noncommercial products provide subsistence and traditional values. In the Southwestern Region, total area of timberland has remained relatively steady since the mid-20th century, and net volume of growing stock on timberland has increased by about 59 percent (Smith et al. 2009: Appendix C, tables 10 and 20). Climate change is expected to affect the potential of forests to provide timber, although the exact nature of this impact is uncertain. Climate change is also likely to increase mortality of tree species (van Mantgem et al. 2009), and increased temperatures and drought stress are projected to result in increased tree mortality and forest decline in the Southwest (McDowell et al. 2015; Williams et al. 2010). In the United States, climate itself is projected to have a relatively small effect on timber, with projected increases in timber inventories and harvests (Irland et al. 2001) and changes in forest types (Wear et al. 2013).

Timber harvests in the United States are expected to remain steady or increase in the future, depending on future climate change and global economy scenarios (USDA Forest Service 2012a). Despite the potential for climate to result in increased mortality for tree species, the net effect of climate on the total benefits derived from timber is likely to be relatively small and positive (Sohngen and Mendelsohn 1998). However, the effect of climate change on timber species specific to the Southwest requires further study.

Detailed geospatial data on areas available and suitable for timber do not exist on a regionwide basis. However, the Forest Service Forest Inventory and Analysis program provides forest unit-level estimates of timberland, defined as forest land exclusive of reserved lands that is capable of producing at least 20 cubic feet of wood per acre per year; forest land is defined as land that is at least 10 percent stocked by forest trees and not currently developed for nonforest use (Nelson and Vissage 2007) (table 4).

Although limited data availability precludes a detailed analysis of climate-change effects on suitable timberland, the ERU vegetative risk data can be leveraged to identify areas where timber vegetation types may be at higher likelihood of change due to climatic changes. From table 2, Spruce-Fir Forest (ERU code SFF), Mixed Conifer with Aspen (ERU code MCW), Mixed Conifer – Frequent Fire (ERU code MCD), and Ponderosa Pine Forest (ERU code PPF) ERUs are identified as vegetation types that support species appropriate for timber production. Summarizing the likelihood of vegetative change for these ERUs can provide an indication of exposure to climate-related vegetative change for areas with vegetation types suitable for timber production. This summary does not estimate timber suitability areas. The vegetative risk analysis does

Table 4—Forest land and timberland[a] by national forest in the U.S. Forest Service Southwestern Region.

Forest unit	Forest land (acres)	Timberland (acres)	Timberland as share of forest land
Total, all forests	15,540,320	4,892,384	0.315
Apache-Sitgreaves	1,716,525	810,961	0.472
Carson	1,271,332	743,696	0.585
Cibola	1,206,497	304,242	0.252
Coconino	1,475,775	714,010	0.484
Coronado	1,239,542	48,899	0.039
Gila	2,907,867	720,252	0.248
Kaibab	1,331,613	488,486	0.367
Lincoln	843,542	181,802	0.216
Prescott	683,632	40,820	0.060
Santa Fe	1,538,155	724,279	0.471
Tonto	1,325,840	114,937	0.087

[a] Area in forest land and timberland are estimates based on sampling plots. Source: USDA Forest Service 2015a.

not filter on other characteristics that may indicate suitability for timber production, such as reserved land status (e.g., Wilderness Areas) or slope. See Nelson and Vissage (2007) for a description of estimates of spatially explicit timberland area.

In total, about 3.2 million acres of montane forest vegetation types are at high or very high risk of vegetative change (fig. 3.12), which represents slightly more than 50 percent of all montane forest vegetation on national forests in the region. The highest exposure ranger districts tend to have large tracts of timber vegetation (>100,000 acres) and a high percentage of timber vegetation at high or very high likelihood of change. The 12 highest-exposure ranger districts each have more than 100,000 acres of timber vegetation and greater than 60 percent of timber vegetation types at high or very high likelihood of change. On the other hand, a handful of ranger districts have large timber vegetation areas but relatively low exposure, including districts in Santa Fe and Carson National Forests.

Recreation

Outdoor recreation is an important benefit provided by national forests and grasslands in the Southwestern Region. National forests in the region receive an estimated 13.8 million visits per year and represent a wide variety of recreation activities and sites (USDA Forest Service n.d.). Recreation may be exposed to climatic changes because nature and ecosystem characteristics are key features of the overall outdoor recreation experience. This section summarizes recreation exposure to climatic changes on each forest unit for broad climate-sensitive recreation categories.

Climatic conditions and environmental characteristics that depend on climate determine the availability of and demand for different outdoor recreation opportunities (Shaw and Loomis 2008). Changing climatic conditions may alter the supply of and demand for recreation opportunities, resulting in changes in the amount and pattern of

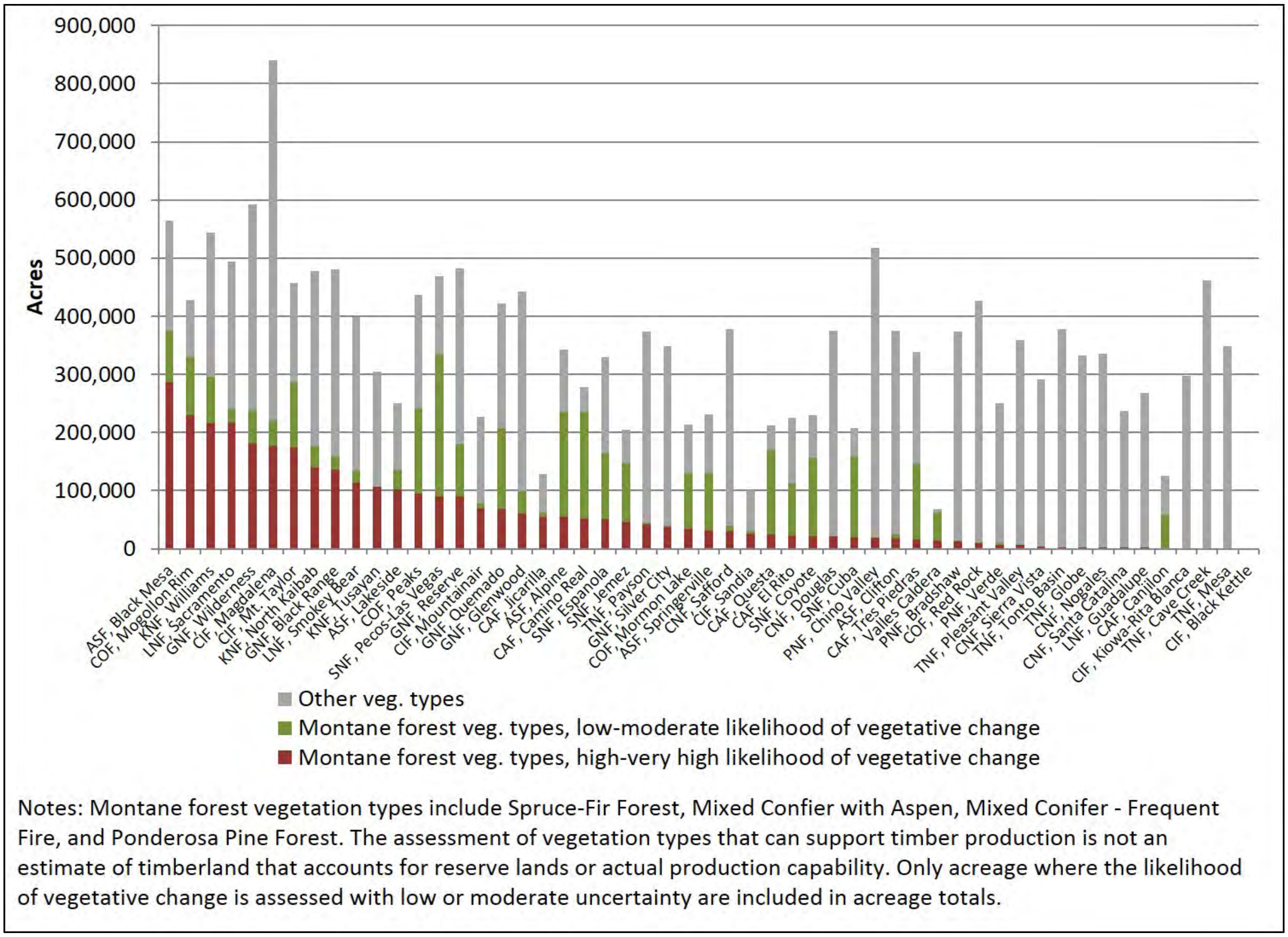


Figure 3.12—Area in montane and other forest vegetation types in the Forest Service Southwestern Region, by likelihood of vegetative change and ranger district. The combined height of each bar is the total area (in acres) of each ranger district. The combined height of the green and red bars is the total area in each ranger district that is predicted to currently be in montane forest vegetation types. The height of the red bars indicates the area of montane forest vegetation that is rated at high or very high likelihood of vegetative change. Abbreviations for national forests: ASF = Apache-Sitgreaves, CNF = Carson, CIF = Cibola, COF = Coconino, CNF = Coronado, GNF = Gila, KNF = Kaibab, LNF = Lincoln; PNF = Prescott; SNF = Santa Fe, TNF = Tonto.

recreation in the future. Climate change is projected to increase outdoor recreation participation in general, although variation in participation by specific activities is possible (Bowker et al. 2013). Benefits provided by recreation are expected to increase under climate change scenarios because increases in warm-weather activities are expected to outweigh losses in winter activities (Loomis and Crespi 2004; Mendelsohn and Markowski 2004).

The supply of and demand for recreation opportunities are sensitive to climate through two primary pathways: a direct effect of changes in temperature and precipitation on the availability and quality of recreation sites, and an indirect effect of climate on the characteristics and ecological condition of recreation sites (Loomis and Crespi 2004; Mendelsohn and Markowski 2004; Shaw and Loomis 2008). Direct effects are important for winter activities that are dependent on seasonal temperatures and the amount, timing, and phase of precipitation (Englin and Moeltner 2004; Irland et al. 2001; Stratus Consulting 2009). Warm-weather activities are also sensitive to direct effects of climate change; warmer temperatures are associated with increased outdoor recreation visits (Richardson and Loomis 2004; Scott et al. 2007), although extreme heat can reduce visitation.

Indirect climate effects may be important for recreation activities that depend on additional ecosystem inputs, such as wildlife, vegetation, and surface water. Indirect effects have been identified for cold-water fishing (Jones et al. 2013), boating, camping, and hiking (Loomis and Crespi 2004), and activities that involve highly valued natural characteristics (e.g., glaciers) (Scott et al. 2007). The indirect climate effect on disturbances, and wildfire in particular, may also play a role in recreation behavior, although the effect may be ambiguous and vary over time (Duffield et al. 2013; Englin et al. 1996, 2001; Hesseln et al. 2003, 2004; Loomis et al. 2001; Rausch et al. 2010; Starbuck et al. 2006).

To summarize the exposure of recreation to changes in climate, annual visitation to national forests and grasslands is estimated for broad primary activity categories. Primary activities are grouped into categories based on common effects of climate on the supply and demand of recreation opportunities drawn from previous research. National forest visitation for five primary categories is summarized: warm-weather activities, wildlife-related activities, snow-based winter activities, gathering forest products, and water-based activities (not including fishing) (table 5).

Overall, recreation visitation on national forests is expected to expand due to longer warm-weather seasons that would offset reduced winter recreation activities. However, effects will probably vary across the region. For example, several national forests currently have little or no snow-based winter recreation and thus have low exposure to climate effects on this category of recreation. On the other hand, these forests may have significant seasonal shifts in warm-weather recreation due to warming winter temperatures and increased likelihood of extreme temperatures in the summer.

Annual recreation visitation estimates for national forests in the Southwest indicate high visitation for warm-weather activities at all the forests (table 6). Across the Southwest, abundant days with sunshine and areas that are snow- and ice-free for much of the year provide ample opportunities for warm-weather recreation. The response of warm-weather recreation to climate change is likely to vary across the region. Areas where extreme heat is more likely to occur in the future (e.g., low-elevation sites) and where the winter season is already short may see decreases in warm-weather recreation. Other areas that become relatively more desirable in the future (e.g., high-elevation sites with less extreme heat) may have increases in warm-weather recreation.

Only the Carson and the Santa Fe National Forests attract a significant amount of winter recreation. These forests may undergo a decrease in winter recreation in the future as climate change results in shorter snow season and reduced site quality due to smaller and shorter-duration snowpacks. Some recreationists may shift recreational demand to nonwinter activities as other opportunities expand; others may choose to engage in winter recreation activities on sites other than national forests or in other regions where winter site quality becomes relatively more desirable.

Wildlife recreation is relatively important on several national forests, particularly the Gila and the Apache-Sitgreaves. However, the effect of climate-related forest changes on these activities is ambiguous. The effect on national forest recreation depends on local effects of climate on wildlife habitat and populations, and on the quality of national forest recreation sites relative to opportunities on State-owned and privately

Table 5—Climate-sensitive recreation activity categories and expected effects of climate on future recreation participation on Southwestern Region national forests.

Activity	Sensitivity to direct and indirect climate changes	Expected effects of climate on participation
Warm-weather activities Hiking/walking Viewing natural features Developed camping Bicycling Other nonmotorized	Participation typically occurs during warm weather; dependent on the availability of snow- and ice-free sites, dry weather with moderate daytime temperatures, and the availability of sites where air quality is not impaired by smoke from wildfires.	Warming temperatures (+); higher likelihood of extreme temperatures (-); increased incidence, area, and severity of wildfire (+/-); increased smoke from wildfires (-)
Wildlife activities Hunting Fishing Viewing wildlife	Wildlife is a significant input for these activities. Temperature and precipitation are related to habitat suitability through effects on vegetation, productivity of food sources, species interactions, and water quantity and temperature (for aquatic species). Disturbances (wildland fire, invasive species, and insect and disease outbreaks) may affect the amount, distribution, and spatial heterogeneity of suitable habitat.	Warming temperatures (+), higher incidence of low stream flows (fishing, -); reduced snow pack (hunting, -); increased incidence, area, and severity of wildfire (terrestrial wildlife, +/-); reduced cold-water habitat, incursion of warm-water tolerant species (fishing, -)
Winter activities Downhill skiing Snowmobiling Cross-country skiing	Participation depends on the timing and amount of precipitation as snow and cold temperatures to support consistent snow coverage. Inherently sensitive to climate variability and interannual weather patterns.	Warming temperatures (-); reduced precipitation as snow (-)
Gathering forest products	Depends on availability and abundance of target species (e.g., berries, mushrooms), which are related to patterns of temperature, precipitation, and snowpack. Disturbances may alter the availability and productivity of target species in current locations, and affect opportunities for species dispersal in new locations.	Warming temperatures (+); increased incidence, area, and severity of wildfire (+/-)
Water-based activities, not including fishing	Participation requires sufficient water flows (in streams and rivers) or levels (in lakes and reservoirs). Typically considered a warm-weather activity, and depends on moderate temperatures and snow- and ice-free sites. Some participants may seek water-based activities as a refuge from heat during periods of extreme heat.	Warming temperatures (+); higher likelihood of extreme temperatures (-)

Note: Positive (+) and negative (-) signs indicate expected direction of effect on overall benefits derived from recreation activity.

owned lands. For example, in New Mexico some private landowners have an incentive to maintain ranchlands to support game species through a State program that grants tradable hunting permits outside of the normal permit lottery system (New Mexico Department of Game and Fish 2016a,b). The relative attractiveness of private versus public lands for hunting depends in part on climate effects to habitat and the ability of landowners to make investments on their land that support game populations.

Table 6—Estimates of share of annual recreation visits to Southwestern Region national forests by primary activity category.

Forest unit	Warm-weather activities	Snow-based winter activities			Wildlife activities	Gathering forest products	Water-based activities (not incl. fishing)
		All	Downhill skiing	Cross-country skiing + snowmobiling			
Apache-Sitgreaves	0.408	0.0	0.0	0.0	0.246	0.005	0.017
Carson	0.309	0.426	0.332	0.094	0.115	0.023	0.010
Cibola	0.652	0.037	0.031	0.006	0.100	0.016	0.0
Coconino	0.662	0.054	0.045	0.009	0.060	0.005	0.015
Coronado	0.751	0.0	0.0	0.0	0.082	0.005	0.010
Gila	0.388	0.0	0.0	0.0	0.309	0.001	0.001
Kaibab	0.420	0.005	0.005	0.0	0.144	0.005	0.005
Lincoln	0.672	0.061	0.061	0.0	0.059	0.009	0.0
Prescott	0.652	0.0	0.0	0.0	0.095	0.003	0.022
Santa Fe	0.664	0.174	0.083	0.091	0.074	0.001	0.008
Tonto	0.330	0.0	0.0	0.0	0.140	0.0	0.089

Source: RMRS calculations of National Visitor Use Monitoring (NVUM) survey responses, round 2 (Apache-Sitgreaves, Carson, Lincoln, Santa Fe, and Tonto) and round 3 (Cibola, Coconino, Coronado, Gila, Kaibab, and Prescott) (USDA Forest Service 2015b). Visits are grouped into activity categories based on reported primary activity participated in during the visit.

