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Future of America's Forests and Rangelands

Update to the Forest Service 2010 Resources Planning Act Assessment

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Abstract

The Update to the 2010 Resources Planning Act (RPA) Assessment summarizes findings about the status, trends, and projected future of forests, rangelands, wildlife, biodiversity, water, outdoor recreation, and urban forests, as well as the effects of climate change upon these resources. Varying assumptions about population and economic growth, land use change, and global climate change from 2010 to 2060 largely influence the outlook for U.S. renewable resources. The key themes from the 2010 RPA Assessment remain relevant. Land development, climate change, and natural disturbances continue to influence the extent, pattern, and conditions of forest and rangeland ecosystems. The interaction of socioeconomic and biophysical drivers affects the productivity of forest and rangeland ecosystems and their ability to meet increasing demands for goods and services. These effects vary regionally and locally, requiring flexible adaptation and management strategies.

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Executive Summary

This report, the Update to the 2010 Resources Planning Act (RPA) Assessment, is the fourth update to the RPA decadal report prepared in response to the mandate in the 1974 Forest and Rangeland Renewable Resources Planning Act (P.L. 93–378, 88 Stat 475), as amended. The key themes from the 2010 RPA Assessment (2010 RPA) remain relevant. Land development, climate change, and natural disturbances continue to influence the extent, pattern, and conditions of forest and rangeland ecosystems. The interaction of socioeconomic and biophysical drivers affects the productivity of forest and rangeland ecosystems and their ability to meet increasing demands for goods and services. These effects vary regionally and locally, requiring flexible adaptation and management strategies.

Key Themes

Land development will continue to threaten the integrity of forest and rangeland ecosystems.

U.S. forest area has continued the slight upward trend reported in the 2010 RPA, while rangeland has continued its slow decline. Developed land cover and urban area have continued to expand. If urban growth were to continue at the average rate exhibited from 1990 to 2010, urban area would increase from 3.5 percent of the conterminous United States in 2010 to 8.6 percent by 2060. The growth of urban area will continue to increase the importance of urban trees in providing ecosystem services. As urban areas become more densely developed, however, tree cover tends to decline.

While forest area increased in the past decade, forest fragmentation increased between 2001 and 2011. Fragmentation rates were higher on private land than on public land. The principal drivers of fragmentation appear to be human activities in the East and biotic and abiotic disturbances in the West. Because most forest land is in the Eastern United States and is privately owned, eastern private forest landowners, in particular, play a critical role in protecting the ecological integrity of forest lands. One cause of fragmentation is housing development, which often occurs in close proximity to public lands such as national forests. Bird communities within protected areas that have higher home densities at their boundary tend to support lower proportions of bird species of conservation concern. Continued expansion of this type of exurban development is likely to diminish the conservation benefit of protected areas.

At-risk species tend to be prominent in areas with high human population densities or where land use intensification has occurred. Prominent hotspots of threatened and endangered species have remained largely unchanged since the late 1990s. Mapping listed species on an equal area grid generally deemphasizes areas in the arid Southwest and highlights the emergence of listed species concentrations associated with the interior highlands and plateau region of southern Missouri, northern Arkansas, western Kentucky, southern Illinois, and southern Indiana.

Land development, through its effects on the total area of natural ecosystems and on their pattern and condition, will continue to be a crucial factor affecting the future of all natural resources considered in this RPA Update. If recent trends continue, future expansion of developed and urban lands will continue to impact natural landscape patterns and increase reliance on protected areas (or relatively undeveloped areas) to preserve functioning natural ecosystems. At the same time, increased development around protected areas impacts the ecological functions of those areas.

Climate change and natural disturbances will alter forest and rangeland ecosystems and affect their ability to provide ecosystem services.

Climate change and natural disturbances will have a major influence on the future health and productivity of natural ecosystems. Uncertainty about future local- and regional-scale changes in climate and disturbances implies uncertainty about projected impacts on nature and society. This uncertainty complicates our ability to create management and adaptation options.

Climate effects on forests and rangeland are projected to have differential impacts across the United States. In the Western United States, northern rangeland ecosystems are likely to experience increased productivity associated with climate change, while southern rangeland productivity declines. Following these same patterns, the vulnerability of cattle production to climate change is lower in the northern portion of the Great Plains than in the southern Great Plains or Southwestern United

States. While greater vulnerability of cattle production for much of the rangeland extent in the United States is indicated, more arid regions have the strongest trends toward greater vulnerability.

Forest growth rates continue to vary as they are influenced by patterns of forest management and cycles of insects, disease, wildfire, and other disturbances. Average annual growth increased in all RPA regions, except the Rocky Mountain Region, between 2007 and 2012. In the Rocky Mountain Region, average annual net growth has slowed by 48 percent since 2007, a change that can be attributed to large increases in mortality resulting from mountain pine beetle infestations. Softwood mortality in the Rocky Mountain Region increased 92 percent between 1996 and 2011.

Mortality caused by insects and diseases has been reported on a declining number of forest acres since 2009. By contrast, acres burned by wildfires in both 2011 and 2012 increased to levels seen in the mid-2000s. Insects and disease will also likely have substantial impacts on species composition and health in urban forests across the United States; these impacts may be exacerbated by climate change.

Terrestrial wildlife habitats, already affected by fragmentation and conversion of native vegetation to urban and developed areas, will be stressed further by changes to terrestrial habitat attributed to climate change. Focusing on the Rocky Mountain Region, climate-induced stress to wildlife habitats was also affected by fire management. Strategies to actively suppress fires result in higher habitat stress among the Intermountain semidesert and desert ecoregions because of turnover in historical vegetation types when temperate forests and woodlands replace temperate shrublands. By contrast, strategies directed at not suppressing fires result in higher stress among the steppe-coniferous and open woodland ecoregions as changes in climate and increased wildfire result in biomass declines.

Individual responses to climate change are difficult to gauge. In the case of outdoor recreation, climate was projected to have negligible effects on participation in most activities, but significant positive and negative effects on participation are projected for a small number of activities in the RPA regions. Positive effects occur for horseback riding on trails, motorboating, and fishing in the North Region. The most negatively affected activities include snowmobiling in the North and Pacific Coast Regions, hunting in the North and Rocky Mountain Regions, undeveloped skiing in the North and Rocky Mountain Regions, and floating in the North and South Regions.

Increasing demands and effects of climate change will impact the provision of ecosystem services.

U.S. economic recovery has placed upward pressure on timber demand since 2009. Growth in the housing sector has improved softwood lumber consumption and sawtimber prices. Housing starts have continued to increase since the 2009 low but single-family housing starts may return only to historical norms of less than 1.1 million rather than the high levels seen in 2004 and 2005. Growth in overseas paper manufacturing output; shrinkage in U.S. manufacturing, which demands paper for final products and packaging; and substitution by electronic media continue to put downward pressure on U.S. paper and paperboard production. As a result, timber growers and derived-product manufacturers are likely to experience only weak improvement in markets in the near term.

Long-term trends in paper use, trade, and U.S. manufacturing activity indicate that U.S. market share is unlikely to return to the peak levels observed in the late 1990s in the foreseeable future. The U.S. share of global output of most timber products has declined since the 1960s, partly because of growth in foreign production and partly because of declines in domestic production. Long-term prospects for market share recovery exist in the wood products sector. The paper sector is less likely to recover in the short or long term. In the longer run, we might expect that the strong resource endowment of the United States and its shift toward production from planted forests will continue to support domestic wood products manufacture, especially if other countries reduce their timber inventories. Observed recent expansion in U.S. timber supply, while not the only requirement, is a step toward some recovery or a slowing of the loss in U.S. market share.

The U.S. wood pellet market will continue to grow, led by production in the South. The South is the primary provider of pellet exports, which has raised concerns about competition with other users of the southern forest resource. Increases in pellet production will provide short-run gains to forest landowners and short-run losses to nonpellet users of pulpwood inputs. Increases in pellet production could significantly increase the South's share of timber removals and lead to increased timber harvests and increased timber prices. The key driver of U.S. pellet production and export will continue to be demand from the European Union (EU) in the near term and will depend on EU energy targets, growth in EU energy demands, and EU policy targets set for the proportion of energy supplies provided by woody biomass and also on the evolution of complementary and competing wood products industries.

U.S. forests will continue to accumulate carbon but at a decreasing rate in the future, primarily because of land use change and forest aging. Annual forest carbon flux was about 0.5 percent of the forest carbon stock from 1990 to 2016; an increase in forest area accounted for about 41 percent of that annual flux. Projections of future rates of net sequestration are sensitive to assumptions of forest area. If forest area begins to decline after 2020, the forest carbon pool will decline from 2015 to 2060. Higher rates of forest loss can result in forests becoming an emissions source; low rates of change maintain the sink. Actual sequestration of carbon by forests is much less variable than forest carbon stock change, and it declines gradually over time, reflecting the influence of forest aging and disturbance.