Composite Exposure of Ecosystem Services to Climate Change

The assessments of ecosystem services and climate-related disturbances illustrate that ecological conditions and exposure to climate change vary widely within the region. Yet combining the assessments can help identify areas in the region where multiple ecosystem services may be exposed to climate change and other stressors. To summarize composite exposure of ecosystem services to climate-related changes, each ranger district is ranked based on its score on four exposure measures: intersecting climate-related stressors (likelihood of vegetative change, wildfire hazard, and insect and disease mortality), important surface watersheds, timber products, and livestock grazing resources. Recreation is not included as a ranked exposure measure because recreation visitation is not directly compared to downscaled climate projections that may affect benefits derived from recreation. For each of the four measures, ranger districts are given a score based on their quartile rankings, where the lowest exposure quartile receives a score of 1, and the highest exposure quartile receives a score of 4. Summing the quartile scores across the four measures yields a composite exposure score (table 7, fig. 3.13).

Few ranger districts exhibit high or low exposure across all measures. Canjilon Ranger District in the Carson National Forest ranks in the lowest quartile for all four measures, resulting in the lowest possible composite exposure score. Smokey Bear Ranger District in the Lincoln National Forest ranks in the highest quartile for all measures and has the highest composite score. Aside from these two districts, all districts fall somewhere between the extremes in the composite exposure ranking.

Summary

This chapter has attempted to assess the potential effects of climate-related changes to national forests and grasslands on the provision of ecosystem services in the Southwest. The assessment is based on a geospatial intersection of projected effects of climate change on vegetation, the existence of climate-related stressors (wildfire hazard and insect and disease mortality), and exposure of ecosystem services to climate-induced vegetative change.

Broad-scale assessments of climate change impacts suggest that the Southwest will experience increases in temperature, more frequent and long-lasting drought, reduced surface water runoff and stream flows, more frequent and intense wildfires, and changing disturbance and natural hazard regimes. Yet significant heterogeneity of climate effects within the region is likely and exposure of climate-sensitive ecosystem services also shows within-region variation. For example, the Tonto Basin Ranger District in the Tonto National Forest ranks in the lowest exposure category for both intersecting stressors and timber products, but in the highest exposure category for municipal surface water and forage for livestock. The Wilderness Ranger District in the Gila National Forest shows the opposite results, even though the overall exposure score is similar to the Tonto Basin Ranger District. Although both ranger districts can be categorized as having moderate exposure to climate-related forest changes overall, differences in the sources of climate exposure and the ecosystem services exposed may be helpful for identifying adaptation and management priorities at a local level.

Table 7—Climate change exposure quartile ranks, by forest unit and ranger district.

National forest unit and ranger district	Quartile ranks					
	Veg. change	Intersecting stressors	Surface water	Livestock grazing	Timber products	Total exposure rating
Apache-Sitgreaves (mean)	*2.4*	*3*	*1.8*	*2.2*	*3*	*12.4*
Alpine	1	3	2	1	3	10
Black Mesa	4	4	3	3	4	18
Clifton	2	2	1	4	2	11
Springerville	1	2	2	1	2	8
Lakeside	4	4	1	2	4	15
Carson (mean)	*1.5*	*2.2*	*2.2*	*1.2*	*2.2*	*9.2*
Canjilon	1	1	1	1	1	5
El Rito	2	3	2	1	2	10
Jicarilla	3	1	4	1	3	12
Camino Real	1	4	3	1	3	12
Tres Piedras	1	1	1	2	2	7
Questa	1	3	2	1	2	9
Cibola (mean)	*3.3*	*1.5*	*2.3*	*3.5*	*3*	*13.5*
Mt. Taylor	3	1	2	3	4	13
Magdalena	3	2	2	4	4	15
Mountainair	4	2	2	3	3	14
Sandia	3	3	3	-	2	n/a
Black Kettle	-	-	-	-	-	n/a
Kiowa-Rita Blanca	3	1	3	4	1	12
Coconino (mean)	*2.7*	*3*	*3.7*	*2*	*3*	*14.3*
Peaks	3	4	3	2	4	16
Mormon Lake	1	3	3	-	3	n/a
Red Rock	2	1	4	2	1	10
Mogollon Rim	3	4	4	2	4	17
Coronado (mean)	*3.8*	*2.8*	*1.4*	*3.8*	*1.4*	*13.2*
Douglas	3	2	1	4	2	12
Nogales	4	2	2	4	1	13
Sierra Vista	4	4	1	4	1	14
Safford	4	4	1	4	2	15
Santa Catalina	4	2	2	3	1	12
Gila (mean)	*1.8*	*2.7*	*1.3*	*2.3*	*3.3*	*11.5*
Black Range	2	3	3	3	4	15
Glenwood	2	3	1	3	3	12
Wilderness	3	4	1	1	4	13
Reserve	1	2	1	2	3	9
Silver City	2	3	1	3	3	12
Quemado	1	1	1	2	3	8

Table 7—*Continued*.

National forest unit and ranger district	Quartile ranks: Veg. change	Intersecting stressors	Surface water	Livestock grazing	Timber products	Total exposure rating
Kaibab (mean)	*4*	*3.3*	*2.7*	*2.3*	*4*	*16.3*
Williams	4	4	4	3	4	19
North Kaibab	4	3	2	2	4	15
Tusayan	4	3	2	2	4	15
Lincoln (mean)	*3.7*	*3*	*3.3*	*3.7*	*3*	*16.7*
Smokey Bear	4	4	4	4	4	20
Sacramento	3	4	3	3	4	17
Guadalupe	4	1	3	4	1	13
Prescott (mean)	*1.7*	*1*	*3.3*	*2.3*	*1.7*	*10*
Chino Valley	2	1	4	4	2	13
Bradshaw	1	1	2	1	2	7
Verde	2	1	4	2	1	10
Santa Fe (mean)	*1.6*	*3*	*2.4*	*1.6*	*2.6*	*11.2*
Coyote	1	2	1	1	2	7
Cuba	1	2	2	1	2	8
Jemez	2	4	3	1	3	13
Pecos-Las Vegas	2	3	3	3	3	14
Española	2	4	3	2	3	14
Tonto (mean)	*2.8*	*2*	*4*	*2.8*	*1.3*	*13*
Cave Creek	3	1	4	3	1	12
Globe	3	3	4	4	1	15
Mesa	4	2	4	1	1	12
Payson	3	3	4	3	3	16
Pleasant Valley	2	2	4	2	1	11
Tonto Basin	2	1	4	4	1	12
Valles Caldera[a]	*1*	*2*	*3*	-	*2*	*n/a*

For each measure, a value of 1 indicates the lowest exposure quartile, while a value of 4 indicates highest exposure. Higher numbers for the total exposure rating indicate greater exposure to climate-related ecological changes. Numbers in italics for each forest are means of the values for each ranger district within that forest.

[a] A national preserve administered by the National Park Service.

The exposure assessment is subject to several limitations. First, the assessment does not quantify all of the pathways that may lead to ecological changes in the future. The focus is on potential climate-induced vegetative change and interactions with existing climate-related disturbances. Other pathways, such as the effects of changing population distributions or direct effects of changes in temperature and precipitation on ecosystem services, may be correlated with vegetative change and disturbances.

Second, this chapter specifically addresses exposure to only a handful of the ecosystem services that may be important in the region. More comprehensive or geographically detailed data are needed to conduct a similar assessment on additional ecosystem services. Some of these data may be available for particular forest units or ranger districts at the local level.

Finally, projections of vegetative change are created by using a single emissions scenario (A1B) and global circulation model (CGCM3); results for specific geographic areas or ecosystem services may be sensitive to the choice of scenario and model to generate likelihood of vegetative change ratings. Neither the emissions scenario nor the future realization of climate-related ecological changes is known with certainty.

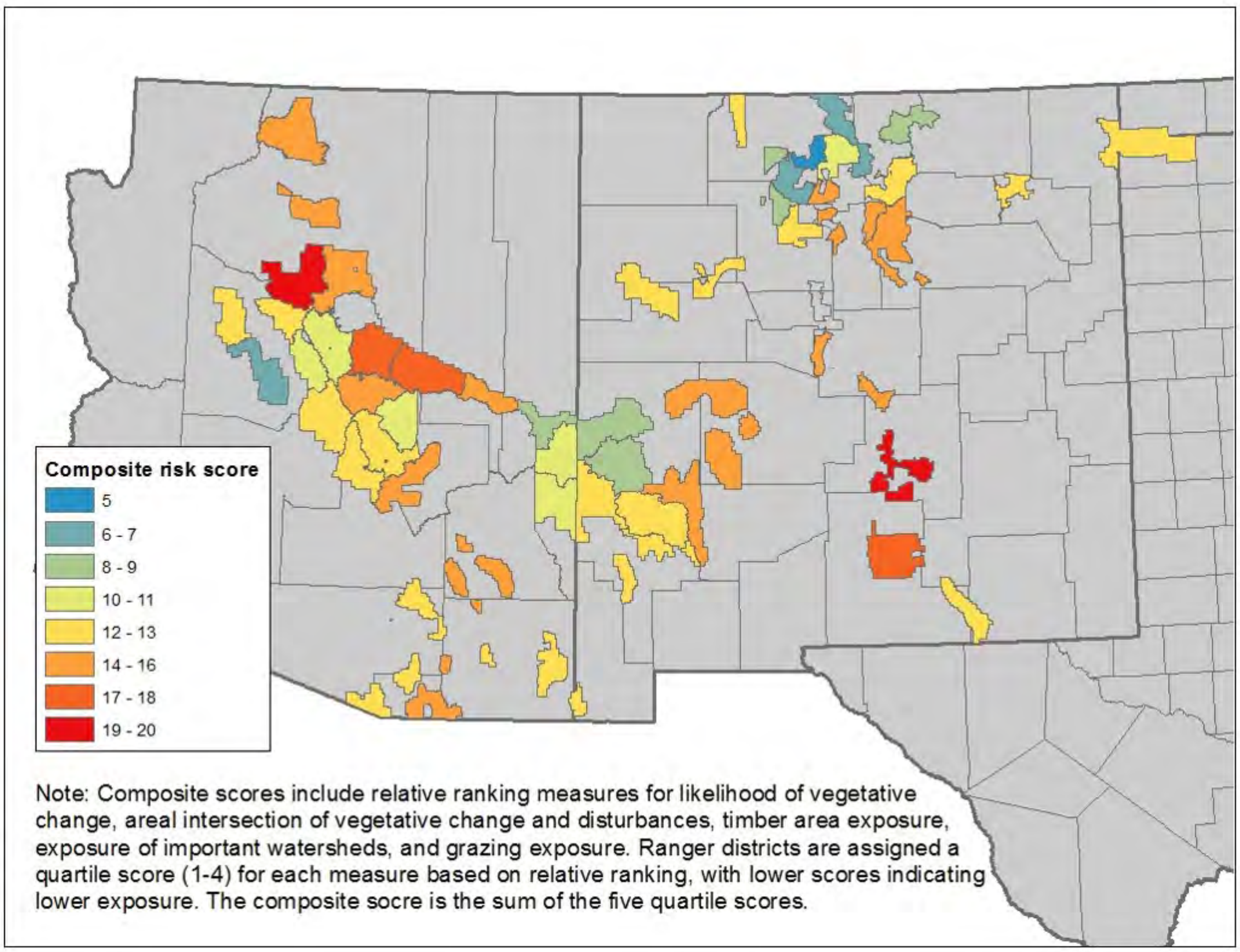


Figure 3.13—Composite risk scores for climate and disturbance vulnerability of ecosystem services in the Forest Service Southwestern Region, by ranger district. Orange and red areas (higher composite scores) indicate higher combined exposure; green and blue areas (lower composite scores) indicate lower combined exposure.

Chapter 4: Economic Dependence on Ecosystem Services Supplied by Southwestern Region National Forests and Grasslands

Communities in the Southwest depend on ecosystem goods and services from national forests and grasslands in many ways and to various degrees. Patterns of use and trade of ecosystem services, along with other economic characteristics at the local and regional level, influence economic dependence. This chapter provides an analysis of economic dependence on a subset of the ecosystem goods and services listed in table 1.

Regional and subregional economic reliance on ecosystem services can be measured through market transactions and nonmarket expressions of value. Contributions to employment and income from market transactions of ecosystem goods are measured by using input-output (I-O) analysis conducted with IMPLAN (IMPLAN 2013). We examine variation across the region in employment and income that can be attributed to ecosystem services from Forest Service lands. This analysis provides insight into the economic reliance of local economies and sectors on ecosystem goods and services provided by national forests and grasslands in the region. The I-O analysis examines goods and services related to recreation, grazing, and forest products.

This chapter also considers economic dependence on other ecosystem services in a qualitative way. These assessments evaluate the reliance on water provided by forests, firewood gathered for personal use and home heating, offsite amenity values, and cultural and spiritual values to the degree possible with available regionwide data and information.

Assessing Market Dependence on Forest Resource Sectors by Using Input-Output Analysis

The conceptual model of household production in Chapter 2 relies on the assumption that households use ecosystem goods and services from forests and grasslands to produce other utility-bearing goods and services. Many inputs from ecosystems are obtained or accessed through market transactions. The value of those transactions (in dollars) provides evidence of the amount of economic activity that depends on ecosystem services traded in markets. Further, well-being in the household production model depends in part on household income; examining employment and income derived from market transactions of ecosystem services indicates the degree to which household well-being is dependent on ecosystem-derived goods and services that may be affected by climatic changes.

Economic contributions of ecosystem services are measured by estimating the direct jobs and labor income generated by expenditures made by recreational visitors to national forest lands, livestock grazing on national forests and grasslands, and logging and processing of forest products derived from national forests. These broad economic sectors are selected because they are closely tied to ecosystem services provided by national forests and grasslands in the region and direct expenditure and activity data for these sectors are available for all forests in the region. Additional indirect and induced multiplier effects on income and employment are generated by the direct expenditures in the I-O model due to relationships between economic sectors (e.g., input markets that support markets where direct expenditures occur). Indirect contributions occur when a firm purchases supplies and services (inputs) from firms in other sectors to produce its products (outputs); induced contributions occur as a result of household spending of income from direct and indirect employment. The direct and multiplier effects compose the total economic contribution to the local economy captured in the analysis.

I-O analysis is a means of examining relationships within an economy, both between businesses and between businesses and final consumers; it captures all monetary market transactions for consumption in a given time period (Miernyk 1965). The resulting representation allows examination of the effect of a change in one or several economic activities on an entire economy, all else constant (see box 2).

IMPLAN is the I-O modeling tool most commonly used by the Forest Service. The IMPLAN modeling system allows the user to build regional economic models of one or more counties for a particular year. The models for this analysis used the 2012 IMPLAN data. IMPLAN translates changes in final demand for goods and services into resulting changes in economic effects, such as labor income and employment in the affected area. This analysis examines current contributions to regional economic models specific to each national forest and grasslands in the Southwestern Region.

Estimating current economic contributions attributable to recreation, livestock grazing, and forest products can indicate the amount of market economic activity that may be sensitive to climate-related changes in the supply of ecosystem services. The contribution analysis can be paired with assessments of exposure (Chapter 3) and

BOX 2—Using Input-Output Models for Regional Economic Impact Analysis

Basic input-output (I-O) models are the most widely used tools of regional economic impact analysis and are well suited for the economic evaluation of resource use. The basic production relations of an I-O model are comprehensive with respect to all inputs, not just primary factors (capital and labor) (Rose et al. 2000). I-O analysis is well suited to the study of community vulnerability to climate change because of the interest in identifying the amount of economic activity that depends on ecosystem services. Specifically, we are interested in identifying communities in existing local economies that may be exposed to the risk of significant economic shocks due to changes in the provision of ecosystem services stemming from climate change.

I-O models can provide a partial-equilibrium analysis of the amount of economic activity that is associated with different economic sectors. Because I-O models account for relationships between inputs and sectors in the economy, the models can describe how changes in one sector relate to employment and income in other sectors and the total economy. However, I-O models do not necessarily account for adjustments in the relationships between inputs and sectors that can occur given a change in one sector. The net economic effects of climate change will depend on market shifts to substitute inputs and final goods and services as climate change alters the supply of ecosystem services. A full accounting of these shifts would require computable general equilibrium (CGE) models, which are based on the simultaneous optimizing behavior of individual consumers and firms, subject to economic account balances and resource constraints (Rose et al. 2000). Shifts in behavior that alter market relationships may be part of the adaptive response of some communities in the region, which were examined separately from economic dependence in this study (see Chapter 5) and may involve management responses (see Chapter 6).

The I-O application in this study was conducted using IMPLAN, a proprietary system of I-O tools and data that is widely used among researchers and practitioners in the United States. Using the IMPLAN system is convenient for providing managers, policy makers, and researchers involved in climate change analysis with a common and replicable method for assessing vulnerability to changes in ecosystem service provision. IMPLAN consists of an extensive national and regional database, algorithms for generating I-O tables for any county or county group in the United States, and algorithms for performing impact analyses. IMPLAN has been used to examine impacts from climate change on numerous resources including agriculture, water, energy (Rosenberg 1993), forestry (Rose et al. 2000; Rosenberg 1993), and recreation (Richardson and Loomis 2004).

adaptive capacity (Chapter 5) to draw inferences about the vulnerability of communities to reductions in well-being due to a changing climate. However, this approach does not explicitly model how projected climate-related changes to ecosystems will affect markets in the Southwest.

An advantage of the contribution analysis approach is that it avoids making assumptions about the structure of the regional economy in the future as climate change affects ecosystem services (Rosenberg 1993). Similarly, assumptions about input substitution effects and the degree of interregional trading that results from the heterogeneous effects of climate change on ecosystem services can have large effects on economic impact analyses (Rose et al. 2000). Thus, the contribution analysis provides a current "snapshot" of how deeply ecosystem services are ingrained in the economy at present, but not necessarily what the economy will look like in the future under a changed climate.

The I-O analysis was conducted according to the following general steps. Each step is described in detail in the following sections.

- Step 1: Determine the set of economic subsectors that rely on recreation access, rangeland for forage, and forest products as ecosystem services inputs.
- Step 2: Specify groups of counties (forest economic impact areas) where direct expenditures occur for each national forest.
- Step 3: Obtain estimates of direct national forest and grassland activities associated with recreation, rangeland grazing, and forest products.
- Step 4: Run IMPLAN I-O model with the Forest Service Excel®-based tool Apheleia to obtain indirect and induced contributions to employment and income derived from direct expenditures in each broad sector for each forest economic impact area.

Economic Subsectors Related to Recreation, Rangeland Grazing, and Forest Products

This section presents data sources and assumptions specific to recreation, livestock grazing, and forest resources that were applied in the market analysis of ecosystem services. This portion of the analysis addressed the extent to which employment and labor income in resource-related sectors is dependent on use of ecosystem goods and services.

Recreation: Forest Service land within the Southwest provides a variety of recreation opportunities. Data on visitation across the region from the National Visitor Use Monitoring (NVUM) survey indicate about 13.8 million annual recreation visits to national forests and grasslands in the Southwest (USDA Forest Service n.d.).

Analyses of expenditures reported by national forest visitors show the primary factor determining the amount spent by a visitor was the type of trip taken and not the specific activity or forest visited (White and Stynes 2008). The six types of recreation trips are defined as follows:

Visitors who reside greater than 50 miles from the visited forest:

- Nonlocal residents on day trips,
- Nonlocal residents staying overnight at a Forest Service site, and
- Nonlocal residents staying overnight not at a Forest Service site.

Visitors who live within 50 miles of the visited forest:

- Local residents on day trips,
- Local residents staying overnight at a Forest Service site, and
- Local residents staying overnight not at a Forest Service site.

The type of trip captures the unique spending patterns by whether visits were local or not (table 8). These shares describe the proportion of visits to a forest across all activities that can be categorized by each visit type.

Traditional economic impact analysis often excludes spending from local residents because the recreation expenditures of local persons do not represent new money introduced into the economy. For example, if Forest Service-related opportunities were not present, residents would probably participate in other locally based activities and their money would still be spent in the local economy. However, climate change is expected to alter opportunities regardless of land ownership and administration, which will alter the availability of substitute recreation opportunities in the local area. Therefore, this analysis included local visitor expenditures to assess the total economic contribution of national forest and grassland recreation. Differences in economic contributions by local and nonlocal visitors are accounted for by reporting their expenditure profiles separately, as specified in White et al. (2013) (table 9).

Similarly, nonprimary visits, defined as visits where the national forest site was not the primary destination for a given recreational trip, were also included because climate change may affect decisions about recreation opportunities that are complementary to national forest sites. The primary recreation activity may have occurred off Forest Service land, but the consequences of climate change may also affect the adjacent Federal, State, and private lands.

Table 8—Forest visitation shares in the U.S. Forest Service Southwestern Region by trip type.

	Nonlocal origin visits			Local origin visits		
National forest	**Day**	**Overnight – FS site**	**Overnight, non-FS site**	**Day**	**Overnight – FS site**	**Overnight, non-FS site**
Apache-Sitgreaves	0.08	0.27	0.12	0.50	0.02	0.01
Carson	0.11	0.07	0.25	0.54	0.02	0.01
Cibola	0.06	0.01	0.11	0.81	0	0.01
Coconino	0.11	0.06	0.25	0.56	0.02	0
Coronado	0.05	0.04	0.04	0.82	0.04	0.01
Gila	0.21	0.17	0.11	0.46	0.04	0.01
Kaibab	0.11	0.17	0.11	0.59	0.01	0.01
Prescott	0.06	0.10	0.04	0.76	0.04	0
Lincoln	0.15	0.16	0.13	0.54	0.02	0
Santa Fe	0.13	0.06	0.07	0.71	0.01	0.02
Tonto	0.06	0.08	0.02	0.76	0.07	0.01

Source: RMRS calculations of National Visitor Use Monitoring survey responses, round 2 (Apache-Sitgreaves, Carson, Lincoln, Santa Fe, and Tonto) and round 3 (Cibola, Coconino, Coronado, Gila, Kaibab, and Prescott) (USDA Forest Service 2015b). Nonprimary visits are included with local-origin day visits.

Table 9—Visitor spending profiles per party per visit to national forests and grasslands in the Forest Service Southwestern Region, by trip segment type, in 2009 dollars.

	Nonlocal origin visits			Local origin visits			
Spending category	**Day**	**Overnight – FS site**	**Overnight, non-FS site**	**Day**	**Overnight – FS site**	**Overnight, non-FS site**	**Non-primary**
Motel	0.00	33.54	151.77	0.00	5.36	33.84	114.86
Camping	0.00	26.81	18.85	0.00	23.63	17.11	11.95
Restaurant	15.30	26.31	111.34	5.19	6.78	33.99	88.62
Groceries	8.63	55.65	68.29	6.31	67.30	54.54	43.36
Gas and oil	23.16	52.67	71.17	12.83	37.57	40.18	48.40
Other transportation	0.58	1.83	3.98	0.13	0.49	1.09	3.26
Entry fees	4.56	8.93	18.39	2.17	3.76	6.86	11.11
Recreation and entertainment	4.34	7.70	27.13	1.50	3.50	5.67	16.71
Sporting goods	2.94	12.19	15.18	4.16	11.23	12.85	6.44
Souvenirs and other expenses	3.15	7.80	28.10	0.72	2.85	6.87	25.83
Total	62.65	233.44	514.20	33.02	162.48	212.99	370.54

Source: White et al. (2013: table 8). Spending profile estimates exclude visitors whose primary activity was downhill skiing (see table 10).

Although the primary factor determining the amount of money spent is the type of trip and not the activity, this analysis examines visits associated with climate-sensitive recreation categories based on activity participation estimates for Southwestern Region forests. Climate-sensitive recreation activities are grouped into five categories: Warm-weather activities, wildlife-related activities, snow-based winter activities, gathering forest products, and water-based activities (not including fishing). Downhill skiing is examined separately from other winter activities given the availability of expenditure profiles unique to skiing (table 10) and the status of this activity as the highest expenditure per visit across all activity types for all national forests (White and Stynes 2010). Within the Southwest downhill skiing occurs in the Carson, Cibola, Coconino, Kaibab, Lincoln, and Santa Fe National Forests. The most recent available NVUM estimates indicate about 600,000 downhill skiing visits occur in these forests annually.

Forest-specific national forest visitation shares by trip type (table 8) and visitation estimates for downhill skiing and the climate-sensitive recreation categories (tables 11 and 12) were combined with expenditure profiles (tables 9 and 10) to generate estimated expenditures by recreation activity category and trip type. These estimates were then used in IMPLAN and Apheleia to calculate direct, indirect, and induced employment and income contributions for each forest in the region.

Rangeland grazing: Grazing of livestock on Forest Service lands plays an important economic and social role for communities in the Southwest, and area residents identify with the tradition, land use, and history of this activity. In 2013, Pinal County, in southern Arizona, and Curry County, in northeastern New Mexico, were the region's first and second largest cattle producers, containing 12 and 7 percent of the regional cattle inventory, respectively (about 2.8 million cattle and calves) (USDA 2013). Ranching on Southwestern Region forests includes both large and small operations. In some areas

Table 10—Visitor spending profiles of downhill skiers per party per visit to national forests and grasslands in the Forest Service Southwestern Region, by trip segment type, in 2009 dollars.

	Nonlocal origin visits		Local origin visits	
Spending category	**Day**	**Overnight**	**Day**	**Overnight**
Motel	0	237.37	0	36.34
Camping	0	0.62	0	18.37
Restaurant	22.52	158.95	13.57	31.47
Groceries	4.60	75.86	3.49	51.01
Gas and oil	20.73	50.38	9.99	47.45
Other transportation	0	3.10	0.01	1.12
Entry fees	45.98	145.32	20.82	6.56
Recreation and entertainment	31.00	84.33	13.13	5.40
Sporting goods	5.32	22.04	3.13	12.62
Souvenirs and other expenses	1.85	20.75	0.77	6.81
Total	132.00	798.72	64.91	217.14

Source: White et al. 2013: table 15.

small-scale noncommercial family herds for local use have been a tradition for centuries (Atencio 2004).

The calculation of direct employment associated with cattle and sheep grazing on Forest Service lands followed protocol developed by economists at the Bureau of Land Management and Forest Service. First, the number of hired farm laborers was taken from the Census of Agriculture for the beef cattle ranching and sheep and goat farming subsectors. Second, unpaid and self-employed individuals are considered because the Census of Agriculture data do not include these individuals. The 2005–2009 American Community Survey includes information on the class of worker (e.g., self-employed, local government, unpaid family worker) by two-digit North American Industry Classification System industry. Industries included in the grazing sector are described in table 13.

To determine how Forest Service forage contributed to industry employment (hired laborers, unpaid, and self-employed individuals), the number of direct jobs per unit of forage was calculated. Data from the Census of Agriculture on total inventory of beef cows that calved, ewes 1 year or older, and all goats were used to calculate total forage requirements. Total cattle annual animal unit months (AUMs) required = total inventory × 12; Total sheep annual AUMs required = (sheep and lambs or goats × 12)/5. The ratio of employment to forage requirements was then used to calculate direct contributions from forests in the Southwestern Region by using data on AUMs that were authorized under a term grazing permit or lease in 2012. Indirect and induced contributions were calculated in IMPLAN by using analysis-by-parts, a method of calculating the impacts of a particular activity by separating out the various spending components of that activity and analyzing their specific impacts. This is done because production functions for cattle ranching and other animal production are not considered completely adequate for capturing indirect and induced contributions.

Table 11—Forest visitor estimates in the Forest Service Southwestern Region, by trip type and activity category, excluding downhill skiing.

National forest and activity category	Nonlocal origin visits: Day	Nonlocal origin visits: Overnight – FS site	Nonlocal origin visits: Overnight, non-FS site	Local origin visits: Day	Local origin visits: Overnight – FS site	Local origin visits: Overnight, non-FS site
Apache-Sitgreaves						
Warm weather	49,661	167,607	74,492	310,383	12,415	6,208
Winter (not incl. downhill skiing)	0	0	0	0	0	0
Wildlife	29,943	101,057	44,914	187,142	7,486	3,743
Gathering forest products	609	2,054	913	3,804	152	76
Water (not incl. fishing)	2,069	6,984	3,104	12,933	517	259
Carson						
Warm weather	30,632	19,493	69,617	150,374	5,569	2,785
Winter (not incl. downhill skiing)	9,318	5,930	21,178	45,745	1,694	847
Wildlife	11,400	7,255	25,909	55,964	2,073	1,036
Gathering forest products	2,280	1,451	5,182	11,193	415	207
Water (not incl. fishing)	991	631	2,253	4,866	180	90
Cibola						
Warm weather	55,796	9,299	102,293	753,250	0	9,299
Winter (not incl. downhill skiing)	513	86	941	6,932	0	86
Wildlife	8,558	1,426	15,689	115,529	0	1,426
Gathering forest products	1,369	228	2,510	18,485	0	228
Water (not incl. fishing)	0	0	0	0	0	0
Coconino						
Warm weather	208,813	113,898	474,576	1,063,049	37,966	0
Winter (not incl. downhill skiing)	2,839	1,548	6,452	14,452	516	0
Wildlife	18,926	10,323	43,013	96,349	3,441	0
Gathering forest products	1,577	860	3,584	8,029	287	0
Water (not incl. fishing)	4,731	2,581	10,753	24,087	860	0
Coronado						
Warm weather	91,360	73,088	73,088	1,498,312	73,088	18,272
Winter (not incl. downhill skiing)	0	0	0	0	0	0
Wildlife	9,975	7,980	7,980	163,597	7,980	1,995
Gathering forest products	608	487	487	9,975	487	122
Water (not incl. fishing)	1,217	973	973	19,951	973	243
Gila						
Warm weather	41,869	33,894	21,932	91,714	7,975	1,994
Winter (not incl. downhill skiing)	0	0	0	0	0	0
Wildlife	33,344	26,993	17,466	73,040	6,351	1,588
Gathering forest products	108	87	57	236	21	5
Water (not incl. fishing)	108	87	57	236	21	5

Table 11—*Continued.*

National forest and activity category	Nonlocal origin visits			Local origin visits		
	Day	Overnight – FS site	Overnight, non-FS site	Day	Overnight – FS site	Overnight, non-FS site
Kaibab						
Warm weather	21,084	32,584	21,084	113,087	1,917	1,917
Winter (not incl. downhill skiing)	0	0	0	0	0	0
Wildlife	7,229	11,172	7,229	38,773	657	657
Gathering forest products	251	388	251	1,346	23	23
Water (not incl. fishing)	251	388	251	1,346	23	23
Lincoln						
Warm weather	68,747	73,330	59,580	247,487	9,166	0
Winter (not incl. downhill skiing)	0	0	0	0	0	0
Wildlife	6,036	6,438	5,231	21,729	805	0
Gathering forest products	921	982	798	3,315	123	0
Water (not incl. fishing)	0	0	0	0	0	0
Prescott						
Warm weather	32,103	53,505	21,402	406,636	21,402	0
Winter (not incl. downhill skiing)	0	0	0	0	0	0
Wildlife	4,678	7,796	3,118	59,249	3,118	0
Gathering forest products	148	246	98	1,871	98	0
Water (not incl. fishing)	1,083	1,805	722	13,721	722	0
Santa Fe						
Warm weather	119,517	55,162	64,355	652,747	9,194	18,387
Winter (not incl. downhill skiing)	16,380	7,560	8,820	89,458	1,260	2,520
Wildlife	13,320	6,148	7,172	72,746	1,025	2,049
Gathering forest products	180	83	97	983	14	28
Water (not incl. fishing)	1,440	665	775	7,864	111	222
Tonto						
Warm weather	95,056	126,742	31,685	1,204,049	110,899	15,843
Winter (not incl. downhill skiing)	0	0	0	0	0	0
Wildlife	40,327	53,769	13,442	510,809	47,048	6,721
Gathering forest products	0	0	0	0	0	0
Water (not incl. fishing)	25,636	34,182	8,545	324,728	29,909	4,273

Source: RMRS calculations of National Visitor Use Monitoring survey responses, round 2 (Apache-Sitgreaves, Carson, Lincoln, Santa Fe, and Tonto) and round 3 (Cibola, Coconino, Coronado, Gila, Kaibab, and Prescott) (USDA Forest Service 2015b). Visits are grouped into activity categories based on reported primary activity participated in during the visit. Activity and segment estimates are calculated as the product of total forest visitation, activity category visitation shares (see table 6), and forest-level segment shares. Segment shares are calculated for each forest and are not activity-specific.

Table 12—Forest visitor estimates for downhill skiing in the Forest Service Southwestern Region.

National forest	Day	Overnight
Carson	164,558	134,639
Cibola	42,446	1,769
Coconino	80,004	49,035
Kaibab	1,118	1,164
Lincoln	32,034	9,569
Santa Fe	86,190	28,730

Source: RMRS calculations of National Visitor Use Monitoring survey responses, round 2 (Apache-Sitgreaves, Carson, Lincoln, Santa Fe, and Tonto) and round 3 (Cibola, Coconino, Coronado, Gila, Kaibab, and Prescott) (USDA Forest Service 2015b). Visits are grouped into activity categories based on reported primary activity participated in during the visit.

Table 13—IMPLAN (IMPLAN 2013) two-digit NAICS sectors used to assess economic contribution of livestock grazing.

IMPLAN sector	Description	Regional employment	Percentage of total regional employment
Total, all livestock grazing sectors		18,176	0.38%
11	Cattle ranching and farming	15,766	0.33%
14	Animal production, except cattle and poultry and eggs	2,410	0.05%

Forest Products: Commercial timber harvests from Forest Service lands in Arizona and New Mexico have varied over time with changing market and policy conditions. Trends on the use of forest products from the Southwestern Region were obtained from reports on cut and sold timber (USDA Forest Service 2013b). Timber harvests in much of the 1990s decreased sharply from the late 1980s on national forests throughout the Nation and in the Southwest (fig. 4.1) and remained at comparatively low levels during the 2000s, suggesting a change in the role of public forest land from traditional commodity use to ecosystem service protection.