Urban trees serve important ecosystem functions by storing carbon and removing air pollutants. Total carbon storage from trees on urban lands was estimated at 643 million metric tons. Pollution removal by trees and forests in the United States was estimated at more than 17 million metric tons in 2010. Although typical annual air-quality improvement resulting from pollution removal by trees was less than 1 percent, the health benefits were still substantial.

Outdoor recreation participation is projected to continue to grow, with some variation among the RPA regions. Growth will be less, in general, in the North Region because population growth is lowest there. The fastest growing activities will be developed skiing, day hiking, and horseback riding on trails. For the South Region, the growth in participation will increase the most in day hiking, birding, visiting developed sites, and motorboating. The Rocky Mountain Region has some of the highest growth rates for participants in outdoor recreation because the region has the highest projected population growth rate. Activities with the highest participant growth rates in this region are developed skiing, challenge activities, day hiking, and birding. In the Pacific Coast Region, the activities with the highest participant growth include developed skiing, motorboating, horseback riding on trails, and swimming.

The combined effects of population growth and climate change put increased pressure on renewable water supplies. On average, and in the absence of further adaptation efforts, the number of basins with at least 1 year of shortage was projected to increase about fourfold from the recent past to 2060. Adaptation options can reduce vulnerability to shortage, but no single option eliminates the likelihood of shortage in all basins. Some of the most effective options for reducing shortages have problematic tradeoffs: allowing continued groundwater mining imposes costs on future water users and can exhaust the recoverable groundwater supply; reducing instream flow tends to harm aquatic life and lower the quality of instream recreation. Because even combinations of adaptations examined will probably be insufficient to eliminate shortages from all basins, additional measures, such as reductions in water use beyond those examined here, may be necessary.

Some resource demands may benefit from complementary actions. One example of potential joint benefits is protecting at-risk aquatic biodiversity while simultaneously protecting drinking water quality. Two-thirds of watersheds that support a high proportion of at-risk aquatic biodiversity have a collateral stake in drinking water protection. Joint benefit watersheds that also have low levels of land protection and high rates of urbanization can serve as targets for land use and conservation planning.

Looking Forward

A growing U.S. population is projected to lead to increased demands for a wide array of goods and ecosystem services from forests and rangelands and to shifts in land uses as public values for ecosystem services change. Climate change, in concert with wildfire, insect infestations, drought, and disease outbreaks, is increasing the vulnerability of many forest and rangeland ecosystems to productivity changes.

The United States has abundant natural resources and capacity to respond to societal demands on its forests and rangelands. Although the RPA Update highlights potential resource concerns, the outcomes portrayed here are not inevitable; they are based on a continuation of current policies. Many policies and management strategies can be used to change the direction of future trends. Changes in markets, technology, trade flows, government policies, and public values all will play key roles in shaping responses to changing resource conditions. Although markets are quite effective at providing incentives for commodity products, incentives to provide other ecosystem services are limited. Increased use of payments for ecosystem services could provide incentives to landowners to maintain a wide array of services, but much progress remains to be made in this area. Other types of programs, such as land retirement programs, conservation easements, and tradable development permits, are all options that can contribute to sustaining forests and rangelands. Social and political perceptions are as important in enabling change as are technical solutions. General societal acceptability sometimes limits management options, particularly on public lands.

The RPA legislation recognizes the importance of our forests and rangelands in contributing to the American public's well-being and quality of life. Maintaining productive forests and rangelands requires continual monitoring and analysis of the effects of changing societal expectations and a changing climate on these resources. The RPA Assessment helps improve our understanding of the multiple and interacting factors that we expect to affect renewable natural resources in the future. This focus is a unique contribution that provides important information to policymakers and resource managers as they develop strategies for sustaining the Nation's renewable natural resources.

Chapter 1. Overview

This report updates the 2010 Resources Planning Act (RPA) Assessment (USDA Forest Service 2012a) that was prepared in response to the mandate in the 1974 Forest and Rangeland Renewable Resources Planning Act (P.L. 93-378, 88 Stat 475), as amended. It is the fourth update the Forest Service, an agency of the U.S. Department of Agriculture (USDA), has made to the decadal reports since the RPA legislation was passed. The RPA Assessment adheres to the following requirements:

- An analysis of present and anticipated uses of, demand for, and supply of the renewable resources, with consideration of the international resource situation and an emphasis on pertinent supply and demand and price relationship trends.
- An inventory of present and potential renewable resources.
- A discussion of important policy considerations, laws, regulations, and other factors expected to influence and affect significantly the use, ownership, and management of forests, rangelands, and other associated lands.
- An analysis of the potential effects of global climate change on the condition of renewable resources on the forests and rangelands of the United States.

The RPA legislation recognizes the importance of our forests and rangelands in contributing to the American public's well-being and quality of life. Maintaining productive forests and rangelands requires continual monitoring and analysis of the effects of changing social expectations and a changing climate on these resources. The RPA Assessment improves our understanding of the multiple and interacting factors that we expect to affect renewable natural resources in the future. This focus is a unique contribution that provides important information to policymakers and resource managers as they develop strategies for sustaining the Nation's renewable natural resources.

Scope of the RPA Assessment

The RPA Assessment focuses on analyzing historical trends of forest and rangeland resources and examining the influences of multiple drivers of change on forest and rangeland resources 50 years into the future. The analyses in the RPA Assessment respond to the mandated national focus and include renewable natural resources and related economic sectors for which the Forest Service has management responsibilities: forests, rangelands, wildlife and fish, outdoor recreation, and water, and the effects of climate change on those resources. We continue to target our research to improve understanding of the multiple and interacting factors that we expect to affect renewable natural resources in the future through a coherent and integrated view of the future.

The 2010 RPA Assessment (2010 RPA) highlighted challenges to maintaining our forest and rangeland resources. Land development to meet the needs of a growing population will continue to reduce the total area of natural ecosystems and also change their patterns and conditions. Climate change will alter natural ecosystems, with varying effects on natural disturbances, such as wildfire, insects, and disease. The interaction of these socioeconomic and biophysical changes will affect the productivity of forest and rangeland ecosystems and their ability to meet increasing demands for goods and services. The effects of land development, climate change, and increasing demands for goods and services will also vary geographically—requiring flexible adaptation and management strategies.

This RPA Update complements the 2010 RPA with more recent information about resource status and trends, new analyses that build on the 2010 RPA, special issues, and a case study comparative analysis of RPA Assessment results for two of the nine National Forest System (NFS) regions. It summarizes the results of analyses that are documented in more detail in a series of technical supporting documents and journal articles that are referenced throughout the following chapters. These supporting publications provide more details on data, methods, and results.[1]

Our analyses typically have a national focus, which requires either nationally consistent data or data that can be consistently compiled to the national level. The national focus often creates data constraints that limit analyses in some resource areas and often restrict analyses to the conterminous United States. For some resource areas, analyses are conducted at a subnational geographic extent to reflect the geographic extent of the resource. For example, our rangeland analyses focus on the Western United

[1] RPA Assessment supporting technical documents are available on the Forest Service's RPA Assessment Web page as they become available: http://www.fs.fed.us/research/rpa/.

States. Urban forest analyses focus on the relatively small percentage of the U.S. land base that is urbanized and often are limited to a subset of urban areas or cities where data are available.

The results of the analyses throughout the subsequent chapters often will be presented for both the entire United States and for the four RPA Assessment regions and subregions (figure 1-1). In chapter 13, results are presented for two NFS regions (also shown in figure 1-1). Other regional definitions are used for specific resource analyses and are described in the resource chapters.

While the RPA Assessment focuses primarily on national analyses, the data supporting these analyses are available at varying spatial resolutions, and, therefore, the geographic scale of our results also varies. As a result, terminology about the "scale" of the analyses can be confusing, especially because *scale* is defined differently across disciplines. In the absence of a universal definition, we have tried to clearly define the context for scale in these RPA Update analyses by specifying when we are referring to extent, resolution, or some other characteristic of scale.

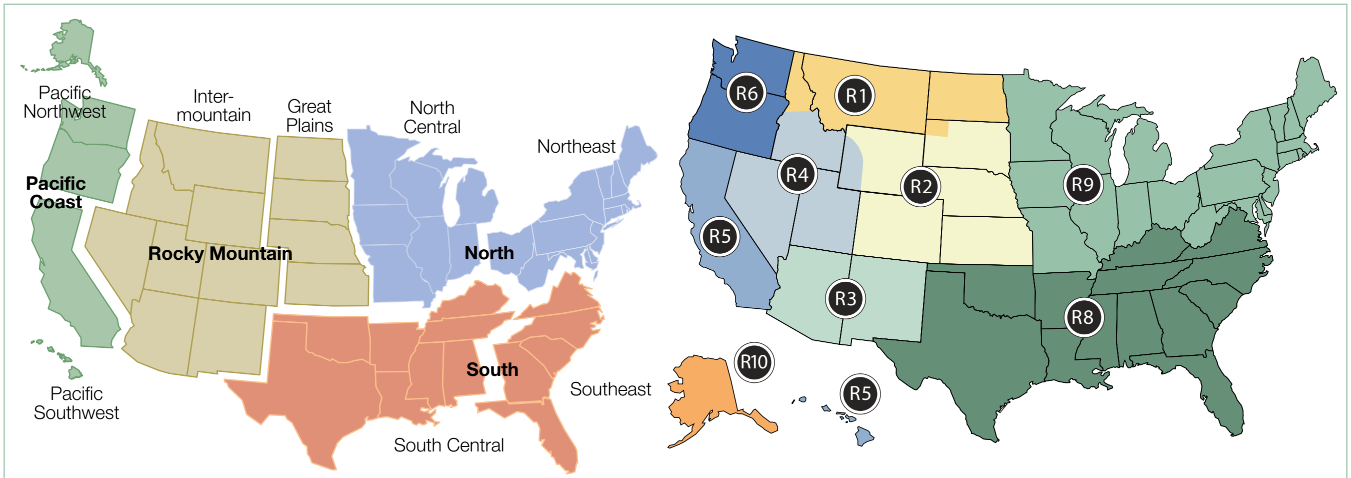
The selection of English versus metric units in reporting RPA results continues to be challenging. While scientific outlets are primarily in metric units, English units are still commonly used in U.S. discussions and analyses. As a result, we have taken a hybrid approach in this RPA Update. In some chapters (e.g., chapter 6, forest products), all units are in metric because metric has become the predominant unit in both technical and policy discussions. In other chapters (e.g., chapter 13, focusing on information related to NFS regions), measures are entirely in English units. In most chapters, a mix is used, providing both English and metric units.

Scenarios in the Update to the 2010 RPA Assessment

The RPA Assessment has always looked 50 years into the future. Characterizations of the future have varied over RPA Assessment decadal cycles. Previous to the 2010 RPA, futures generally were constructed based on consensus views on key socioeconomic variables affecting demands for goods and services from forests and rangelands, resulting in one likely future. Variations from the likely future were limited in scope (e.g., low and high population growth), and they often focused on variables specific to forest product markets (e.g., low and high housing starts) and alternative assumptions about softwood imports from Canada. Given rapid globalization in recent decades, these limited "futures" became insufficient to address the forces driving natural resource change.

The environment affecting supplies and demands for goods and services from U.S. forests and rangelands is much more dynamic today than even 20 years ago. Demands for goods and services from our forests and rangelands are very much affected by global markets and international environmental policies. A consensus view of the future is both unlikely and unable to address uncertainty across the range of potential future political, economic, social, and environmental changes. As a result, we adopted a scenario approach for the 2010 RPA to explore a range of possible futures for U.S. renewable natural resources, referred to as the 2010 RPA scenarios. This RPA Update includes new projections for some resource areas based on those same 2010 RPA scenarios, while other analyses use alternative scenarios. In the next section, we review the 2010 RPA scenarios and then describe other scenarios used in the RPA Update analyses.

Figure 1-1. RPA Assessment regions and subregions (left) and National Forest System regions (right).



R1 = Region 1, Northern Region. R2 = Region 2, Rocky Mountain Region. R3 = Region 3, Southwestern Region. R4 = Region 4, Intermountain Region. R5 = Region 5, Pacific Southwest Region. R6 = Region 6, Pacific Northwest Region. R8 = Region 8, Southern Region. R9 = Region 9, Eastern Region. R10 = Region 10, Alaska Region. RPA = Resources Planning Act.

2010 RPA Scenarios

In the 2010 RPA, we developed scenarios based on the comprehensive global scenarios that were used in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) and Fourth Assessment Report (AR4) to provide global context and quantitative linkages between trends in the United States and the rest of the world. The range of scenarios considered in the IPCC assessments provided a broad spectrum of potential futures from which we selected a subset relevant to evaluating potential U.S. future resource conditions and trends.

The three 2010 RPA scenarios described alternative national and county-level futures linked to IPCC assumptions and projections of global population growth, economic growth, bioenergy use, and climate (IPCC 2007; Nakicenovic et al. 2000). For continuity, we retained the scenario designations used in the TAR and AR4, with the addition of "RPA" to remind the readers that these scenarios were tied to IPCC assumptions. The RPA scenarios were therefore designated as RPA A1B, RPA A2, and RPA B2.[2] Detailed information about the selection of IPCC scenarios and adjustments that were made to define RPA A1B, RPA A2, and RPA B2 are in USDA Forest Service (2012b).

Table 1-1 describes socioeconomic characteristics of the three 2010 RPA scenarios. The global assumptions were identical to IPCC assumptions. The U.S. population and gross domestic product projections were updated from the IPCC with the most recent U.S. information at the time, but the rates of change over time were almost identical to IPCC rates of change for the United States. We disaggregated these updated national estimates to obtain county-level income and population data (USDA Forest Service 2012b). Although not directly linked to IPCC land use projections, land use change was projected for each of the three scenarios based on the county-level population and economic projections (Wear 2011).

For each 2010 RPA scenario, we chose climate projections from three general circulation models (GCMs) to capture a range of future climates. Table 1-2 lists the IPCC scenarios and associated GCM projections that were used to develop climate projections for the RPA scenarios. The IPCC climate projections were downscaled to the approximately 10-kilometer scale. Three climate variables were downscaled for the 2010 RPA climate projections: (1) monthly mean daily maximum temperature, (2) monthly mean daily minimum temperature, and (3) monthly precipitation. We also estimated mean daily potential evapotranspiration using the downscaled temperature values. Detailed documentation of the development of the 2010 RPA scenario-based climate projections and downscaling process is available in Joyce et al. (2014a).

The combination of the socioeconomic scenarios and the climate projections resulted in nine RPA scenario-climate combinations to support resource analyses. These combinations were used for the projections in the water resources (chapter 10) and outdoor recreation (chapter 12) chapters. A revised version of the 2010 scenarios was developed to revisit 2010 RPA forest product projections (chapter 6).

Table 1-2. IPCC scenarios and GCMs used for the 2010 RPA climate projections.[a]

Scenario	GCM	Model vintage
A1B	CGCM3.1 (T47)	AR4
	MIROC3.2 (medres)	
	CSIRO-Mk3.5	
A2	CGCM3.1 (T47)	AR4
	MIROC3.2 (medres)	
	CSIRO-Mk3.5	
B2	CGCM2	TAR
	CSIRO-Mk2	
	UKMO-HadCM3	

2010 RPA = 2010 Resources Planning Act Assessment. AR4 = IPCC Fourth Assessment. GCM = general circulation model. IPCC = Intergovernmental Panel on Climate Change. TAR = IPCC Third Assessment.

[a] AR4 climate projections were downloaded from the Web portal for the World Climate Research Program, Coupled Model Intercomparison Project phase 3, and TAR climate projections were downloaded from the IPCC Data Distribution Centre. See Joyce et al. (2014a) for details on the climate data and the downscaling procedures used.

Table 1-1. Key characteristics of the 2010 RPA scenarios.[a]

Characteristic	Scenario RPA A1B	Scenario RPA A2	Scenario RPA B2
IPCC general global description	Globalization, economic convergence	Regionalism, less trade	Slow change, localized solutions
IPCC global real GDP growth (2010–2060)	High (6.2X)	Low (3.2X)	Medium (3.5X)
IPCC global population growth (2010–2060)	Medium (1.3X)	High (1.7X)	Medium (1.4X)
IPCC global expansion of primary biomass energy production	High	Medium	Medium
U.S. GDP growth (2006–2060)	Medium (3.3X)	Low (2.6X)	Low (2.2X)
U.S. population growth (2006–2060)	Medium (1.5X)	High (1.7X)	Low (1.3X)

2010 RPA = 2010 Resources Planning Act Assessment. GDP = gross domestic product. IPCC = Intergovernmental Panel on Climate Change.

[a] Numbers in parentheses are the factors of change in the projection period. For example, U.S. GDP increases by a factor of 3.3 times between 2010 and 2060 for scenario RPA A1B.