Timber harvest data from the cut and sold reports depicted in figure 4.2 were reported by forest and then used to estimate contributions in IMPLAN. Data used to estimate the direct effects from timber harvest and processing were provided by the University of Montana's Bureau of Business and Economic Research (BBER) (Morgan et al. 2014). Industries included in the forest products sector are described in table 14.

The national data are broken into multi-State regions and are considered more accurate than those available from IMPLAN. The Four Corners States (Arizona, Colorado, New Mexico, and Utah) were used as a reference area for this analysis given the concentration of processing facilities in Arizona and New Mexico that receive timber volume originating from Southwestern Region forests. The BBER data represent the results of mill censuses that correlate production, employment, and labor income.

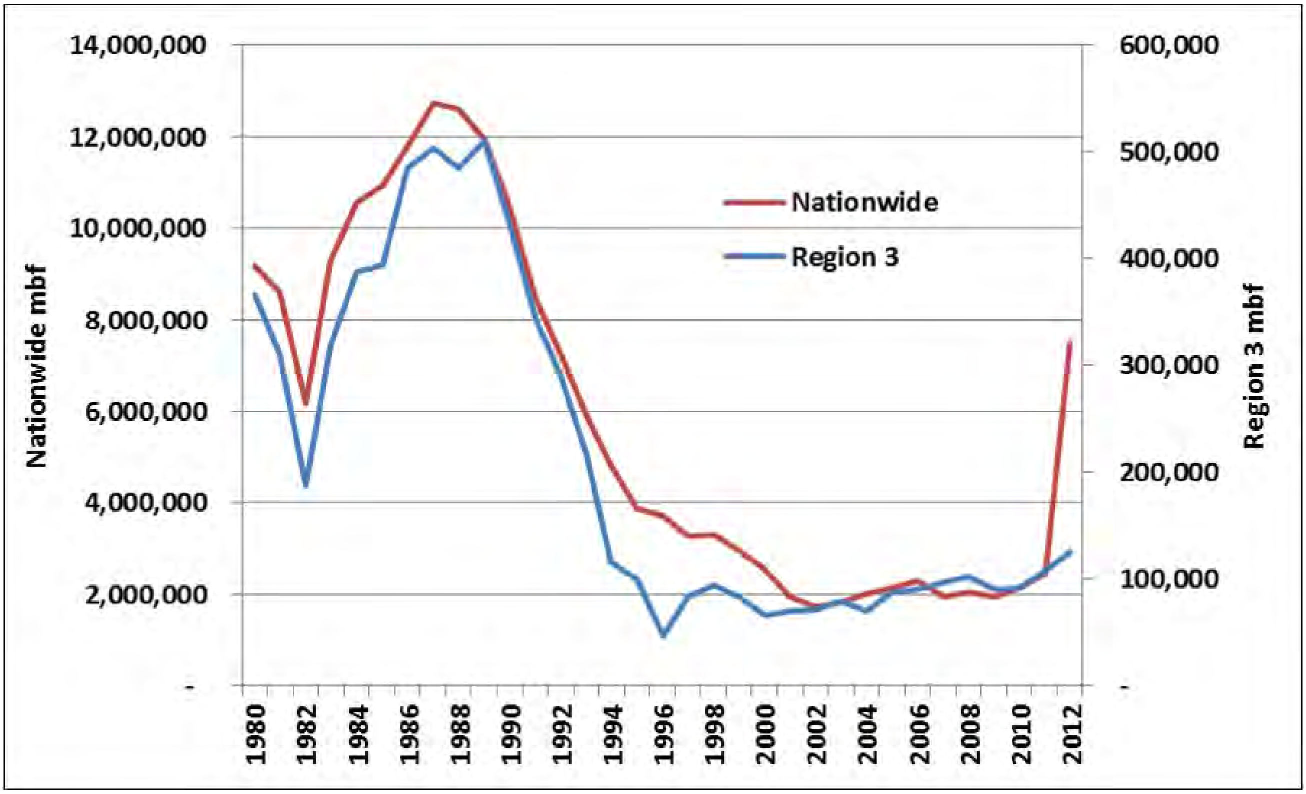


Figure 4.1—Annual timber removed from national forest land in Arizona and New Mexico (blue line, right axis) and total from all national forest land in the United States (red line, left axis). (Data source: USDA Forest Service 2013b.)

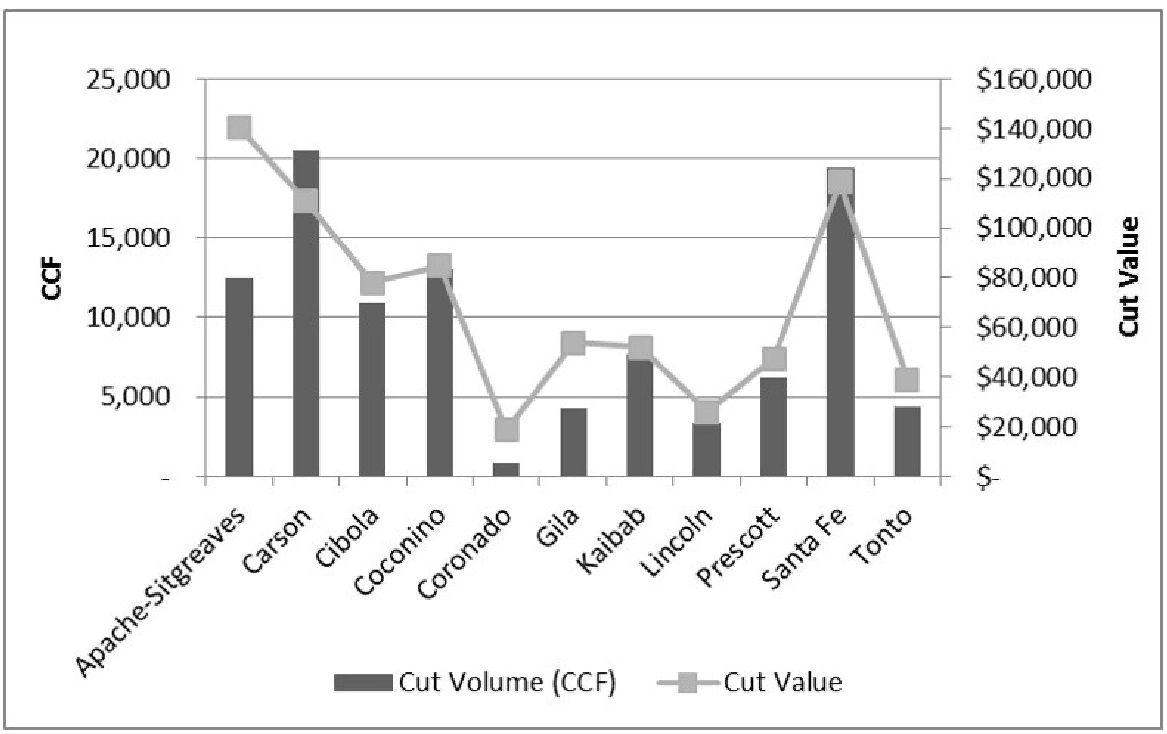


Figure 4.2—Average cut timber volume and value in the Forest Service Southwestern Region, FY 2010–FY 2012. Bar height indicates cut volume from each forest in hundred cubic feet (CCF, left axis); the points indicate the total market value (dollars, right axis) of cut timber from each forest. (Data source: USDA Forest Service 2013b.)

Table 14—IMPLAN (IMPLAN 2013) sectors used to assess economic contributions of timber and forest products.

IMPLAN sector	Description	Regional employment	Percentage of total regional employment
Total, all timber and forest products sectors		*27,418*	*0.57%*
15	Forestry, forest products, and timber tract production	80	<0.01%
16	Commercial logging	382	0.01%
19	Support activities for agriculture and forestry	20,842	0.43%
95	Sawmills and wood preservation	258	0.01%
96	Veneer and plywood manufacturing	18	<0.01%
97	Engineered wood member and truss manufacturing	892	0.02%
98	Reconstituted wood product manufacturing	93	<0.01%
99	Wood windows and doors and millwork manufacturing	1,604	0.03%
100	Wood container and pallet manufacturing	837	0.02%
102	Prefabricated wood building manufacturing	295	0.01%
103	All other miscellaneous wood product manufacturing	297	0.01%
104	Pulp mills	17	<0.01%
105	Paper mills	465	0.01%
106	Paperboard mills	47	<0.01%
107	Paperboard container manufacturing	1,291	0.03%

Delineation of Forest Area County Groupings for Analysis of Economic Contributions

The economic contributions from Southwestern Region forests depend on the economic characteristics of the area examined. The unit of analysis for assessing economic contributions of ecosystem services is the forest economic impact area, which is a grouping of counties that exhibit functional economic integrity relative to the ecosystem goods and services examined.

Defining the economic impact areas followed Forest Service protocols (Retzlaff 2009). The first step in delineating analysis areas is to identify the counties where market transactions associated with recreation, range, and timber are likely to occur. We then further refined broad areas based on additional criteria developed by the Forest Service Ecosystem Management Coordination Office. These specialists' method assumes that the location of market transactions is represented by data on the NVUM visitor market area and the location of range permittees and timber bid winners.

The relevant market area for recreation was based on travel distances reported in the NVUM survey. To be included in an economic impact area, a county must be (1) classified as part of the 50 percent market area for the forest (group of counties from which at least 50 percent of forest visits originated), (2) within 50 road miles (leading to a nearby town) from the forest boundary, and (3) contiguous with the rest of the counties in the study area; in addition, if the county was in a classified metropolitan area, (4) it must contain Forest Service land. The fourth criterion allows for inclusion of Office of Management and Budget-designated metropolitan counties with stronger recreational ties to particular forest units. Many metropolitan counties may contribute to the 50-percent visitor market area for a particular forest (given their larger populations than rural counties adjacent to a national forest), but market transactions associated with forest recreation make up smaller portions of their overall economic activity. In addition, inclusion of these counties would dilute important local economic relationships between forest recreation and adjacent rural counties.

Both range and timber data were obtained from the Forest Service reporting tool I-Web, which records the addresses as well as grazing head-months and cut timber volume for grazing permittees and timber bidders, respectively. A county is included in the economic impact area for a grassland or forest if it contains permittees or timber bid winners that utilized at least 5 percent of all authorized AUMs or timber sale volume for that grassland or forest unit.

For those counties where direct expenditures for range, timber, or recreation were identified, a laborshed analysis was performed by using data on where workers live taken from the decennial census. The main criterion used in this analysis is that counties must provide at least 25 percent of local jobs to forest analysis areas. Applying this protocol yields 12 analysis areas unique to the labor market and recreation, range, and timber resources provided by each forest unit in the region (table 15).

Contributions to individual counties may accrue from multiple forests. These forest contributions are unique and thus no double-counting occurs. For example, contributions to employment in Gila County are tied to unique recreation visitation in the Apache-Sitgreaves, the Coconino, and the Tonto National Forests. Total contributions (direct, indirect, and induced) to analysis areas from Forest Service resource use were not distinguished at the individual county level.

Table 15—Definitions of forest economic impact areas.

National forest (NF) or national grasslands (NG) unit	Counties included in analysis area
Apache-Sitgreaves NF	Apache (AZ), Coconino (AZ), Gila (AZ), Graham (AZ), Greenlee (AZ), Maricopa (AZ), Navajo (AZ)
Carson NF	Alamosa (CO), Conejos (CO), Mora (NM), Rio Arriba (NM), San Miguel (NM), Taos (NM)
Cibola NF	Bernalillo (NM), Catron (NM), Cibola (NM), Harding (NM), McKinley (NM), Rio Arriba (NM), Sandoval (NM), Santa Fe (NM), Socorro (NM), Torrance (NM), Union (NM)
Cibola NG	Harding (NM), Mora (NM), Union (NM), Cimarron (OK), Roger Mills (OK), Dallam (TX), Gray (TX), Hemphill (TX)
Coconino NF	Coconino (AZ), Gila (AZ), Maricopa (AZ), Navajo (AZ), Pinal (AZ), Yavapai (AZ)
Coronado NF	Cochise (AZ), Pima (AZ), Pinal (AZ), Santa Cruz (AZ)
Gila NF	Apache (AZ), Catron (NM), Grant (NM)
Kaibab NF	Coconino (AZ), Mohave (AZ), Navajo (AZ), Yavapai (AZ), Garfield (UT), Kane (UT), Washington (UT)
Lincoln NF	Chaves (NM), Eddy (NM), Lincoln (NM), Otero (NM), El Paso (TX)
Prescott NF	Maricopa (AZ), Yavapai (AZ)
Santa Fe NF	McKinley (NM), Mora (NM), Rio Arriba (NM), Sandoval (NM), San Miguel (NM), Santa Fe (NM)
Tonto NF	Coconino (AZ), Gila (AZ), Maricopa (AZ), Pinal (AZ)

Forest Area Economic Contributions to Employment and Income of National Forest Climate-Sensitive Recreation, Rangeland Grazing, and Forest Products

Economic contributions associated with uses on Southwestern Region forests (climate-sensitive recreation, rangeland grazing, and timber) (table 16) were estimated with the IMPLAN I-O model, resource data, and the assumptions described earlier. Forests with relatively high contributions of resource sectors to total area income and employment include Carson and Gila national forests and the Cibola National Grasslands (consisting of grasslands in eastern New Mexico, Texas, and Oklahoma that are administered by Cibola National Forest and included as a separate unit for the contribution analysis). Economic activity related to national forests and grasslands accounts for between 0.9 and 1.7 percent of employment in these economic impact areas.

Other forests contribute more in terms of absolute income and employment, but the contributions account for a smaller share of all income and employment in those areas. The highest absolute contributions to income and employment are from the Coconino, Apache-Sitgreaves, and Tonto National Forests. These forests each contain Maricopa County, Arizona in their respective economic impact areas, which explains the low contribution relative to total income and employment: Maricopa County includes the Phoenix metropolitan area. Yet recreation, grazing, and timber activities in these forests account for more than 40 percent of employment and more than 50 percent of income contributed by all national forests in the region.

Overall, the contributions from recreation account for most of the employment and income derived from natural resource activities in national forests and grasslands. Although certain forests have larger economic contributions derived from grazing (e.g., Cibola Grasslands, the Gila, the Prescott) or timber (e.g., the Kaibab), recreation activities are the largest contributor to national forest-related employment for six forests, and the largest contributor to income for nine forests. Warm-weather recreation activities account for the majority of economic contributions in all forests except for the Carson, where downhill skiing accounts for the largest economic contribution (table 17).

Dependence on Forest Resources not Measured in Market Transactions

The Importance of Water to Communities and Industry Sectors

We examined regional dependence on water supplied from Southwestern Region forests in order to demonstrate the Forest Service's role in providing this ecosystem service. Estimates of water supply from forests in the region indicate that the Forest Service plays an integral role in supplying water, for a variety of uses, across the Southwest.

Water supply estimates that were obtained from Brown et al. (2008) define water supply as estimated precipitation minus evapotranspiration. Their estimates are based on data for 1953 through 1994, which they note "may not represent future hydrologic conditions." Because estimates were given for all land ownerships, they provide a reliable depiction of dependence on water from Forest Service lands across broad scales, such as national forests in the Southwest. It is important to acknowledge that these sources of supply are only a portion of the total supply from surface diversions that originate from outside the immediate area and sometimes outside the State. For example, the Central

Table 16—Average annual total (direct, indirect, and induced) employment and labor income contributed by activities on national forests (NFs) and grasslands (NGs) in the Forest Service Southwestern Region, by forest analysis area and resource sector.