[2] We developed a fourth scenario, "Historical Fuelwood," with the same global economic growth assumptions as the RPA A1B scenario but that followed historical projections in use of U.S. wood energy consumption rather than the higher levels of future expansion in IPCC. Because that scenario is not used in this RPA Update, it is not included in this section.

The socioeconomic components of the 2010 RPA scenarios were projected to 2060, but climate projections were available to 2100. Several analyses in this RPA Update used the 2010 RPA climate projections to extend their biophysical analyses to 2100 (e.g., projections in chapter 9 on rangeland productivity). Other analyses replaced the 2010 RPA B2 climate projections based on IPCC's TAR with additional climate projections from AR4 for IPCC scenario B1. This strategy was used for analyses that relied solely on climate data and not the socioeconomic projections, including the analysis of terrestrial habitat stress (chapters 11 and 13) and rangeland productivity and livestock vulnerability (chapter 9).

Additional Update Scenarios

New scenarios were designed for analyses that were targeted at a special issue (e.g., chapter 7, wood pellet production) or undertaken to meet interagency needs (chapter 8, forest carbon). The scenarios for the analysis of wood pellet production used the Subregional Timber Supply model (Abt et al. 2009) to test traditional and bioenergy demand under varying assumptions about wood utilization in the U.S. South. Published empirical estimates of supply, demand, and land use coefficients for the South and recent current and projected feedstock consumption by pellet mills and other bioenergy producers were used to simulate wood pellet demand to 2040 under varying assumptions about timber prices and bioenergy demand.

The forest carbon projections were based on three scenarios developed by a USDA interagency team to project greenhouse gas emission pathways in the forestry and agricultural sectors. These scenarios accounted for the economic downturn of the mid-2000s and subsequent recovery, and they improved the link between forest projections and other economic sectors. Variations in U.S. economic growth, population growth, and land use change were defined to provide a range of possible forest carbon outcomes that were input for the U.S. Biennial Report to the United Nations Framework Convention on Climate Change (U.S. Department of State 2015).

Future Use of Scenarios

Evaluations of the individual climate models used in the 2010 RPA concluded that the models used for scenarios RPA A1B and RPA A2 performed reasonably well when compared with other AR4 climate models and, in some cases, were ranked high in terms of performance (Joyce et al. 2014a). The IPCC released the Fifth Assessment Report (AR5) in 2014 (IPCC 2014). Downscaled climate projections were not available in time to support these RPA Update analyses. When projections from the AR4 and the recent AR5 are compared, the conclusion is that these projections are similar in pattern and magnitude when scenario differences are taken into consideration (IPCC 2014).

Unlike in the two previous IPCC reports, socioeconomic scenarios were not developed to correspond to the AR5 climate projections. Instead, a new process was developed with the goal of enhancing the analysis of adaptation and mitigation possibilities (Moss et al. 2010). As a result, we have no clear path to link socioeconomic assumptions and AR5 climate outcomes, the primary reason we chose to use the AR4 IPCC scenarios for the 2010 RPA and this RPA Update. Although we expect to use the AR5 climate results as the basis for future RPA climate scenarios, we face numerous challenges in constructing a coherent set of consistent socioeconomic and climate assumptions to underpin future RPA Assessment analyses.

Document Organization

A **summary of findings** is provided in chapter 2. Chapters 3 through 13 present findings by resource area or resource sector. These chapters include new updates about historical trends, new projections, and special issue analyses. The **land resources** chapter (chapter 3) updates trends presented in the 2010 RPA on land development from the National Resources Inventory and the National Land Cover Database (NLCD) and on urban land extent based on the U.S. Census. The chapter also presents new urbanization projections based on 2010 U.S. Census data. The status of protected areas in the United States using the Protected Areas Database for the United States is also updated from the 2010 RPA.

The **forest resources** chapter (chapter 4) updates U.S. forest data from the Forest Inventory and Analysis (FIA) program from 2007 to 2012. We update the analysis of forest cover by comparing trends from the 2001, 2006, and 2011 NLCD and also by examining temporal changes in forest cover, landscape pattern, and trends in interior forests. We then expand the treatment of intact forest introduced in the 2010 RPA on eastern forests to all forests of the conterminous United States. The **urban forest** resource is the topic of chapter 5. In the 2010 RPA we reviewed trends in urbanization (updated in chapter 3), reported on the percent tree cover in urban areas circa 2005, reviewed urban forest ecosystem services, provided preliminary estimates of carbon stored in urban forests, and reviewed threats to urban forest health. In this RPA Update, we examine planting and natural regeneration in urban forests, evaluate potential risk to urban forests from insects and invasive tree species, and provide updated and expanded information about the carbon storage and sequestration from urban forest and the effects of trees in both urban and rural areas on air quality.

Chapter 6 focuses on **forest products**. The 2010 RPA reviewed historical trends in forest product consumption and production and also projected trends under the four 2010 RPA scenarios. In this RPA Update, we focus on the status of economic recovery of the U.S. forest products industry and recent trends in the housing market. We also describe the historical U.S. role in international forest product markets and reflect on potential effects of current and expected trends on the future U.S. role. We then revisit projections of the forest sector with a revised scenario that accounts for the 2007-through-2009 recession and, finally, we examine trends and projections in forest sector employment.

Chapter 7 is a special issue report summarizing an analysis of **wood pellet export markets** and their effects on forests in the Southeastern United States. The use of forests as feedstock for the production of wood pellets is not new, but the recent increase in pellet production due to international policies is changing markets for wood products in the United States, particularly in the South. This chapter reviews the current policy environment, provides trends in pellet production and demand, and analyzes the potential effects of projected demand on forests of the U.S. South.

The 2010 RPA reviewed historical forest carbon stocks and flows and projected future carbon stocks and flows from forests and harvested wood products that raised questions about the ability of U.S. forests to continue to provide a net sink. The **forest carbon** chapter (chapter 8) uses the most recent forest carbon inventory based on the U.S. Forest Carbon Accounting Framework, a comprehensive approach to using the annual FIA data to improve historical forest carbon data and to seamlessly model future forest carbon. Projections complement the 2010 RPA scenarios with projections based on recent measured changes in forest inventory, new estimates of forest soil organic carbon, and projections of land use changes. We report on advances in separating changes in forest carbon associated with change in the total area of forests from changes associated with forest growth.

The **rangeland resources** chapter (chapter 9) continues the 2010 RPA focus on the sustainability of rangelands with a series of impact studies on the effects of climate change on rangeland resources. We revisit rangeland productivity by examining the potential effects of climate change on net primary productivity of rangelands in the future. We also characterize the soil organic carbon flux from and storage on rangelands in the conterminous United States and estimate future storage capability expressed against the backdrop of a changing climate. We quantify the vulnerability of U.S. livestock operations that depend on rangeland forage for all or part of their lifecycle to projected future changes in climate and vegetation, and then we quantify the broad-scale status and trends of degradation on U.S. rangelands. Finally, we examine the present and ongoing drought situation to understand conditions that have led to relatively low U.S. cattle inventories.

The **water resources** chapter (chapter 10) builds on the 2010 RPA analysis of the vulnerability of U.S. freshwater supplies to shortage. Projections of water supply and demand over the 21st century showed that, in the absence of adaptation, serious water shortages are likely in some regions of the United States. In this RPA Update, we focus on four main topics. First, we build on analyses from the 2010 RPA and evaluate several possible adaptations designed to lessen identified shortages. Second, we report on the effects of using a more detailed description of water users on water demand projections with a focus on the Upper Colorado River Basin. Third, we report on an analysis that assessed nonpoint source threats to water quality nationwide. Finally, we provide updated estimates of mean annual water supply for the conterminous United States.

Chapter 11 focuses on **wildlife, fish, and biodiversity**. The 2010 RPA reviewed recent trends in wildlife, fish, and biodiversity, showing varied responses depending on the resource, suggesting varied conditions that depend on region, species group, or habitat type. First, we extend 2010 RPA work on the effects of elevated housing growth in and around protected areas by testing whether biodiversity of protected areas was affected by housing development near public lands. Second, we provide a more detailed case study of wildlife habitat stress attributable to climate change across the RPA Rocky Mountain Region, with particular emphasis on the effects of wildfire management. Third, we update the status of imperiled species using a new approach for assessing the distribution of formally listed and imperiled species. Finally, we report on an analysis of at-risk aquatic species and drinking water protection as an example of the potential joint benefits that can accrue from actions to protect both drinking water quality and aquatic species.

The 2010 RPA provided information about available outdoor recreation resources in the United States, described the status and historical trends in outdoor recreation participation (regionally and by different demographic groups), and projected national recreation participation. In this RPA Update, the **outdoor recreation** chapter (chapter 12) builds on the national projections done for the 2010 RPA and presents projections for the four RPA regions to focus on variation in patterns across the regions and also to examine whether climate change is likely to have different impacts across both recreation activities and regions. We also analyze outdoor recreation use on national forests and grasslands, based on the Forest Service's National Visitor Use Monitoring program. Visitor use, visitor characteristics, and visitor satisfaction are summarized at the RPA region level.

The 2010 RPA highlighted resource implications specific to the four large RPA regions. Chapter 13 explores our ability to apply 2010 RPA data and analyses to identify trends and projected futures in **natural resources, human settlement patterns, and economic development** at a subregional scale. We chose two Forest Service NFS regions: the Northern Region (Region 1) and the Southwestern Region (Region 3) within the RPA Rocky Mountain Region. The chapter explores those regions' historical patterns of human settlement and economic development, and it explores how the regions will potentially be influenced by future population dynamics, economic growth, and climate change.

Chapter 2. Summary of Findings

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) and this RPA Update summarize the present condition and outlook for the Nation's forest and rangeland resources. This chapter summarizes the RPA Update's highlights in chapters 3 through 13 around three thematic topics: land development, climate change and natural disturbances, and ecosystem services from forests and rangelands. While the RPA Assessment examines forest and rangelands on all ownerships, in this RPA Update we also include a targeted set of analyses for the Northern (Region 1, or R1) and Southwestern (R3) National Forest System (NFS) regions as case studies demonstrating the use of RPA data in more geographically focused analyses. The RPA Assessment regions and NFS regions are shown in figure 2-1.

Land Development

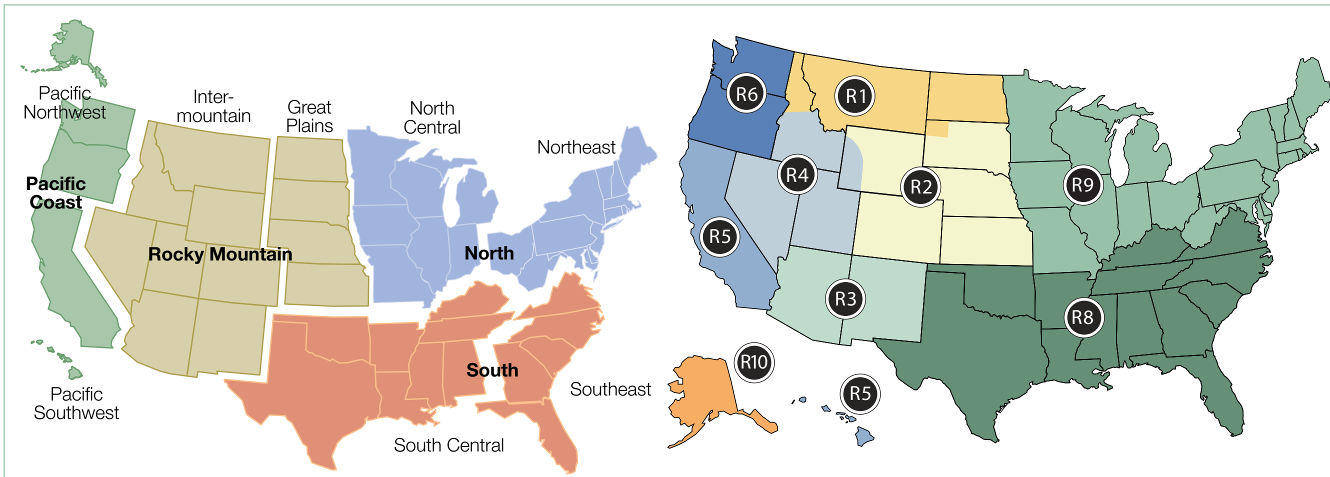
Land development—including the expansion of housing, commercial enterprises, industrial capacity, and related facilities such as roads, mines, and electricity-generating plants—continues across the United States, influencing the extent and character of forest and rangeland ecosystems. Between 2007 and 2012, U.S. forest area increased slightly, continuing the upward trend reported in the 2010 RPA. Non-Federal rangeland area declined less than 1 percent between 2007 and 2012. While this stability in extent may suggest ecosystem condition is being maintained, RPA Update findings about increases in forest fragmentation, increasing population density in counties with national forest lands, housing development effects on bird species of conservation concern, the spatial distribution of federally listed species, and the effects of development on water quality indicate continued detrimental changes to the pattern and composition of forest and rangelands.

➔**Finding:** Developed land cover of the conterminous United States increased 15 percent between 1992 and 2011; urban area expanded 45 percent between 1990 and 2010.

Developed land cover of the conterminous United States increased by 15 percent between 1992 and 2011, increasing to nearly 6 percent of the land area. The largest regional percentage increase in developed land cover occurred in the RPA South Region, at 22 percent. Urban area, defined by population density, expanded by 45 percent between 1990 and 2010 (figure 2-2); both the RPA South and Rocky Mountain Regions exceeded the national average with urban area growth of 61 percent.

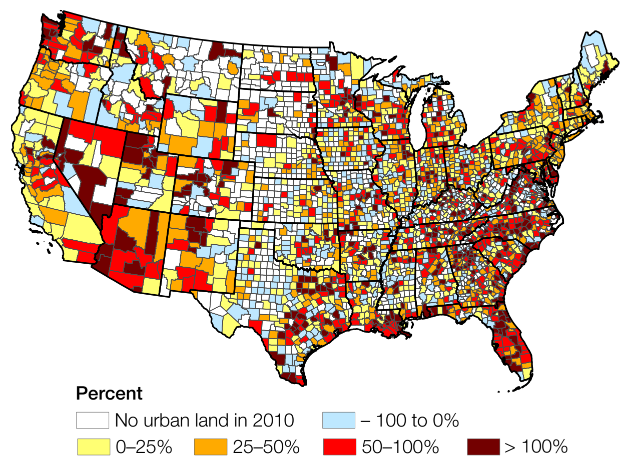
Urban and developed land area remains a relatively small percentage of the U.S. land base, but these changes have a variety of effects on natural resources, both through the absolute loss

Figure 2-1. RPA Assessment regions and subregions (left) and National Forest System regions (right).



R1 = Region 1, Northern Region. R2 = Region 2, Rocky Mountain Region. R3 = Region 3, Southwestern Region. R4 = Region 4, Intermountain Region. R5 = Region 5, Pacific Southwest Region. R6 = Region 6, Pacific Northwest Region. R8 = Region 8, Southern Region. R9 = Region 9, Eastern Region. R10 = Region 10, Alaska Region. RPA = Resources Planning Act.

Figure 2-2. Percent change in urban land by county between 1990 and 2010 for the conterminous United States.



Source: U.S. Census Bureau (2010).

of forest and rangeland acres and through changes in the condition of the remaining resource base. If urban growth continued at the average rate exhibited from 1990 to 2010, urban area would increase from 3.6 percent of the conterminous U.S. land area in 2010 to 8.6 percent by 2060, an increase of 141 percent.

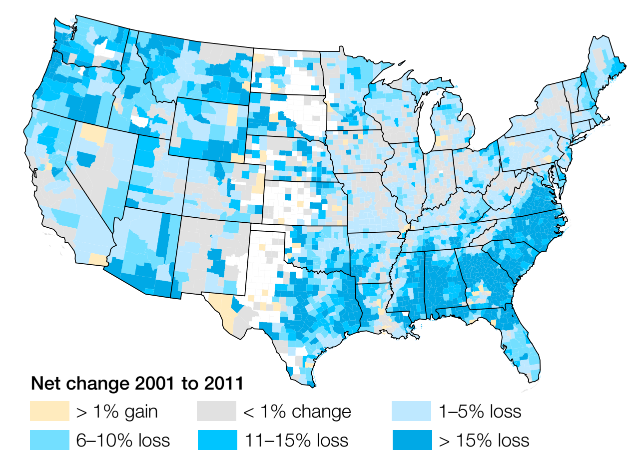
The growth of urban areas will continue to increase the importance of urban trees in providing ecosystem services. As urban areas become more densely developed, however, tree cover tends to decline. In addition, natural regeneration in urban areas can result in the spread of exotic and invasive species. Optimizing the benefits from urban trees may require more focused planning for the choice and placement of urban trees.

➔**Finding:** Forest cover fragmentation increased from 2001 to 2011, with fragmentation rates higher on private land than on public land.