	Climate-sensitive recreation		Grazing		Timber		Total – All activities	% Total empl.
Employment (full- and part-time jobs)								
	Number	%	Number	%	Number	%		
Apache-Sitgreaves NF	561	45.9	288	23.5	374	30.6	1,223	0.05
Carson NF	771	77.7	202	20.4	18	1.8	992	1.68
Cibola NF	338	55.6	238	39.1	32	5.3	608	0.10
Cibola NG	4	1.4	285	98.6	0	0.0	289	0.93
Coconino NF	1,553	81.4	238	12.5	117	6.1	1,908	0.08
Coronado NF	387	36.6	671	63.5	0	0.0	1,057	0.17
Gila NF	108	16.2	545	81.6	14	2.1	668	1.57
Kaibab NF	97	26.0	166	44.5	111	29.8	373	0.11
Lincoln NF	251	41.8	262	43.6	88	14.6	601	0.12
Prescott NF	185	36.6	278	54.9	43	8.5	506	0.02
Santa Fe NF	384	69.7	146	26.5	22	4.0	551	0.24
Tonto NF	747	65.1	379	33.0	20	1.7	1,147	0.05
Labor income (thousands of 2012 dollars)								
	Income	%	Income	Share	Income	%		
Apache-Sitgreaves NF	21,881	53.5	4,588	11.2	14,400	35.2	40,869	0.03
Carson NF	19,165	84.9	2,541	11.3	878	3.9	22,584	1.08
Cibola NF	10,273	68.4	3,047	20.3	1,702	11.3	15,022	0.05
Cibola NG	116	3.0	3,761	97.0	-	0.0	3,876	0.27
Coconino NF	56,967	87.0	3,787	5.8	4,722	7.2	65,477	0.05
Coronado NF	12,270	53.1	10,846	46.9	-	0.0	23,116	0.08
Gila NF	2,530	23.2	7,910	72.5	467	4.3	10,907	0.66
Kaibab NF	2,834	34.1	2,159	25.9	3,330	40.0	8,323	0.06
Lincoln NF	6,972	48.4	3,261	22.6	4,180	29.0	14,413	0.06
Prescott NF	7,286	53.7	4,494	33.1	1,800	13.3	13,580	0.01
Santa Fe NF	10,776	78.0	1,785	12.9	1,248	9.0	13,808	0.14
Tonto NF	29,979	80.8	6,135	16.5	1,004	2.7	37,118	0.03

Table 17—Average annual total (direct, indirect, and induced) employment and labor income associated with climate-sensitive recreation on national forests (NFs) and grasslands (NGs) in the Forest Service Southwestern Region, by forest analysis area and activity.

	Warm-weather activities	Downhill skiing	Snow-based winter activities (not incl. downhill skiing)	Wildlife activities	Gathering forest products	Water-based activities (not incl. fishing)
Employment (full- and part-time jobs)						
Apache-Sitgreaves NF	308	0	0	237	4	13
Carson NF	131	532	40	54	10	4
Cibola NF	321	7	2	0	8	0
Cibola NG	4	0	0	0	0	0
Coconino NF	1,191	191	16	119	9	27
Coronado NF	337	0	0	43	2	4
Gila NF	54	0	0	54	0	0
Kaibab NF	67	0	0	28	1	1
Lincoln NF	195	33	0	20	3	0
Prescott NF	152	0	0	27	1	5
Santa Fe NF	234	85	32	29	0	3
Tonto NF	415	0	0	220	0	112
Labor income (thousands of 2012 dollars)						
Apache-Sitgreaves NF	11,795	-	-	9,450	145	491
Carson NF	3,388	12,912	1,031	1,473	252	110
Cibola NF	9,772	210	47	-	243	-
Cibola NG	116	-	-	-	-	-
Coconino NF	43,761	6,695	595	4,593	331	992
Coronado NF	10,597	-	-	1,461	71	141
Gila NF	1,237	-	-	1,286	3	3
Kaibab NF	1,944	-	-	843	23	23
Lincoln NF	5,450	846	-	603	73	-
Prescott NF	5,934	-	-	1,124	27	200
Santa Fe NF	6,702	2,204	919	859	10	81
Tonto NF	16,435	-	-	9,112	-	4,432

Arizona Project provides a considerable amount of water from the Colorado River every year to Arizona counties.

National forests in Arizona and New Mexico are estimated to provide 55 percent and 46 percent, respectively, of the water supply originating in those States in an average year (table 18). These shares are similar to the 11 contiguous Western States, where national forest lands provide 51 percent of the water supply. The contributions from Arizona and New Mexico national forests are, however, relatively greater than the contributions of the remaining 48 States, where 18 percent of water supply originates from national forest lands (Brown and Froemke 2009).

Table 18—Estimated volume of surface water supplied by national forests and grasslands in the Forest Service Southwestern Region.

National forest	State	Water volume (million cubic meters per year)	Water volume (billion cubic feet per year)	Share of state total supply (percent)
Apache-Sitgreaves	AZ	693	24.5	15
Coconino	AZ	465	16.4	10
Coronado	AZ	469	16.6	10
Kaibab	AZ	263	9.3	6
Prescott	AZ	182	6.4	4
Tonto	AZ	464	16.4	10
Total, Arizona forests		2,536	89.5	55
Carson	NM	736	26.0	13
Cibola	NM	119	4.2	2
Gila	NM	486	17.2	9
Lincoln	NM	276	9.7	5
Santa Fe	NM	923	32.6	17
Total, New Mexico forests		2,540	89.7	46

Source: Brown and Froemke 2009.

Examining water supply estimates from individual forest units provides insight on human dependence within Arizona and New Mexico. For national forests in Arizona, 15 percent of total water supply to the State originates from the Apache-Sitgreaves; in New Mexico 17 percent of total water supply originates from the Santa Fe (table 18). Concerns exist about the accuracy of water supply estimates for national forest units at smaller spatial scales. However, estimates were developed because they may be useful for large-scale planning purposes (Brown and Froemke 2009).

The U.S. Geological Survey (USGS) estimates that in 2010, water withdrawals from groundwater and surface water totaled 8,412 million cubic meters per year (Mm^3/yr) (297 billion cubic feet per year [ft^3/yr]) in Arizona and 4,367 Mm^3/yr (154 billion ft^3/yr) in New Mexico (Maupin et al. 2014). These estimates of water withdrawals at the State level are useful alongside supply estimates, across all ownerships, at the State level from Brown et al. (2008) (these analyses use the same definition for water supply: Estimated precipitation minus evapotranspiration). Supply estimates across all ownerships are 4,709 Mm^3/yr (166 billion ft^3/yr) in Arizona and 5,486 Mm^3/yr (194 billion ft^3/yr) in New Mexico; estimated supply exceeds annual withdrawal in New Mexico. Supply estimates specific to national forests and grasslands (2,536 Mm^3/yr or 90 billion ft^3/yr in Arizona and 2,540 Mm^3/year or 90 billion ft^3/yr in New Mexico) suggest Southwestern Region lands are an important source of water for both States.

Firewood Gathered for Personal or Residential Use

Harvesting firewood from national forests supports both heritage values and economic well-being, and national forests are a major source of firewood in the Southwest. Firewood provides fuel for cooking and winter heating, offers economic opportunities, and contributes to traditional ceremonies. For some in the region, gathering firewood also strengthens ties to ancestral lands.

Firewood gathering is particularly important in northern New Mexico, as indicated by the large volumes cut in the Carson and Santa Fe National Forests (fig. 4.2). For centuries, Hispano communities in northern New Mexico have relied on firewood as their primary fuel and as a part of their cultural heritage (Raish 2000). High poverty rates in the region underscore the importance of affordable fuel sources, such as firewood.

In addition to high firewood dependence in northern New Mexico, these data show the importance of firewood gathering to tribes in Arizona. The three Arizona counties with high firewood dependence also contain large shares of tribal lands (table 19): Nearly 40 percent of Coconino County and about two-thirds of both Apache and Navajo Counties are owned by tribes (USGS 2012).

Communities with high dependence on wood heating may be vulnerable to changes in the availability of firewood. Firewood availability may be affected if climate change induces vegetative change through fire or disease, affects the price of alternative fuel sources, and alters the demand for firewood.

Cultural and Spiritual Values Associated with Southwestern Region National Forests and Grasslands

Numerous sites and resources on national forests and grasslands contribute to cultural and spiritual values. In addition to firewood, special forest products such as boughs and plants are collected for medicinal and ceremonial uses (USDA Forest Service 2008, 2009b). The collection of these materials in the region predates the establishment of the national forests and is an integral part of individuals' connection to the land. Climate change may influence the availability of these products and the characteristics of important sites.

Sites such as the San Francisco Peaks in the Coconino National Forest, Mount Graham in the Coronado National Forest, and the White Mountains in the Lincoln National Forest have particular spiritual importance for tribes in the region. Although climate change may not alter the presence or spiritual importance of these sites, it may affect ecological health and access to the sites. Such changes may inhibit enjoyment of sacred sites in the forests. In addition, paleontological resources, heritage resources, and research areas in the region offer opportunities for scientific discovery of national or global importance (USDA Forest Service 2011).

Cultural and spiritual values associated with national forest land may be difficult—and undesirable—to quantify and monetize. These are nonmarket values: goods and services that lack markets, and therefore, prices. The lack of prices, however, does not reflect a lack of value. The spiritual and cultural services provided by forests in the Southwest contribute to resilience, health, and quality of life for the individuals and communities that rely on them.

Conclusions

The analyses in this chapter demonstrated the economic contributions from national forests and grasslands in the region that are derived from climate-sensitive ecosystem

Table 19—Use of firewood for home heating, by county.

County	Percentage of households heating with wood	County	Percentage of households heating with wood
Arizona		New Mexico	
Apache County	57.8	Bernalillo County	1.8
Cochise County	2.6	Catron County	48.3
Coconino County	17.4	Chaves County	1.6
Gila County	9.8	Cibola County	23.9
Graham County	4.2	Colfax County	13.9
Greenlee County	5.2	Curry County	1.7
La Paz County	1.8	De Baca County	7.8
Maricopa County	0.2	Doña Ana County	1.5
Mohave County	2.6	Eddy County	0.6
Navajo County	33.5	Grant County	13.7
Pima County	0.6	Guadalupe County	13.7
Pinal County	0.5	Harding County	19.0
Santa Cruz County	1.7	Hidalgo County	10.5
Yavapai County	4.5	Lea County	0.5
Yuma County	0.4	Lincoln County	14.2
		Los Alamos County	2.0
		Luna County	3.8
		McKinley County	37.0
		Mora County	48.8
		Otero County	8.3
		Quay County	5.1
		Rio Arriba County	18.7
		Roosevelt County	3.6
		San Juan County	14.1
		San Miguel County	27.6
		Sandoval County	5.5
		Santa Fe County	4.9
		Sierra County	4.6
		Socorro County	18.2
		Taos County	29.2
		Torrance County	21.5
		Union County	5.2
		Valencia County	6.8

Source: U.S. Census Bureau 2012.

services. Forests in the region contribute to employment and income generated by activities in recreation, grazing, and timber sectors.

About 10,000 full- and part-time jobs and about $270 million in labor income are generated by climate-sensitive activities derived from national forests and grasslands, which represent about 0.2 percent of total employment and 0.1 percent of total labor income in the region. On average, climate-sensitive activities account for less than one-half of 1 percent of the region's total economic activity, although in some forest areas (e.g., the Carson and the Gila) the contribution from climate-sensitive activities is between 1.0 and 1.5 percent of employment and income. In half of national forests and grasslands in the region recreation is the largest contributor to employment and income among climate-sensitive activities. Livestock grazing is the largest contributor in the remaining national forests and grasslands.

National forests and grasslands in the region also provide a significant portion of water supplied to residential and industrial users, provide firewood for home heating, and are home to numerous culturally and spiritually important sites. About half of surface water supply in the Southwest is derived from national forests and grasslands, and forests in the region are an important source of supply for households that heat their homes primarily with firewood.

The economic analyses in this report did not model how climate change is likely to alter the economic contributions of forests in the region. However, the results can be used to indicate the relative importance of different ecosystem services in each forest for supporting economic activities and well-being. The analyses demonstrated the broad importance of recreation opportunities and surface water supply that are derived from forests in the region. But the degree to which other ecosystem services are important varies across the region. For example, livestock grazing is relatively important for several forests, and certain counties in the region that have a large national forest land area have many households that rely on firewood for home heating.

Chapter 5: An Indicator Analysis of Adaptive Capacity at the County Level

In a household production model, adaptive capacity describes the degree to which households can alter the allocation of inputs to mitigate a decrease in well-being in response to an exogenous decrease in the quantity or quality of ecosystem services. The ability to make such changes is probably not uniform across households in the Southwest. A uniform reduction in the provision of ecosystem goods and services may affect many Southwestern households, but households with greater flexibility to make production changes may face smaller decreases in well-being.

The ability of households to adapt to ecological changes may be derived from several sources. Household socioeconomic conditions may play a role to the extent that labor market outcomes, wealth, education, and other observable characteristics are associated with the ability to adjust household activities in response to changes in the supply of ecosystem services. Community-level characteristics, such as social capital, community facilities, and strong governance and institutions, may also help households adapt. Adaptive capacity may be a function of both internal and external characteristics and factors (Murphy et al. 2015).

The method for assessing adaptive capacity applied here is to summarize household indicators of socioeconomic conditions at the county level to describe factors that may be related to household adaptive capacity in each county. This approach yields insight into the observable characteristics that may relate to adaptive capacity for the average household, and can indicate where in the Southwest there may be a greater or lesser concentration of households that would have difficulty adapting to changing ecological conditions. However, this approach is limited in that it does not account for social interactions among community members or facilities and institutions that may aid households in responding to change. Nor does this approach account for variation in socioeconomic characteristics within counties (e.g., where there is high income inequality). Other assessment methods, such as case studies, scenario building, and participatory methods, may overcome some of the limitations of an indicator method (Fischer et al. 2013; Murphy et al. 2015), and could be applied as complementary assessments.

An Indicator Approach to Assessing Adaptive Capacity

Several factors may be related to a household's capacity to adapt to ecological changes. Household assets may be an important component of adaptive capacity (Heltberg et al. 2009). These could include income and wealth, and various forms of human capital such as knowledge, skills, and abilities. Health status, education, and traditional knowledge may also be important factors contributing to a household's ability to adapt to changing ecological conditions.

Income has been identified as a primary factor governing household well-being and is believed to be negatively correlated with household vulnerability (Yohe and Tol 2002). As income rises, households are anticipated to become less vulnerable to climate-related changes in the provision of forest ecosystem services. Higher household income is believed to reduce vulnerability for a number of reasons including:

- Overall greater well-being, indicating a lower likelihood of experiencing negative outcomes;
- Greater ability to absorb increases in the costs of ecosystem inputs;
- Greater ability to use substitutes for ecosystem services in the production of household well-being, such as increased time or equipment to offset changes in the supply of ecosystem services; and
- Greater ability to substitute other goods that do not use ecosystem services as an input (or, use less of them); for example, higher-income households may have a larger menu of substitute goods because they are willing and able to pay higher prices for substitutes.

Related to income, household wealth and poverty status may also indicate a household's ability to adjust production and consumption to avoid reductions in well-being.

Characteristics that are associated with labor market outcomes may be important determinants of vulnerability. Educational attainment is associated with earning potential and labor market status. In general, labor markets tend to support more employment opportunities for households with high levels of education relative to those with less education. Age could be associated with vulnerability, although the direction of the relationship is not clear. Younger workers may have greater labor market potential and flexibility, but lack of experience may limit immediate labor market options. Older workers with more experience may have greater earning potential but less labor market flexibility.

Other life-cycle characteristics, such as the presence of children, may also indicate the degree of flexibility in responding to ecological changes or other shocks. Retirees and other elderly households are generally assumed to be more vulnerable, perhaps due to dependence on access to healthcare, limited labor market potential, and fixed incomes. However, fixed incomes also imply some level of certainty that can insulate households against negative outcomes.

Health is an important human capital factor that can affect a household's ability to work and earn income and engage in other activities that involve ecosystem services. Similarly, coverage by health insurance may indicate a household's ability to obtain health care and avoid financial problems associated with major health issues.

Several characteristics (e.g., being a member of a racial or ethnic minority) are often associated with poor economic outcomes or higher likelihood of experiencing a reduction in well-being. Commonly applied vulnerability indices (e.g., Cutter et al. 2003) incorporate demographic characteristics to capture these associations. Yet these associations can often be measured directly (e.g., by measuring income). However, demographic characteristics can also be associated with otherwise unobserved labor market potential. For example, discrimination in the labor market can decrease the returns to education for some races, which may be difficult to account for in other ways. In general, demographic characteristics are not used in this study to indicate socioeconomic adaptive capacity unless those characteristics are related to human capital factors (e.g., age as a proxy measure for potential labor market experience).

Because demographic characteristics and vulnerability are related to the notion of environmental justice, it is important to distinguish between environmental justice and vulnerability assessments. The goal of a vulnerability assessment is to identify households that have a high likelihood of reductions in well-being; environmental justice assessments are used to examine whether and how members of groups that have traditionally been socioeconomically disadvantaged may be affected by Federal management actions. Although members of traditionally disadvantaged demographic groups may be vulnerable to climate change, association with historically underserved populations does not necessarily imply greater vulnerability. However, there may be cases when high vulnerability is correlated with membership in a disadvantaged group.

Summarizing Socioeconomic Characteristics by Using Indices

Summarizing socioeconomic status to assess vulnerability draws on common index approaches from the vulnerability literature. In the simplest form, these approaches gather data at the appropriate administrative level (counties, in this case) that are thought to be related to components of vulnerability. For example, Cutter et al. (2003) and Cutter and Finch (2008) develop a Social Vulnerability Index (SVI) that uses a principal components analysis to summarize 42 socioeconomic variables into 11 factor scores. These scores are then summed for each county in the study area to calculate a single SVI score for each county. Other standardized indices that are constructed in a similar manner include the Climate Vulnerability Index (Pandey and Jha 2012) and the Livelihood Vulnerability Index (Safi et al. 2012).