One indicator of the ecological condition of forests is the fragmentation of forest cover, because increasing fragmentation erodes the ecological integrity of forest lands. Most forests are naturally extensive; breaking up previously intact forest cover alters the types and quality of ecosystem services that can be provided. Fragmentation of the extant forest increased from 2001 to 2011. The greatest increase in fragmentation occurred in interior forests (forest area that is surrounded by 90 percent or greater forest cover), for which the net rate of loss in the conterminous United States was two to seven times the net rate of total forest cover loss (figure 2-3).

Intact forest area—forest area that is surrounded by 100 percent forest cover—is more likely to be found on public land than on private land. Western forest types have larger shares of intact forest than eastern forest types because of the distribution of forest landownership. Because most forest land is in the East, however, 74 percent of intact forest area is in the East. Forest fragmentation rates of intact forests were driven primarily by private land dynamics. While 59 percent of total intact area was privately owned in 2001, 79 percent of total net loss of intact forest occurred on private lands. As a result, private forest landowners play a critical role in protecting the ecological integrity of forest lands, particularly in the East.

Figure 2-3. Net change of interior forest cover area from 2001 to 2011, by county. Interior cover includes forest cover surrounded by a 38-acre neighborhood that is at least 90 percent forested. Counties are shaded and State boundaries are shown for comparison. Counties without color had no interior forest cover in 2001 and/or 2011.



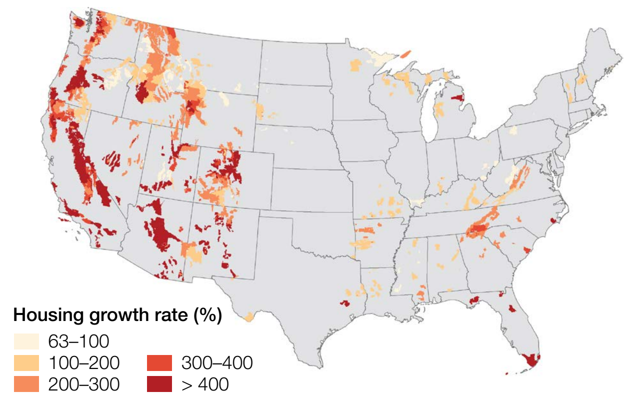
Sources: Data from 2001 and 2011 National Land Cover Database.

We were unable to quantify the proximate causes of fragmentation or whether fragmentation was due to temporary disturbances (e.g., fire, harvest) or permanent land cover conversions. The principal drivers of change appear to be human activities in the East and biotic and abiotic disturbances in the West.

➔**Finding:** Housing development in proximity to protected areas can affect bird communities both at the boundary of and within the protected area.

The 2010 RPA highlighted the trend of higher-than-average rates of housing development in and adjacent to protected areas, including national forests, wilderness areas, and national parks (figure 2-4), a trend attributed to the attraction of living in close proximity to natural amenities. New analyses found that housing density has varying effects on bird community composition within, on the boundary of, and outside protected areas. Species that thrive in the presence of humans were a more abundant component of bird communities outside of and on the boundary of protected areas. Analysis of bird communities within protected areas that had higher housing densities at their

Figure 2-4. Relative housing growth rates within a 50-kilometer (~31-mile) buffer around the outer boundary of each national forest, wilderness area, and national park during the period 1940 to 2000.



Source: Radeloff et al. (2010).

boundary tended to support lower proportions of species of conservation concern. Without effective measures to curtail the rates and locations of exurban development, the conservation benefit of protected areas will likely diminish.

➔**Finding:** Endangered and threatened species continue to be concentrated in distinct regions of the United States.

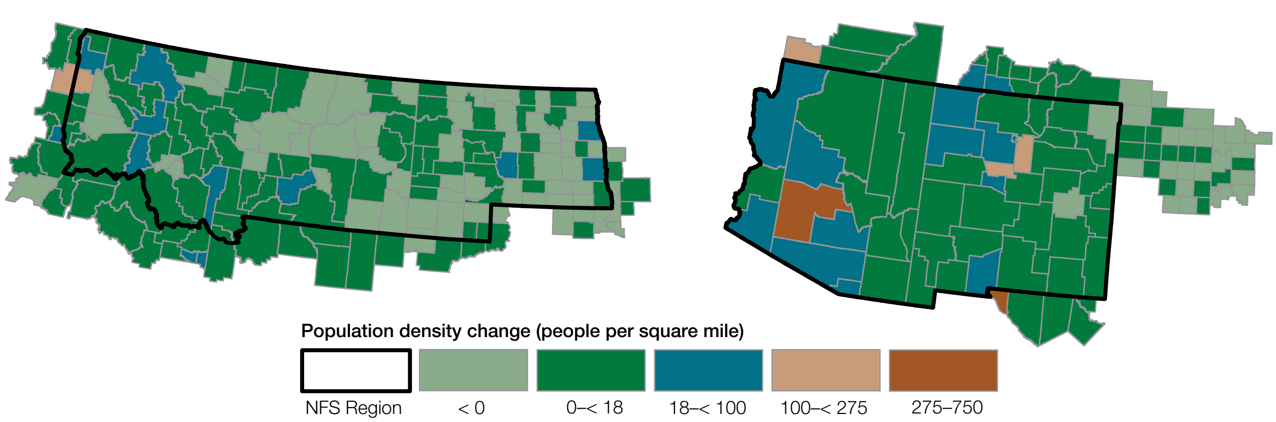
Past RPA Assessments have depicted areas of species concentration geographically based on county-level occurrence data. For this RPA Update, we analyzed the occurrence records of federally listed species on an equal-area grid across the United States, thus removing the area effects created by large variation in county size (figure 2-6). Prominent hotspots of threatened and endangered species occurring in Hawaii, the southern Appalachians, peninsular Florida, coastal areas, and

➔**Regional Finding:** Population increases in the National Forest System Northern and Southwestern Regions are projected to be greatest in areas that currently have high-density populations, while other areas are projected to lose population.

Both the Northern (R1) and Southwestern (R3) Regions face growing populations, but R3 is projected to have higher population growth and increasing density than R1. Population increases from 1990 to 2010 were concentrated in metropolitan areas where population density is already high, and future growth is likely to also be concentrated in those areas. Comparing housing growth rates in figure 2-4 with projected changes in population density in R1 and R3 (figure 2-5) indicates continued pressure around national forests and grasslands in both regions. In R3, 22 percent of national forest land area is associated with high-density counties in contrast with only 6 percent in R1. For national forests adjacent to major metropolitan areas in R3, population density increases could be substantial.

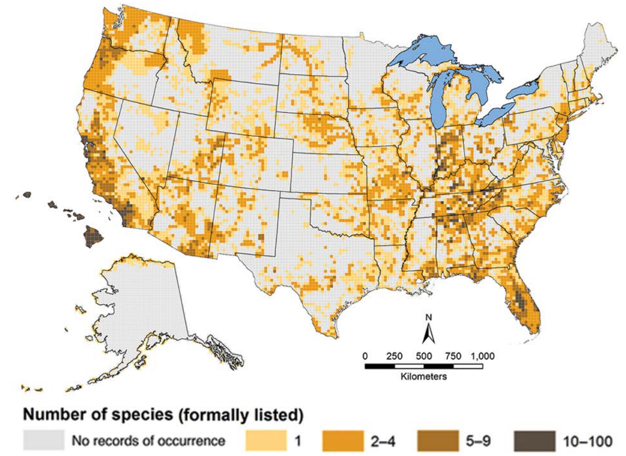
Natural amenities located in the forested areas of both regions are likely to continue to attract increased development in proximity to national forests. This type of development, particularly on lands converted from forest or rangeland, will potentially impact wildlife species composition and diversity within national forests. Integrating information about socioeconomic stressors (e.g., concentrations of intensive land uses that could affect wildlife movements) and spatially explicit information on habitat stress attributed to climate change can aid decisionmakers in evaluating potential risks to wildlife resources attributable to multiple stressors.

Figure 2-5. Projected change in county population density for National Forest System (NFS) R1, Northern Region (left), and R3, Southwestern Region (right), and counties within 50 miles of an R1 or R3 national forest or grassland, 2010 to 2060, based on the RPA A1B scenario.



RPA = Resources Planning Act.
Source: Data from http://www.unh.edu/demographic-indicators.

Figure 2-6. Geographic distribution of federally listed species under the Endangered Species Act. Data are derived from the National Heritage Programs as maintained by NatureServe (2014) and mapped onto a systematic equal-area grid (647.5 km^2 [250 mi^2]) of the United States. Alaska and Hawaii are displayed on a different scale for presentation purposes.



the arid Southwest have remained largely unchanged since the late 1990s. The regions supporting relatively high numbers of species have remained surprisingly consistent with earlier geographic descriptions, particularly among the smaller county Eastern States. Notable differences using the equal-area grid include a general deemphasis of areas in the arid Southwest and the emergence of listed species concentrations associated with the interior highlands and plateau region of southern Missouri, northern Arkansas, western Kentucky, and southern Illinois and Indiana. The greatest number of species often occurs in areas with high rates of urban growth (figure 2-2). Many regions outside the areas of concentration contain very few listed species. Overall, 54 percent of U.S. lands have no occurrence records of listed species.

Since publication of the 2010 RPA, a settlement agreement to process the backlog of species awaiting listing decisions under the Endangered Species Act (ESA) will result in a more rapid pace of species additions to the list of those determined to be threatened or endangered than has been observed in the recent past. Approximately 750 species will be considered for listing by 2018. A mapping of occurrence among species identified in the settlement agreement indicates that species likely to receive protection in the near term will both emphasize existing areas of concentration (e.g., the southern Appalachians) and also lead to the potential emergence of new areas of concentration (e.g., the southern Great Basin and the Ouachita and Boston Mountains of western Arkansas and eastern Oklahoma).

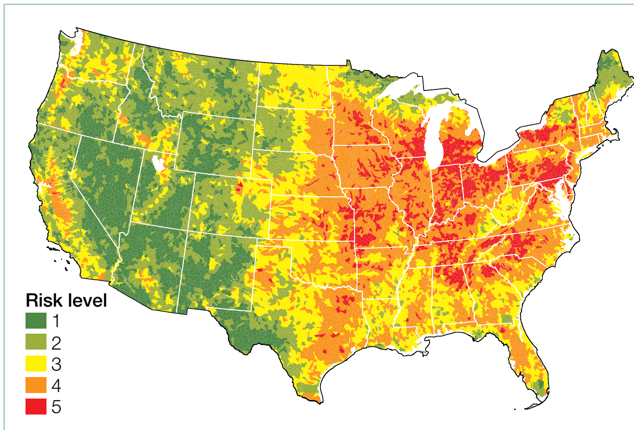
Resource management agencies, like the Forest Service, are going to be challenged to design novel multiple resource management strategies that also contribute to the recovery of a growing ESA list as species listings increase in response to efforts to eliminate the backlog of candidate and proposed species by 2018. Whether the number of proposals to list species will also increase is unclear at this time. Climate-induced stresses may lead to more proposals for specific areas and species.

➔ **Finding:** The highest risk levels of impaired water quality resulting from land and resource use generally were found in the eastern half of the United States, corresponding to higher population and development density and concentrations of agricultural production.

Land development affects water quality through runoff of sediment, nutrients, and toxics. The highest levels of risk of impaired water quality resulting from land and resource use generally were found in the eastern half of the United States (figure 2-7). High levels of risk from sediment loss tend to occur in concert with high levels of risk from excess nutrients and toxics, in part because some individual activities or uses, such as agriculture or housing, produce multiple pollutants and because some activities tend to occur together, such as housing and roads.

Land development, through its effects on the total area of natural ecosystems and on their pattern and condition, will continue to be a crucial factor affecting the future of all natural resources considered in this RPA Update. If recent trends continue, future expansion of developed and urban lands will continue to impact natural landscape patterns and increase reliance on protected areas or relatively undeveloped areas to preserve functioning natural ecosystems. Future forests and rangelands may or may not look like they do today—climate change and natural disturbances will also play a major role in their future composition and function.

Figure 2-7. Overall risk of water-quality impairment for 15,272 watersheds.



Source: Brown and Froemke (2012).

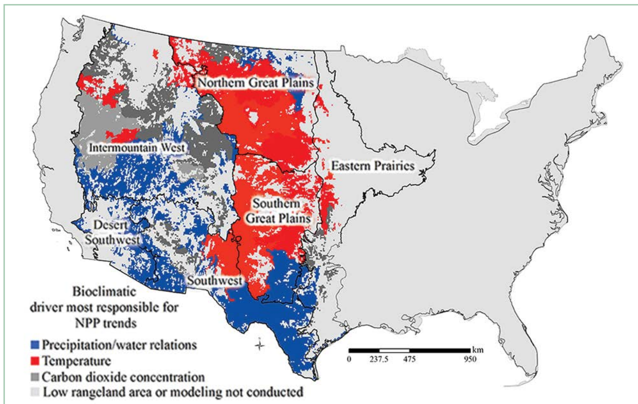
➔Regional Finding: Interactions among rangeland, agriculture, and energy uses will increase and further change the natural landscape, particularly in the National Forest System Northern Region.

Rangeland, agriculture, and energy are increasingly interconnected in both the Northern (R1) and Southwestern (R3) Regions. Rangelands in eastern Montana and western North Dakota and South Dakota are some of the most productive rangeland systems in the United States, and they also encompass hydrocarbon-rich shale formations from which relatively clean fuel—natural gas—can be developed. Agricultural markets, new technology, and Federal policy influence the direction of land use change between agriculture and rangeland and also influence a mix of uses, including energy development. The availability of technology and markets for bioenergy can expand cropland and initiate a series of cascading changes in which corn/soy replaces small grains, small grains replace pasture, and pasture replaces rangeland. New technology has spurred an expansion of oil and gas development on rangelands. Oil and gas production can be developed in such a fashion that allows other land uses to occur, although permanent infrastructure reduces cover and production of rangeland vegetation. Rapid increases in oil and gas development also result in rapid socioeconomic change, including large localized population increases and competition among sectors for services in areas of expansion. Expansion of agriculture and energy uses can bring new economic opportunities, but it also can create conflicts with traditional uses, such as livestock grazing, and cause resource degradation.

Climate Change and Natural Disturbances

Climate change and natural disturbances will have a major influence on the future health and productivity of natural ecosystems. Uncertainty about future local- and regional-scale changes in climate and disturbances implies uncertainty about projected impacts on natural resources and society. This uncertainty complicates our ability to design management and adaptation options. The RPA Update highlights the effects of climate change on rangelands—their future productivity and the likely vulnerability of cattle production—and recreation use, interactions of climate change and fire suppression on terrestrial wildlife habitat, and recent trends in forest growth and mortality.

Figure 2-8. Bioclimatic driver with the highest correlation to estimated net primary productivity (NPP) trends for six U.S. rangeland ecoregions.



➔Finding: In the Western United States, northern rangeland ecosystems are likely to experience increased productivity associated with climate change while southern rangeland productivity declines.

Models of net primary productivity (NPP) predict overall better growing conditions for the northern Great Plains, but the opposite is true of the southern Great Plains. Estimated increases in NPP in the northern Great Plains are best explained by increased growing season length, but reductions in NPP in the Southwestern United States are best explained by lack of precipitation and increased evapotranspiration (figure 2-8). Moisture limitations to vegetation growth appear to intensify over time for all rangelands but are somewhat offset through greater water use efficiency from increasing carbon dioxide. The signal is often mixed—the exception appears to be northern grasslands, where increasing temperatures improve the growing season but are not sufficient to deteriorate the water balance. Some ecosystems could exhibit sharp reductions in productivity, which could lead to negative ecological changes and losses of critical goods and services. Even increases in productivity cannot be assumed to translate to increased economic gain without flexibility and adaptation. Adaptation strategies may prove difficult to develop because the timing and length of growing seasons may produce unforeseen growth patterns requiring novel management techniques. Integrating flexibility into operations, conducting risk analyses, improving forecasting tools, and coordinating monitoring are all potential approaches to improve our ability to respond to future rangeland productivity changes.