Although measures may be similar, they often differ slightly in construction and interpretation. The assessment of adaptive capacity explores three indices that use characteristics observable at the county level to serve as indicators of adaptive capacity: a mean (average) index based on values of each indicator relative to the sample average, an index based on values of each indicator relative to the minimum (worst-case) values, and an index based on an observation's rank for each indicator.

The mean index creates a standardized value for each indicator based on the value of each observation relative to the sample average. This type of index has been used to rank counties based on the presence of climate amenities (McGranahan 1999). For observation *i* of indicator *j* (X_{ij}), the standardized measure is calculated as:

$$\text{Mean\_Index}_{ij} = \frac{(X_{ij} - \overline{X}_j)}{\sigma_j},$$

where $\overline{X}_j$ is the sample mean of indicator *j*, and σ_j is the standard deviation of indicator *j*. The standardized value for each indicator is positive when the raw value of an indicator for a given observation is greater than the sample mean and negative when the raw value is less than the sample mean. The standardized value for each indicator is unbounded above and below the mean, meaning that it can take any positive or negative value. The unit of measurement for the standardized indicator is standard deviations: The number of standard deviations the observation is from the sample mean. These indicators can be compiled into a single vulnerability index by estimating the mean of each standardized indicator for each observation in the sample, or:

$$\text{Mean\_Index\_Sum}_i = \frac{\Sigma_j \text{ Std\_Index}_{ij}}{J},$$

where J is the total number of indicators that make up the set of socioeconomic characteristics of interest.

The relative-to-minimum index is a standardized scale ranging from zero to one that summarizes each indicator based on the value of each observation relative to the minimum sample value (or maximum sample value for indicators where higher values indicate worse socioeconomic outcomes, such as poverty rates). This is a common type of index for climate vulnerability studies (e.g., Pandey and Jha 2012; Safi et al. 2012). The standardized value for each indicator is calculated as:

$$\text{Min\_Index}_{ij} = \frac{(X_{ij} - X_j^{min})}{(X_j^{max} - X_j^{min})}$$

Values of the minimum index for a given indicator are interpreted as a relative comparison to the worst-case value in the sample. Like the mean vulnerability index, a single vulnerability index is created by calculating the mean of each standardized indicator for a given observation in the sample.

Adger et al. (2004) argue that indices based on standardized values can be problematic for interpretation of vulnerability. Instead, they develop a ranking-based index that does not rely on a standardization calculation. Following the approach of Adger et al. (2004), county observations of each indicator are ranked from the worst-case outcome to the best-case outcome. Each observation is then assigned to a quintile category (1–5) based on the ranking. The quintile index is then constructed by calculating the sum of the quintile scores for each indicator.

Data

Data used to construct the indices were drawn from publicly available U.S. Census products summarized for each county in Arizona and New Mexico, plus counties in Utah, Colorado, Texas, and Oklahoma that were included in the forest analysis areas (described in Chapter 4). County-level data were used to describe representative households for each county, rather than observations of individual households that are not publicly available. Counties are convenient observational units because data for a wide array of detailed socioeconomic indicators are readily available at the county level. Smaller geographic units (e.g., Census block groups) could provide additional spatial detail, but Census privacy and disclosure requirements limit the availability of some indicators at the subcounty level.

A core set of nine indicators was identified to summarize adaptive capacity (table 20). These variables were categorized into indicators of income and earning potential (median income, poverty rate, receipt of public assistance), labor market outcomes (unemployment rate, labor force participation), and human capital (education attainment, health insurance coverage, population under age 18, and population age 65 and over).

Table 20—Socioeconomic indicators gathered at the county level to develop adaptive capacity indices (observations = 58 counties).

Indicator	Description	Source	Mean	Minimum	Maximum
Health uninsured	3-year average share of population without health insurance	Small Area Health Insurance Estimates, 2008–2010 (U.S. Census)	0.239	0.050	0.357
No HS diploma	Share of age 25 and older population without a high school diploma	American Community Survey 5-year (U.S. Census)	0.180	0.014	0.302
Public assistance	Share of households receiving public assistance or food stamps/SNAP[a] benefits	American Community Survey 5-year (U.S. Census)	0.133	0.028	0.244
Labor force participation	Labor force participation rate: Share of age 16 and older civilian population in the labor force	American Community Survey 5-year (U.S. Census)	0.567	0.356	0.733
Unemployment	Unemployment rate: Share of age 16 and older civilian labor force not employed	American Community Survey 5-year (U.S. Census)	0.084	0.009	0.188
Income	Median household income (2011 $)	American Community Survey 5-year (U.S. Census)	41,764	26,152	104,914
Poverty rate	Share of families below the Federal poverty threshold	American Community Survey 5-year (U.S. Census)	14.5	1.60	28.4
Under 18	Share of population age 18 and under	2010 Decennial Census	0.247	0.132	0.317
Over 65	Share of population age 65 and older	2010 Decennial Census	0.163	0.089	0.326

[a] Supplemental Nutrition Assistance Program

Results

The three index measures used in this analysis are fairly consistent in how they describe county-level socioeconomic status. According to these measures, counties that consistently show low adaptive capacity (lower index scores) include Apache, Santa Cruz, La Paz, Navajo, and Yuma in Arizona; Luna, McKinley, Cibola, and Guadalupe in New Mexico; and El Paso in Texas (table 21). The counties that tend to show higher adaptive capacity (higher index scores) are the urban counties (except for El Paso in Texas, and Doña Ana in New Mexico), including Maricopa and Pima in Arizona (which contain Phoenix and Tucson, respectively), and Sandoval, Santa Fe, and Bernalillo in New Mexico (which contain Rio Rancho, Santa Fe, and Albuquerque, respectively). Los Alamos County in New Mexico consistently had the highest index values, indicating the county was the least socioeconomically vulnerable to changes in the provision of forest ecosystem services.

Counties characterized by a large share of lands in national forests and grasslands do not have consistently high or low adaptive capacity (fig. 5.1). Although several counties with low adaptive capacity measures have a high share of national forest land (e.g., Santa Cruz County in Arizona and Rio Arriba County in New Mexico), several other counties with a large proportion of national forest land have more moderate to high

Table 21—Adaptive capacity index values[a] by county in the Forest Service Southwestern Region[b]. For all index measures, higher values indicate higher average relative adaptive capacity.

County	Mean index	Minimum index	Quintile rank index
Apache (AZ)	-12.5	1.73	15
Cochise (AZ)	2.67	4.70	30
Coconino (AZ)	5.90	5.42	38
Gila (AZ)	-0.712	4.07	25
Graham (AZ)	-2.53	3.68	25
Greenlee (AZ)	2.28	4.59	30
La Paz (AZ)	-5.45	3.15	19
Maricopa (AZ)	5.64	5.30	36
Mohave (AZ)	-0.640	4.07	26
Navajo (AZ)	-5.92	3.00	19
Pima (AZ)	3.90	4.97	34
Pinal (AZ)	2.30	4.63	32
Santa Cruz (AZ)	-7.01	2.82	17
Yavapai (AZ)	3.12	4.84	32
Yuma (AZ)	-5.03	3.19	20
Alamosa, CO	0.749	4.40	30
Conejos, CO	-1.91	3.86	24
Bernalillo (NM)	5.54	5.33	36
Catron (NM)	-0.832	4.16	27
Chaves (NM)	-1.46	3.97	23
Cibola (NM)	-6.30	3.00	20
Colfax (NM)	2.24	4.71	31
Curry (NM)	0.925	4.43	29
De Baca (NM)	-2.32	3.86	22
Doña Ana (NM)	-3.12	3.66	20
Eddy (NM)	3.53	4.89	35
Grant (NM)	0.877	4.41	26
Guadalupe (NM)	-6.46	3.07	20
Harding (NM)	0.161	4.41	27
Hidalgo (NM)	-4.57	3.37	18
Lea (NM)	-0.36	4.15	27
Lincoln (NM)	2.89	4.84	32
Los Alamos (NM)	19.9	7.81	41
Luna (NM)	-9.65	2.36	13
McKinley (NM)	-8.76	2.58	15
Mora (NM)	3.54	5.00	33
Otero (NM)	-.600	4.17	24
Quay (NM)	-1.85	3.93	24
Rio Arriba (NM)	-0.908	4.07	24

Table 21—*Continued.*

County	Mean index	Minimum index	Quintile rank index
Roosevelt (NM)	-1.09	4.08	23
San Juan (NM)	1.31	4.53	30
San Miguel (NM)	-1.05	4.07	24
Sandoval (NM)	7.23	5.59	40
Santa Fe (NM)	6.13	5.45	37
Sierra (NM)	-2.71	3.77	27
Socorro (NM)	-4.24	3.46	20
Taos (NM)	-0.130	4.29	25
Torrance (NM)	-3.92	3.51	19
Union (NM)	4.74	5.24	34
Valencia (NM)	-1.29	3.98	24
Cimarron (OK)	-1.79	3.98	24
Roger Mills (OK)	5.29	5.28	34
Dallam (TX)	1.94	4.71	31
El Paso (TX)	-6.24	3.06	21
Gray (TX)	0.532	4.37	26
Hemphill (TX)	5.44	5.31	33
Kane (UT)	7.30	5.66	38
Washington (UT)	4.18	5.00	33

[a] Each index is reported as a summation, meaning that the nine standardized indicators or quintile ranks are summed to create the index. (The overall ranking for each type of index does not depend on whether a summation or average is used to calculate the final index values.)
[b] Note: El Paso (Texas) and counties in Colorado and Utah are not geographically within the Southwestern Region, but are included because they appear in at least one forest economic impact area (see Chapter 4).

adaptive capacity (e.g., Coconino and Yavapai Counties in Arizona and Lincoln County in New Mexico).

An advantage of constructing the indices at the county level is that the counties can be aggregated at the forest level (table 22) by using the definitions of the forest impact analysis areas described in Chapter 4. Across all three index measures, counties in the economic analysis area for the Gila and the Lincoln have lower adaptive capacity scores relative to counties in other forest areas. The forest areas with the highest adaptive capacity scores include the Prescott, Tonto, Apache-Sitgreaves, and Coconino. These forest areas are dominated by the inclusion of the most populous county in the region, Maricopa, which has relatively high adaptive capacity rankings.

Summary

Adaptive capacity, as measured by three indices that summarize socioeconomic data at the county level, appears to vary substantially across the region. Results indicate that in some counties households on average have access to substantial resources and

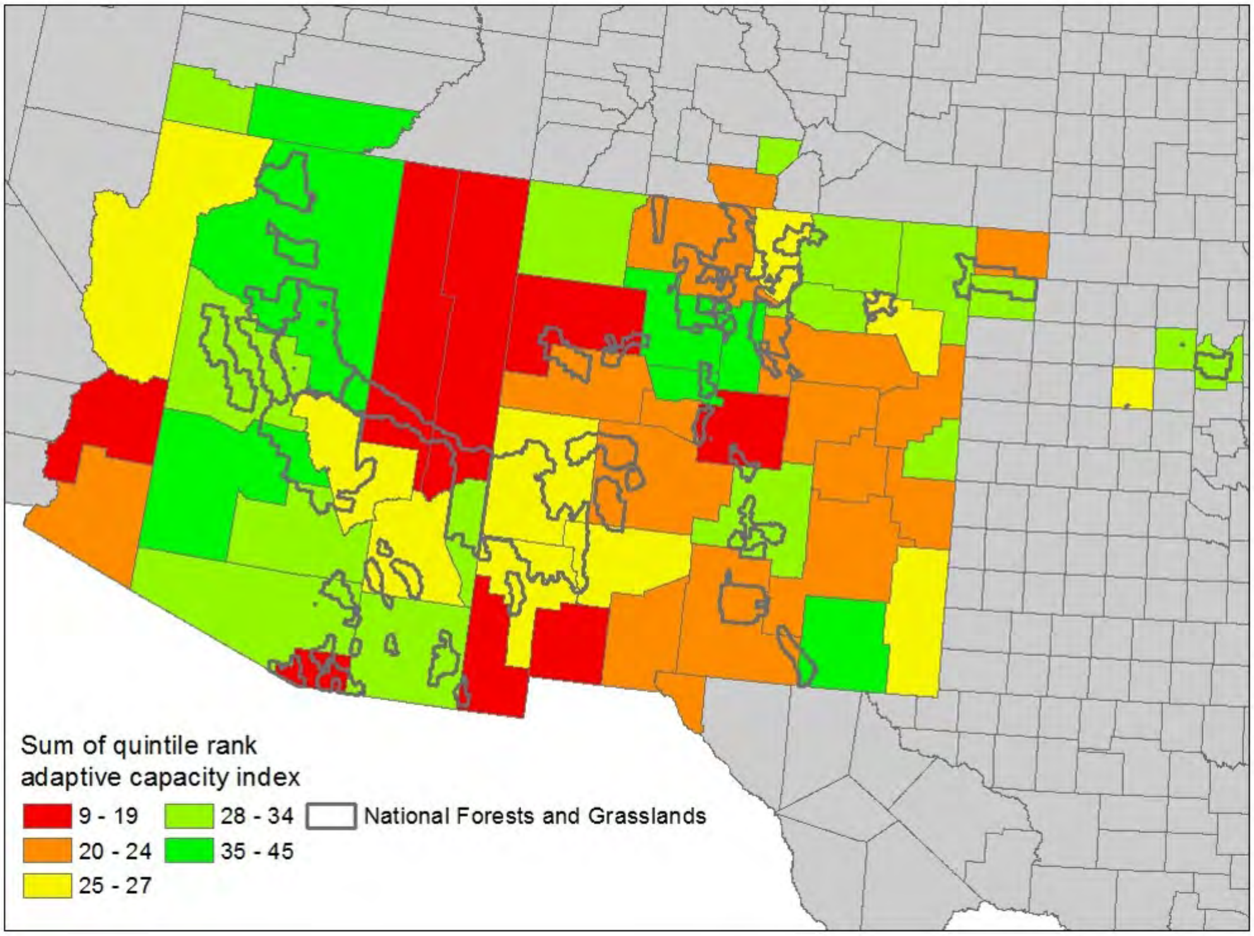


Figure 5.1—Summary index of adaptive capacity (quintile rank index) in the Forest Service Southwestern Region, by county. Red and orange counties (lower ranks) indicate lower adaptive capacity as measured by socioeconomic variables. Green counties (higher ranks) indicate greater adaptive capacity as measured by socioeconomic variables.

Table 22—Household population-weighted values of adaptive capacity indices for national forests (NFs) and grasslands (NGs) in the Forest Service Southwestern Region, by forest economic impact area. For all index measures, higher values indicate higher average relative adaptive capacity of counties included in each forest analysis area.

Forest unit	Mean index	Minimum index	Quintile rank index
Apache-Sitgreaves NF	5.01	5.17	35.2
Carson NF	-0.46	4.19	25.3
Cibola NF	4.48	5.12	34.5
Cibola NG	2.02	4.68	29.1
Coconino NF	4.97	5.17	35.1
Coronado NF	3.20	4.83	32.8
Gila NF	-6.86	2.87	19.8
Kaibab NF	1.69	4.54	30.0
Lincoln NF	-4.62	3.37	22.5
Prescott NF	5.49	5.27	35.8
Santa Fe NF	3.49	4.92	33.1
Tonto NF	5.31	5.23	35.6

Note: Some counties appear in multiple forest economic impact areas.

assets and can draw on high levels of human capital to adapt to ecological changes to forests and grasslands. In other counties, low measures suggest that adaptive capacity is more limited for the average household.

The indicator approach used here provides a broad snapshot of socioeconomic conditions across the region. But it does not incorporate other information that may be important for assessing adaptive capacity, such as information about social capital or social processes within communities (Fischer et al. 2013). Further, some within-county variation in socioeconomic conditions may be masked when data are summarized at the county level.

The analysis of adaptive capacity can be used in conjunction with the analyses in the previous chapters to assess whether socioeconomic conditions may exacerbate or mitigate exposure and sensitivity to ecological changes. The analysis in Chapter 3 indicates that the Coconino National Forest contains two ranger districts (Mogollon Rim and Peaks) where at least 50 percent of area is considered to be at high hazard for two or three climate-related stressors (Chapter 3, fig. 3.7). Among national forests in the region, the Coconino also contributes the most to employment and income (Chapter 4, table 16). These two results suggest that the Coconino has relatively high exposure to climate-related changes to the provision of ecosystem services, and nearby communities have high sensitivity to changes in the supply of ecosystem services. However, the Coconino National Forest analysis area contains counties ranked among the highest in adaptive capacity. In this case, high exposure and sensitivity may be mitigated by socioeconomic conditions that are consistent with the ability to avoid negative consequences associated with ecological changes.

Chapter 6: Incorporating Socioeconomic Vulnerability Assessment Information Into Forest Planning and Adaptation Activities

The data and analyses in the preceding chapters were designed to provide public land managers in the Southwest with information to better understand the relationships among ecosystem services, socioeconomic well-being, and climate change. This information can be used to plan for the effects of climate change on national forests and grasslands and their impacts on people and communities who rely on ecosystem services that are derived from these lands. Proposed actions by organizations seeking to adapt to climate change can be evaluated along three dimensions (Adger et al. 2005): (1) Effectiveness: Does the action achieve the intended result? (2) Efficiency: Does the action achieve the result using the fewest resources? and (3) Equity: Does the action promote well-being of vulnerable groups? This chapter addresses inclusive decision-making, decision support tools, the potential role of partnerships, and the evaluation of tradeoffs in managing for climate change vulnerability.

This chapter also discusses the management implications of climate-related changes to forests in the Southwestern Region and the potential for the socioeconomic vulnerability assessment to provide information to forest and grassland managers planning for climate effects. Specific results for particular forest units are not discussed in detail here; summaries are provided by forest unit in the Appendix. The focus is how managers can support adaptation to the projected climate-related changes that affect socioeconomic well-being. Although specific proposals to respond to climate change in the region are not developed here, this chapter is meant as a guide for using the analyses presented in previous chapters to inform adaptation activities.

Using the Socioeconomic Vulnerability Assessment Results for Forest Planning and Adaptation

The primary contribution of the vulnerability assessment is to describe the various ways that people in the Southwest depend on national forests and grasslands and the potential role of climate change in altering ecosystem services. This information can be used in two ways. First, national forests across the region can be compared to indicate where climate-related changes to certain ecosystem services are expected to have the largest or smallest socioeconomic effects. This type of comparison can help regionwide planning and prioritization efforts.

For example, the importance of snow-based recreation activities in northern New Mexico national forests (the Carson, Santa Fe) suggests that higher winter temperatures and less reliable snowpack will have a larger socioeconomic impact in those areas compared with other forests where little winter recreation occurs. Note also that counties in northern New Mexico, particularly Rio Arriba and Taos, tend to have lower than average adaptive capacity measures (see Chapter 5 and figure 5.1). Compared with, for example, northern Arizona counties around the Kaibab National Forest, people and communities that depend on winter recreation in northern New Mexico may fare worse under future climate scenarios. This type of information may help frame managers' approach and decisions about the relative needs for adaptive management as they set regionwide priorities related to recreation.

A second use of the vulnerability assessment is at the local level by national forests and, in some cases, individual ranger districts (see box 3). During development of forest plans, comparisons between forests may be less important than understanding the most important ecological and economic stressors to expect in the future. Forest managers can use the assessment to help identify sources of climate-related change that may affect well-being of nearby communities. For some ecosystem services, climate change may have relatively little impact on well-being. For other ecosystem services, even if projected climate-related changes are minor, changes in service provision may meaningfully affect people and communities.

For example, ranger districts in the Coronado National Forest tend to have relatively high exposure to climate-related changes to livestock grazing. Most animal unit months permitted in the Coronado are on grazing allotments that are at high or very high likelihood of vegetative change. However, the exposure of surface drinking water to climate change is relatively low in the forest. Although the assessment did not develop comparable metrics for how much people will be affected for a given change in each ecosystem service, the comparison between grazing and surface water for the Coronado suggests that climatic changes are likely to have a relatively large impact on grazing activities.

BOX 3—Socioeconomic Vulnerability and Forest Planning Under the 2012 Planning Rule

Direction related to climate change can be found throughout the 2012 Planning Rule and its directives for management planning on National Forest System lands (USDA Forest Service 2012b). The rule stipulates that managers assess "system drivers, including dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change; and the ability of terrestrial and aquatic ecosystems on the plan area to adapt to change" (USDA Forest Service 2012b: 21263).

Social and economic considerations play a key role in the new planning rule and its directives. Language in the rule requires consideration of forest contributions to social and economic sustainability. The directives indicate that these contributions include those from ecosystem services and multiple uses of national forests and grasslands (USDA Forest Service 2012b: 21265). Examples of ecosystem services and multiple uses are:

- Recreational settings and opportunities for recreation activities,
- The provision of fresh water for downstream uses,
- Forage for domestic livestock grazing,
- Volume of timber or biomass offered for sale,
- Opportunities for hunting and fishing, and
- Water quality and aquatic organisms sustained by watersheds in properly functioning condition.

The directives state that the drivers and stressors affecting key ecosystem services should be identified (USDA Forest Service 2012b: 21263). Further, the directives and planning rule require "that the plan contain other plan components for integrated resource management to provide for multiple use as necessary" (USDA Forest Service 2012b: 21266).

The analysis of likelihood of vegetative change developed by Triepke et al. (2014) and applied in this study (Chapter 3), provides a rigorous approach to meeting the climate change-related requirements under the 2012 Planning Rule and its directives, such as the assessment of stressors and disturbance regimes. Further, consideration of economic dependence and community vulnerability (chapters 4 and 5) provides a framework to meet requirements for the assessment of the supply and demand of ecosystem services and how they benefit people and communities.

Management Approaches to Planning for Climate-Related Changes to Forests and Grasslands

There is no single way for public land managers to respond to climate change or incorporate vulnerability assessment information into the planning process. We have summarized prominent management approaches, with the recognition that multiple approaches may be needed, and no single strategy will fit across all potential situations. These approaches include: inclusive decisionmaking, adaptive management frameworks, partnerships and innovative funding, and evaluating tradeoffs. The analyses in this report that form the vulnerability assessment can provide a contextual backdrop for these approaches, although results from the assessment may be used differently in each case.

Inclusive Decisionmaking

Where the costs of an action would be borne by vulnerable populations, alternative actions or mitigation measures may be considered along with an evaluation of uncertainty (Millar et al. 2007). Although Executive Order 12898 (Federal actions to address environmental justice in minority populations and low-income populations, February 11, 1994) already requires the evaluation of environmental justice in Federal decisions, vulnerability to climate change may not align with traditional metrics that focus on income, race, and ethnicity. Adaptive capacity and dependence on forest and grassland resources are not typically used as criteria in identifying populations for environmental justice purposes. Therefore, community vulnerability to climate change may not be adequately addressed by the tools of environmental justice. One means of addressing vulnerability is through the involvement of marginalized individuals and communities in decisionmaking.

As described in Chapter 5, socioeconomic vulnerability is linked to lower levels of social and human capital. Participation in public decisionmaking about land is more likely among individuals who understand the regulatory process, are part of networks that share information on opportunities to participate, have the time and resources to attend public meetings, and can interpret technical findings. In other words, socioeconomically vulnerable populations are less likely to influence public decisionmaking (Adger 2003). Therefore, in addressing vulnerability to climate change, managers may need to adopt new approaches to public involvement. Two of these approaches are discussed next.

Participatory action research (PAR) seeks to involve individuals and communities in the decisions that affect their well-being. PAR can identify local information not included in the assessment results, develop likely future scenarios, and provide input to managers (Sheppard et al. 2011). Treating climate change adaptation as an exclusively expert-driven process may hamper the effectiveness of local action (Shaw et al. 2009). These authors emphasize that the co-production of knowledge can drive ownership of both problems and solutions. The use of PAR, therefore, may encourage community participation in decisionmaking and implementation. The downscaled scenarios provided in this report can serve as a starting point for community involvement in developing knowledge and identifying desired future conditions.

The community visioning process promotes inclusive decisionmaking about public resources to align management with community well-being. This process encourages communities to identify desired outcomes and plan achievable ways to attain them (Green et al. 2010; Okubo 2000). The State of Oregon uses community visioning widely, with four basic components: (1) A community profile, (2) a trend statement, (3) a vision statement, and (4) an action plan (Green et al. 2010). This model is used increasingly to address climate change adaptation (Sheppard et al. 2011). In areas vulnerable to climate change, community visioning can be a useful tool to educate individuals on the science and implications of climate change as well as to involve them in designing and supporting adaptive strategies. The process may produce an additional benefit of expanding social capital, and, therefore, adaptive capacity (Okubo 2000). Community visioning may help to prioritize adaptation actions to secure critical ecosystem services. Through the process, communities produce measures of success, which may be incorporated into the evaluation of tradeoffs.

Past efforts to encourage local participation in climate change adaptation and mitigation have been hampered by the lack of information specific to local communities (Sheppard et al. 2011). This report provides county-level findings on both ecological and socioeconomic vulnerability to climate change, which makes the risks—and opportunities—more salient to individuals and communities. Findings in this report may serve as a starting point for the PAR and community visioning processes.

Adaptive Management Frameworks

Adaptive management approaches involve a cycle of planning, acting, monitoring, and evaluating (Stankey et al. 2005). Adaptive management recognizes that both causes and effects of social and environmental change are uncertain, especially in how changes are manifested locally (Millar et al. 2007). The two processes discussed here, scenario planning and structured decisionmaking, help to incorporate and address uncertainty, particularly as it relates to vulnerability. For instance, monitoring and validation, as part of adaptive management, are key elements of scenario planning (Weeks et al. 2011).

Scenario planning is a management tool that is particularly useful in environments of high uncertainty and low control. This type of planning is used to develop and test management actions under multiple potential futures. The National Park Service has used collaborative scenario planning to address climate change uncertainty (Weeks et al. 2011). The development of multiple future scenarios allows for variation in ecological and socioeconomic conditions.

Scenario planning can help managers incorporate uncertainty related to social, political, and economic variables. Similar to community visioning, scenario planning can improve community understanding of the complexity of climate change (Sheppard et al. 2011). Indeed, scenario planning can be used in tandem with a community visioning process. Information in Chapter 3 provides a starting point for scenario planning related to the condition of future ecosystem services; chapters 4 and 5 provide a starting point for scenario planning related to socioeconomic conditions.

The implications of the future scenarios can guide adaptation actions. The prioritization of actions may depend on the perceived likelihood of each scenario, the implications for vulnerable populations, and the presence of actions that produce positive outcomes under multiple scenarios.

Structured decisionmaking (SDM) combines scientific knowledge and social values to generate management actions (Wilson and Arvai 2011). An effective process allows diverse stakeholders to (1) understand the problem, (2) share their values and concerns, and (3) evaluate the tradeoffs of various actions (Wilson and Arvai 2011). Before developing and evaluating management strategies, an SDM approach to climate change requires the assessment of system vulnerabilities (Ohlson et al. 2005).

Information in chapters 3, 4, and 5 could be used as key inputs into an SDM process in the Southwest. Following the development of potential actions, SDM makes the inevitability of tradeoffs explicit, which can help in conversations among managers, scientists, and the public. For example, chapters 3 through 5 provide information on potential ecological changes, dependence on ecosystem services, and socioeconomic conditions. This information fosters an effective SDM process by helping stakeholders understand the problem and giving them context to share their values and concerns about the potential management actions.

Further, the collaborative evaluation of tradeoffs can lessen the desire of some participants to consider only their particular concern (Wilson and Arvai 2011). The use of a tradeoff matrix allows participants to see how a change in their objectives (e.g., minimizing cost) affects another objective (e.g., ecosystem health). The evaluation of tradeoffs is discussed in greater detail at the end of this section.

Partnerships and Innovative Funding

The U.S. Department of Agriculture and the Forest Service have promoted an "all-lands" approach to forest management (USDA 2009; USDA Forest Service 2010). This approach seeks collaboration across jurisdictions to improve ecosystem health across the landscape. Climate change and its effects on ecosystem services are not bound by political and administrative designations. Land use changes that occur on private and other public lands will affect national forests and grasslands, and vice versa. Vulnerable populations are likely to be affected by decisions that occur across jurisdictions. The all-lands approach, therefore, is particularly relevant when considering responses to climate change vulnerability.

Forest Service managers cannot dictate actions on private or non-Forest Service public lands. Similarly, Forest Service managers will not undertake inappropriate actions for the sake of consistency with other management actions on the landscape. The all-lands approach places a premium on partnerships and the potential for public-private collaboration to improve ecosystem resilience and the provision of critical ecosystem services.

Partnerships with the private sector, State and local agencies, and not-for-profit and community-based groups may help to overcome resource constraints. For example, in 2010 the Rocky Mountain Region of the Forest Service and Denver Water worked as partners to provide $33 million of restoration treatment in high-risk and high-value watersheds in the Denver metropolitan area (Stanton and Zwick 2010). In 2012, voters in the City of Flagstaff (Arizona) approved a $10 million bond measure to fund restoration activities in the Coconino National Forest in the city's two watersheds to reduce the risk of catastrophic wildfire and subsequent flooding (City of Flagstaff 2012). Elsewhere in the Southwest, the Santa Fe Municipal Watershed Restoration Project is funding forest restoration in the Santa Fe National Forest to protect water quality and reduce the risk of forest fire in the watershed above the City of Santa Fe's intake (City of Santa Fe 2013). In all of these cases, the beneficiaries of ecosystem services, such as municipal water users, pay for activities to improve or maintain the delivery of these services. With declining budgets and increasing wildfire costs, external funding through partnerships can allow for proactive forest management to mitigate and adapt to climate change.

One type of partnership used by national forests—stewardship contracting—may be an opportunity to manage forests in response to climate change. One type of stewardship contract permits the removal of timber and biomass in exchange for forest restoration services (USDA Forest Service 2009a). The 2014 Farm Bill permanently authorized stewardship contracting; other types of stewardship contracts that do not involve the exchange of goods for services are described in Moseley et al. (2015). The authority for stewardship provides another mechanism for completing forest restoration activities despite budget limitations. Whereas traditional commercial harvesting of timber on lands managed by the Forest Service requires that revenue in excess of costs be returned to the U.S. Treasury, stewardship contracting keeps the revenue in the forest to support restoration activities that may otherwise be too costly to implement. As a result, stewardship contracts may promote economic, ecological, sociological, recreational, and administrative benefits (Hausbeck 2007).

Forest partnerships are not unidirectional. In addition to working with State and local agencies to fund restoration activities on Forest Service-managed lands, the Forest Service may support State and private forest owners through the Cooperative Forestry program. One aim of this program is to prepare forest owners and managers to participate in emergent ecosystem service markets, such as through the sale of offsets in carbon markets. By the end of fiscal year 2012, 29 States had agreements with the Forest Service to help private forest landowners market ecosystem services (USDA Forest Service 2013a).

Enabling private landowners to participate in ecosystem service markets creates incentives to maintain forest land, which can support both climate change mitigation (i.e., carbon sequestration) and adaptation (e.g., protection of highly valued resources, such as water). Most of the approximately 750 million acres of U.S. forest land is privately owned (USDA Forest Service 2012a). Fragmentation and intensive land use are more likely on private forest land (USDA Forest Service 2012a). Rapid population growth in the Southwest will increase the importance of urban forests, which provide ecosystem services that promote health and well-being (USDA Forest Service 2012a). As a result, creating incentives for preservation of private forest land may be particularly important for adaptation to climate change.

Evaluating Tradeoffs

In evaluating the tradeoffs of management actions in response to climate change, several considerations may affect decisionmaking. First, consequences of climate change may occur at spatial or temporal scales not addressed in most plans or project analyses. Second, management actions with co-benefits (i.e., benefits other than climate change mitigation or adaptation) may be desirable. Finally, distributional implications may be explicitly accounted for in the assessment of tradeoffs.

Some management actions may produce negative consequences, necessitating the consideration of tradeoffs. Sometimes, the effects of management actions appear immediately in the study area and are relatively easy to identify and mitigate. However, some management actions may produce spillover effects that occur outside of the spatial or temporal scale of the project analysis. These effects may be more difficult to identify and mitigate, particularly if the effects occur outside of lands managed by the Forest Service. This report provides analyses at spatial scales extending beyond lands managed by the Forest Service, which may be helpful in identifying potential consequences of climate change for vulnerable communities.

The temporal scale of climate change exceeds the typical temporal scale of land management plans and project-level analyses. Whereas a forest plan might project influence over the next 20 years, the timescale for changes in climate may be considerably longer. Under these circumstances, the application of standard discount rates (e.g., 4 percent) may discourage investment in adaptation actions because current costs are weighed more heavily than future benefits (Goulder and Williams 2012). Furthermore, climate change is influenced by the behavior of people around the world. Actions taken by individuals and land managers in the Southwest may have consequences in other regions or countries, and vice versa. Resource specialists may adopt longer temporal and broader spatial scales in their analyses, but these approaches are likely to generate greater uncertainty as socioeconomic, political, and ecological changes become more difficult to estimate.

Given the risk and uncertainty in applying adaptation strategies, managers may prioritize "no-regrets" actions in evaluations of tradeoffs. No-regrets actions are those where benefits exceed costs, regardless of the extent of climate change (City of London 2010). Such actions may deliver co-benefits; for instance, they may promote adaptation to climate change *and* improve ecosystem health, regardless of climate outcomes. Many forest restoration and fuels reduction projects could be categorized as no-regrets activities. Although such activities are not guaranteed to produce the highest benefit-cost ratio, they are expected to improve outcomes under all potential climate scenarios. This report provides useful information for identifying and carrying out no-regrets actions with consideration of the equity effects to vulnerable communities.

Socioeconomic vulnerability is not a familiar metric in many conventional tradeoff studies, where efficiency is the main objective. Evaluations may include multiple criteria, such as cost, time, and number of acres protected or restored. However, equity may also serve as an evaluation criterion. Distributional considerations may be explicitly incorporated into a tradeoff matrix by assigning higher weight to effects to vulnerable communities than effects to more resilient communities. Weights can reflect a concern with burdening communities that are least able to adapt to environmental and economic changes (OECD 2006). For Southwestern Region planners and managers who are interested in incorporating distributional considerations into decisionmaking, this report identifies the counties with the lowest adaptive capacity and the types of decisions that may disproportionately affect those communities. This information can be used as an input in determining whether and how distributional weights should be applied in the evaluation of tradeoffs.

Caveats and Limitations to the Assessment

There are several limitations to the assessment, both in terms of the scope of information provided and how it can be used by managers. By necessity the analyses did not address all ecosystem services provided by forests and grasslands in the region. Because of a lack of available data or clear conceptual links between climatic changes and the provision of certain ecosystem services, the assessment could not provide information about all socioeconomic effects of climate-related changes to these ecosystems.

The assessment also is not well suited for developing benefit-cost analyses for specific projects, or for predicting the value of proposed adaptation strategies. That is, from the analyses we cannot say that climate change will affect well-being derived from an ecosystem service by a certain amount, or whether an investment to mitigate negative effects of climate change will improve well-being by a certain amount.

Although the assessment is useful for identifying places and ecosystem services that may be affected by climate change, not enough information is available to determine whether management interventions will successfully mitigate changes or avoid negative consequences. The assessment may be used to flag high-priority socioeconomic impacts of climate change, but more work is required to determine the most effective and desirable management approaches.

Finally, what is known or projected about future climate scenarios, how ecosystems will be affected by climatic changes, and the effect on the provision of ecosystem services involve considerable uncertainty. Some dimensions uncertainty can at least be evaluated by examining results under multiple future scenarios (e.g., different emissions scenarios that drive global circulation models) or different assumptions (e.g., which socioeconomic characteristics are closely related to adaptive capacity). But we know very little about other sources of uncertainty, such as how some ecosystems will respond to climate characteristics outside of previously observed ranges, and how people will respond to ecological changes that have not previously been observed.

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Appendix—Summaries of Forest-Level Socioeconomic Vulnerability Assessments

The analyses of exposure, sensitivity, and adaptive capacity can be used to explore how well-being may be affected by changes to the provision of ecosystem services. Although the analyses are not meant to be combined into a single vulnerability metric for each national forest and grassland, it is possible to get a broader understanding of vulnerability by examining the analysis results for each forest unit.

A difficulty in creating forest-level vulnerability summaries is that the analyses were conducted at varying spatial and administrative scales (e.g., county, ranger district, forest unit, watershed). The following summaries do not attempt to aggregate or downscale results to a common scale. Instead, the results are examined for each forest to provide a broad view of socioeconomic vulnerability. For example, if a national forest and its ranger districts consistently appear to have low exposure, low sensitivity, and high adaptive capacity relative to other forests, then the forest is likely to exhibit low socioeconomic vulnerability. Given the multidimensionality of the analyses, results may point in different directions or suggest high vulnerability for some ecological changes (e.g., timber resources) and low vulnerability for others (e.g., water supply). A full discussion of these nuances is not feasible here; the summaries are meant as starting points for further exploration and detailed forest-level analysis.

Finally, we emphasize that the vulnerability assessment does not account for all factors that relate to socioeconomic vulnerability to ecological changes. Other ecological changes not examined in this report, and unobserved socioeconomic factors, may be important determinants of vulnerability that are not captured here.

Apache-Sitgreaves

Apache-Sitgreaves National Forest exhibits average exposure to ecological changes, although there is high variability in exposure across ranger districts. The Alpine and Springerville Ranger Districts tend to have low exposure measures, while Black Mesa and Lakeside Ranger Districts both rank in the upper quartiles of exposure. Primary sources of high exposure for these ranger districts are vegetative change, intersecting stressors, and timber.

Economic sensitivity is relatively low for the Apache-Sitgreaves. Relatively little employment and income in counties within the forest economic impact area are derived from resource sectors, probably reflecting the prominence of Maricopa County (Phoenix metropolitan area) in the regional economy.

Counties in the Apache-Sitgreaves economic impact area are rated relatively high on adaptive capacity measures. As with economic activity, the presence of Maricopa County plays an important role in adaptive capacity measures. However, there is great variability across counties within the Apache-Sitgreaves economic impact area. Navajo and Apache Counties rank relatively low on adaptive capacity, whereas Maricopa and Coconino rank relatively high.

Overall vulnerability may be low to moderate for Apache-Sitgreaves National Forest due to moderate exposure, low sensitivity, and high overall adaptive capacity.

But within-forest variability suggests that some areas could experience greater socioeconomic pressures due to ecological changes. These are likely to be areas that depend on ecosystem services from the Black Mesa and Lakeside Ranger Districts in the eastern portion of the forest, and those communities with limited economic connections to the larger metropolitan area in Maricopa County.

Carson

Ranger districts in Carson National Forest tend to exhibit relatively low exposure to climate-related ecological change. Canjilon and Tres Piedras rank in the lowest or second lowest quartile for all exposure measures. The only instances of exposure ranking in the top quartile in the forest is for intersecting stressors in the Camino Real Ranger District and important surface water supply exposure in the Jicarilla Ranger District.

The Carson is among the forests with the highest sensitivity in the region. It is the only forest where economic contributions from resource sectors account for more than 1 percent of both employment and income in the economic impact area. A large portion of this contribution is derived from recreation activities, of which the most sensitive is winter recreation. Potential reduced likelihood of viable ski seasons may negatively affect recreation for the forest, but other types of warm-weather activities may increase in the future, potentially offsetting negative consequences of decreased winter recreation.

Adaptive capacity is moderate for counties in the Carson economic impact area. However, average adaptive capacity probably masks variation between counties, and even within counties.

Overall vulnerability is likely to be moderate for Carson National Forest. Although it appears to be highly sensitive to ecological changes and to have average to low adaptive capacity, exposure to climate-related ecological changes is low. That is, the likelihood of degradations in the provision of ecosystem services is low, although if drastic ecological changes do occur communities have a higher than average likelihood of being negatively affected.

Cibola

Cibola National Forest exhibits relatively high exposure, primarily driven by high likelihood of vegetative change on grazing allotments. The likelihood of vegetative change overall is higher than average in all ranger districts in the forest, although intersecting stressors and important surface watershed exposure tend to be moderate. In the grassland areas, we could not completely assess exposure due to data limitations.

Economic sensitivity to ecological changes is low, although there is an important distinction between the grasslands and the other ranger districts. Resource sector employment and income are relatively important in counties that make up the economic impact area for the Cibola grasslands. In contrast, resource sectors for the other districts are relatively less economically important, probably due to the presence of Bernalillo County (Albuquerque metropolitan area) in the economic impact area for the nongrassland districts.

Adaptive capacity is relatively high for the nongrassland ranger districts, and moderate but above average for the grasslands. The Cibola is spread across a large area in central New Mexico, and its economic impact area is composed of 11 counties. Given the range of socioeconomic conditions across these counties, it is likely that a high degree of heterogeneity exists for adaptive capacity.

Overall vulnerability is likely to be moderate to high for Cibola National Forest, with vulnerability probably higher for the grasslands areas. Given the large geographic area, more localized information about potential ecological changes and socioeconomic conditions could help future assessments.

Coconino

Coconino National Forest has relatively high exposure to climate-induced ecological changes. All ranger districts in the forest exhibit higher than average surface water exposure, and the Mogollon Rim Ranger District ranks higher than average on all exposure analyses except grazing exposure. Relatively low exposure to vegetative change is evident in the Mormon Lake and Red Rock Ranger Districts, although most other exposures are high for these areas.

Economic sensitivity is relatively low for the forest based on share of employment and income contributed by climate-sensitive resource sectors. As with other forests in central Arizona, the presence of Maricopa County plays a large role in keeping economic sensitivity low.

Adaptive capacity is high for the economic impact area associated with Coconino. As with sensitivity, Maricopa County is an important driver of this result, and variation across the economic impact area is likely. For example, Navajo County is ranked among the counties with the lowest adaptive capacity in the region.

Vulnerability is low overall for Coconino National Forest. Although there is higher than average likelihood of ecosystem service impacts due to climate change, low overall sensitivity and high adaptive capacity may provide a buffer against negative outcomes for communities that rely on ecosystem services from the forest. Some localized effects may be more severe, particularly for communities in Navajo County that rely on forest ecosystem services and have lower adaptive capacity.

Coronado

Coronado National Forest exhibits moderate to high exposure to ecological changes, although this result is likely due to variation in exposure for different ecosystem services. All Coronado ranger districts exhibit high exposure to vegetative change and grazing, but relatively low exposure for surface water. Timber is also rated as low exposure because there is limited timberland in the forest.

Sensitivity is moderate to low for the forest, with a low share of employment and income derived from resource sectors. Grazing and recreation contribute nearly equally to labor income for the forest economic impact area. However, given high exposure for grazing and ambiguous effects of climate on recreation, grazing sectors may be more likely to suffer economic impacts due to climate.

Adaptive capacity is moderate to high. The Coronado is the only forest in Arizona where Maricopa County is not included in the economic impact area. Two counties in the economic impact area are on the extremes of socioeconomic status: Pima County (which includes Tucson) ranks relatively high, whereas Santa Cruz County is among the counties ranked lowest on socioeconomic measures.

Overall vulnerability is likely to be moderate for Coronado National Forest. Certain ecosystem services, such as forage for livestock, have a higher likelihood of change and are likely to have greater economic impacts for communities that rely on these services. Although the area is on average likely to be able to cope with ecological changes, some areas (particularly in Santa Cruz County) may experience greater than average effects from moderate ecological changes.

Gila

Exposure to ecological changes is moderate for Gila National Forest. Although exposure rankings are high for the Black Range Ranger District, the Quemado and Reserve Ranger Districts have among the lowest relative exposure rankings, particularly for vegetative change and surface water exposure.

Counties in the Gila economic impact area are likely to be highly sensitive to ecological changes. The Gila is the most economically dependent on climate-sensitive resources in the region, with more than 1.5 percent of employment derived from resource sectors in the Gila economic impact area. Grazing activity is the largest contributor to resource employment and income in the area.

Adaptive capacity is low for counties that are associated with Gila National Forest. The indices for socioeconomic conditions are lower (indicating lower adaptive capacity) for the Gila than for any other forest in the region. Although indicators of socioeconomic conditions in Catron and Grant Counties in New Mexico are near the regional average, indicators for Apache County in Arizona are among the lowest in the region.

Socioeconomic vulnerability is likely to be high for Gila National Forest due to high sensitivity and low adaptive capacity. Although the exposure analyses suggest that the likelihood of climate-induced degradations to ecosystem service provision is close to the regional average, ecological changes may have a large negative effect on well-being for nearby communities. This effect may be felt especially acutely by communities in eastern Arizona, which may have limited capacity to adapt to changes and limited connections to large metropolitan areas in the region.

Kaibab

Kaibab National Forest is among the forests with the highest exposure in the region based on the factors studied in this report. All of the ranger districts in the forest rank in the highest quartile for exposure to vegetative change and changes to timber production. The Williams Ranger District also is among the districts with the highest exposure for intersecting stressors and important surface watersheds.

Economic sensitivity to ecological change is low in the Kaibab. About 1/10th of 1 percent of employment in the Kaibab economic impact area is derived from forest resource sectors, with grazing accounting for the largest employment contribution.

However, exposure to climate change of grazing resources is moderate to low for the Kaibab.

Adaptive capacity is moderate for the counties in the Kaibab economic impact area. Overall, socioeconomic indicators are slightly above average for these counties compared to the rest of the region, but significant variation exists across counties. Navajo County is among the counties with the lowest ratings on socioeconomic indicators, yet Coconino County in Arizona and Kane County in Utah are among the counties rated highest on socioeconomic indicators.

Overall vulnerability is likely to be moderate to low for Kaibab National Forest. High exposure is mitigated by relatively low economic sensitivity and average adaptive capacity. Certain economic sectors, such as grazing and timber sectors that rely on access to the Kaibab, may be at risk of ecological changes that result in economic disruption. Limited adaptive capacity may also put some communities, especially in Navajo County, at greater risk of negative consequences from ecological changes.

Lincoln

Lincoln National Forest is rated as the forest with the highest exposure. For both the Smokey Bear and Sacramento Ranger Districts all of the exposure measures are above average or in the top quartile, indicating high exposure across all ecosystem services. The Guadalupe Ranger District exhibits lower exposure for intersecting stressors and timber products, but higher than average exposure for the other measures (vegetative change, important surface watersheds, and grazing resources).

Economic sensitivity is relatively low, with about 1/10th of 1 percent of employment derived from climate-sensitive forest resource sectors. Recreation and grazing sectors are the primary resource sectors contributing to employment in the forest economic impact area; these two sectors account for 85 percent of resource sector employment and 71 percent of resource sector labor income. Climate effects on recreation activities are ambiguous, but all three ranger districts are rated at above average or high exposure to potential climate effects to grazing resources.

Adaptive capacity is low, with socioeconomic indicators in the economic impact area counties well below the regional average. The Lincoln economic impact area includes El Paso County in Texas, which is among the counties with the lowest ratings on socioeconomic indicators in the region. Because it is also populous, this county pulls down the overall average for the economic impact area even though a change to forest ecosystem services is likely to have minimal impact in the metropolitan economy associated with El Paso.

Overall vulnerability for Lincoln National Forest is likely to be moderate due to high exposure but limited sensitivity and moderate adaptive capacity outside of El Paso County.

Prescott

Prescott National Forest exhibits overall low exposure of ecosystem services to ecological changes. Exposure measures are below average or in the lowest quartile for most ecosystem services, except for important surface watersheds in the Chino Valley and Verde Ranger Districts. Higher watershed exposure is likely because multiple watersheds in the forest are upstream suppliers of surface water for Maricopa County.

Economic sensitivity is low for Prescott National Forest. Forest resource sectors contribute a smaller share of employment and income to the economic impact area than any other national forest. This is partly due to the inclusion of Maricopa County in the economic impact area, although total employment in the resource sectors is relatively small.

Adaptive capacity is high for Prescott National Forest. However, only two counties are included in this area: Maricopa and Yavapai. Both are rated as relatively high on socioeconomic indicators, with Maricopa County being the main driver of the adaptive capacity measures due to its large population.

Vulnerability is likely to be low for Prescott National Forest due to low exposure, low sensitivity, and high adaptive capacity. However, the quantitative measures may obscure localized vulnerabilities due to the presence of Maricopa County in the economic impact area. Communities not well connected with the Phoenix metropolitan area and those reliant on grazing may be more vulnerable. Further, the presence of important surface watersheds in the forest that are likely to serve greater Phoenix suggests additional potential vulnerabilities to climate-related ecological changes.

Santa Fe

Exposure to ecological changes is moderate for Santa Fe National Forest. The forest covers a large area in five ranger districts, and exhibits significant variation in exposure. Above-average exposure is measured for intersecting stressors in the Jemez and Española Ranger Districts, while the lowest exposure ecosystem services are vegetative change and grazing resources in the Coyote and Cuba Ranger Districts, and also grazing resources in the Jemez Ranger District.

Economic sensitivity is moderate for Santa Fe National Forest. About one-fourth of 1 percent of employment in the Santa Fe economic impact area is derived from forest resource sectors. Recreation is the largest climate-sensitive forest resource sector, accounting for 70 percent of employment and 78 percent of labor income in climate-sensitive resource sectors.

Adaptive capacity is high for the Santa Fe, with most counties in the economic impact area being rated high for socioeconomic indicators. The exception is McKinley County, which is among the counties rated lowest on socioeconomic status measures (but it has a relatively small population and hence a smaller effect on the overall Santa Fe adaptive capacity measures).

Vulnerability is moderate to low for the Santa Fe. Some pockets of greater vulnerability could arise, however, in communities with limited adaptive capacity (e.g., in McKinley County) or those sensitive to economic changes. Climate effects on recreation tend to be ambiguous, but climate effects on winter recreation tend to be negative. The Santa Fe has higher sensitivity for recreation due in part to winter recreation, which could raise vulnerability.

Tonto

Overall exposure of ecosystem services to ecological change is moderate for Tonto National Forest. However, for all ranger districts in the forest exposure for important surface water supply is high because watersheds in the forest supply surface water for Maricopa County.

Economic sensitivity is relatively low for the Tonto. Relative to other forests, total employment and income from climate-sensitive forest resource sectors are high, but make up a small share of total employment and income in the area due to the presence of Maricopa County in the economic impact area. Recreation is the most important forest resource sector, accounting for 65 percent of employment and more than 80 percent of labor income derived from climate-sensitive forest resources.

Adaptive capacity is high for the counties in the Tonto economic impact area. As with other forests where Maricopa County is included in the economic impact area, the relatively high socioeconomic ratings and high population there tend to prop up adaptive capacity measures.

Overall vulnerability for Tonto National Forest is likely to be low due to low sensitivity and high adaptive capacity. Higher exposure for important watersheds that serve greater Phoenix is a potential source of vulnerability. Communities in Gila County in Arizona, which is rated lower on socioeconomic measures, may be more vulnerable than other counties associated with Tonto National Forest.

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