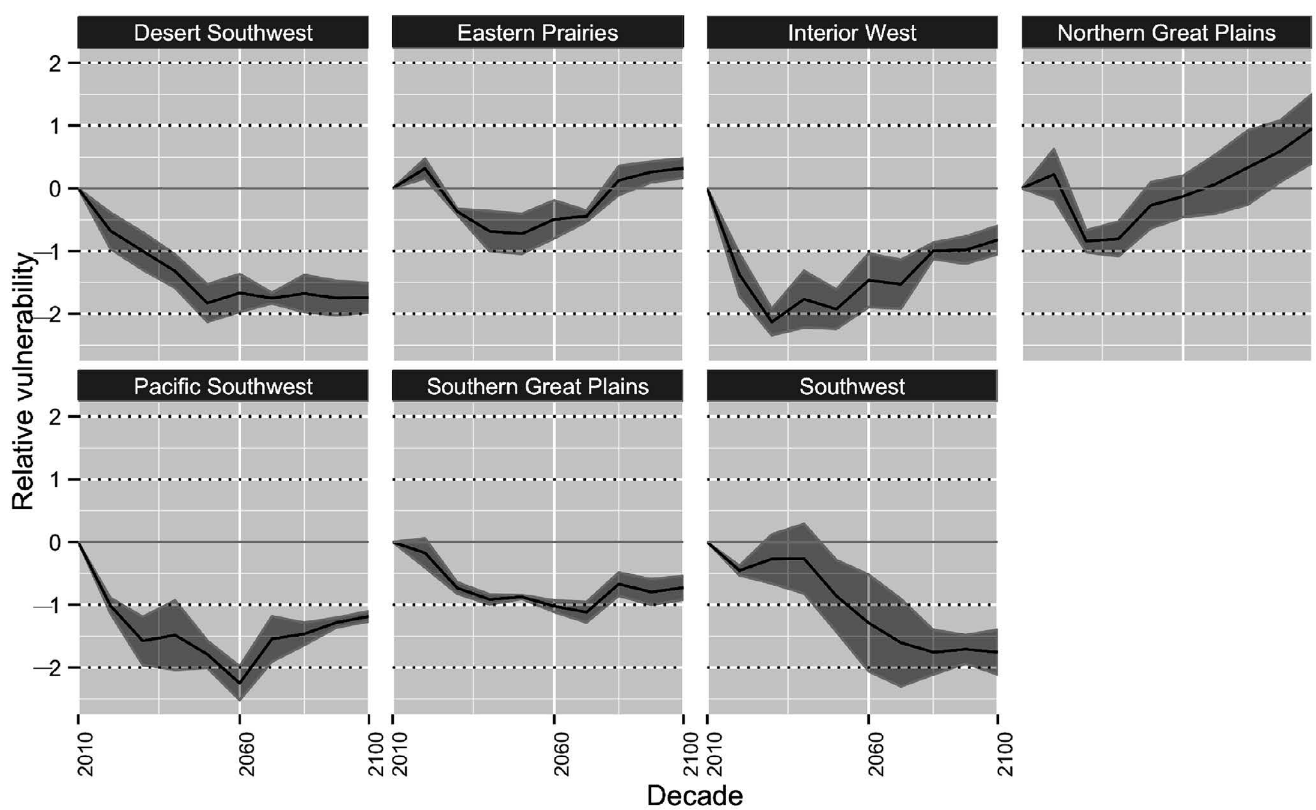
➔Finding: The vulnerability of cattle production to climate change is lower in the Northern Great Plains rangeland ecoregion than in the Southern Great Plains ecoregion or Southwestern United States.

The varying outlook for rangeland productivity described in the previous finding and the effects of climate change on cattle also indicate greater vulnerability of cattle production for much of the rangeland extent in the United States, but more arid regions had the strongest trends toward greater vulnerability (figure 2-9). The Eastern Prairies, Northern Great Plains, and Southern Great Plains rangeland ecoregions are expected to change the least and show some areas of potential resilience into the latter half of the century. Benefits of increased productivity in more northern latitudes are mostly tempered by increasing heat stress and variability in production. Expected impacts are consistently negative across multiple elements in southwestern and western rangeland regions. Diversifying livestock operations and maintaining flexibility in herd sizes and stocking rates are potential adaptation strategies.

➔**Finding:** Climate change is expected to have varying effects on future recreation participation.

Participation in a few recreation activities at national and regional levels may change by large amounts as climate differences impact both opportunities and demand. The effects of climate change on both individual willingness to participate in outdoor recreation activities and the level of participation (average days per year), by comparison with a “no climate change” alternative, indicate that climate change has negligible effects for many recreation activities. Significant positive and negative effects were indicated for participation in a small number of activities in the RPA regions. The activities affected most positively were horseback riding on trails, motorboating, and fishing in the North Region. The most negatively affected activities included snowmobiling in the North and Pacific Coast Regions, hunting in the North and Rocky Mountain Regions, undeveloped skiing in the North and Rocky Mountain Regions, and floating in the North and South Regions. Annual days per participant were more negatively influenced than participation rates. Participation in activities such as developed skiing, motorized off-roading, nature viewing, visiting developed and interpretive sites, birding, and challenge activities appear largely unaffected by climate effects.

Figure 2-9. Trend in average overall vulnerability index for U.S. rangeland ecoregions, averaged across scenarios, 2010 to 2100. Standard error is shown in the shaded region. Negative numbers indicate greater vulnerability and positive numbers indicate less vulnerability compared with present day numbers.

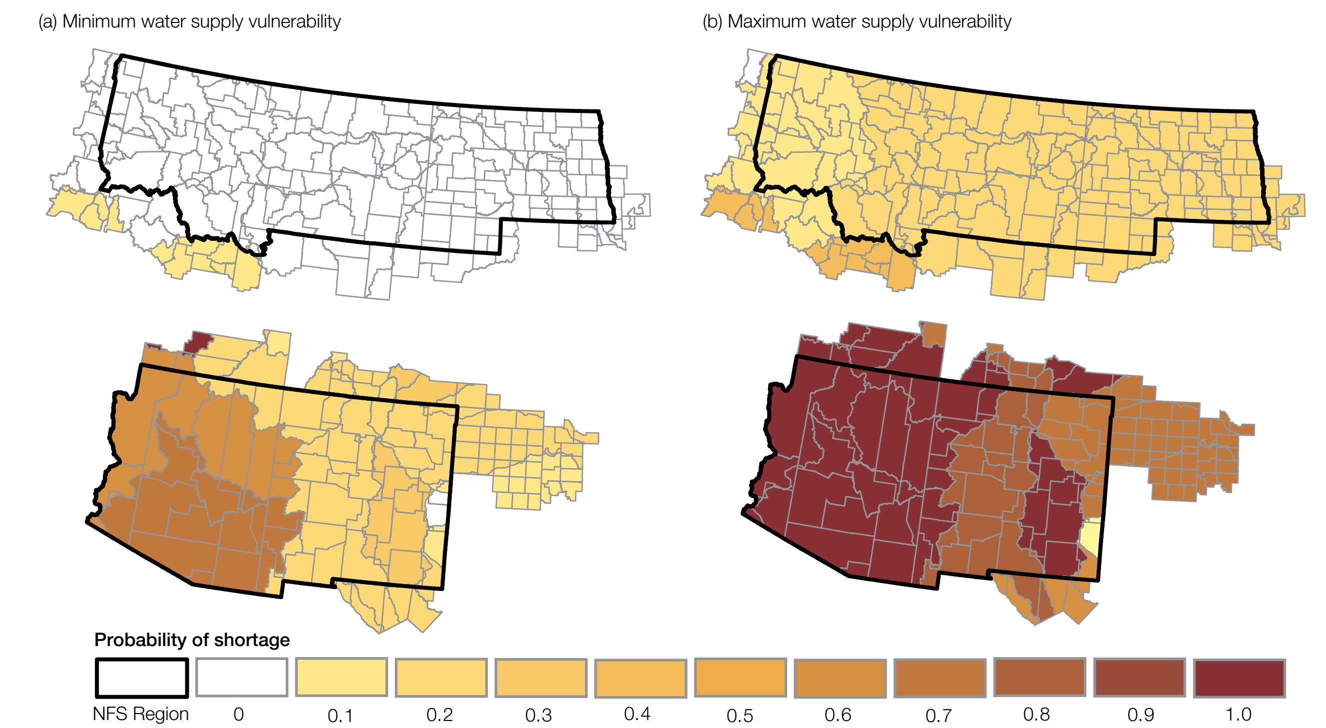


➔Regional Finding: Vulnerability to future water shortages, when adaptation is not considered, is highest in the National Forest System Southwestern Region.

The greater projected change in climate between the Northern (R1) and Southwestern (R3) Regions is in R3 as temperatures warm and precipitation is projected to decrease. While both R1 and R3 will face challenges in managing for climate change effects, R3 is likely to be more vulnerable to multiple climate change effects. Projections indicate that climate effects on potential water shortage will have more negative impacts in R3 than in R1.

Water is already scarce in many parts of the Western United States, and, as the population grows, the demand for and consumptive use of water will increase. R3 already has a greater population than R1 and is projected to have greater future population growth. Comparing projected water supply vulnerability in 2060 between the two regions (figure 2-10) shows that R3 faces consistently higher vulnerability levels than does R1. As the spread between the minimums and maximums shows, however, in many counties the level of vulnerability remains quite uncertain.

Figure 2-10. Composite maps of (a) minimum and (b) maximum water supply vulnerability (probability of shortage) in 2060 by the northern-influence area and National Forest System (NFS) Northern Region (top) and southwestern-influence area and NFS Southwestern Region (bottom) across nine alternative futures.



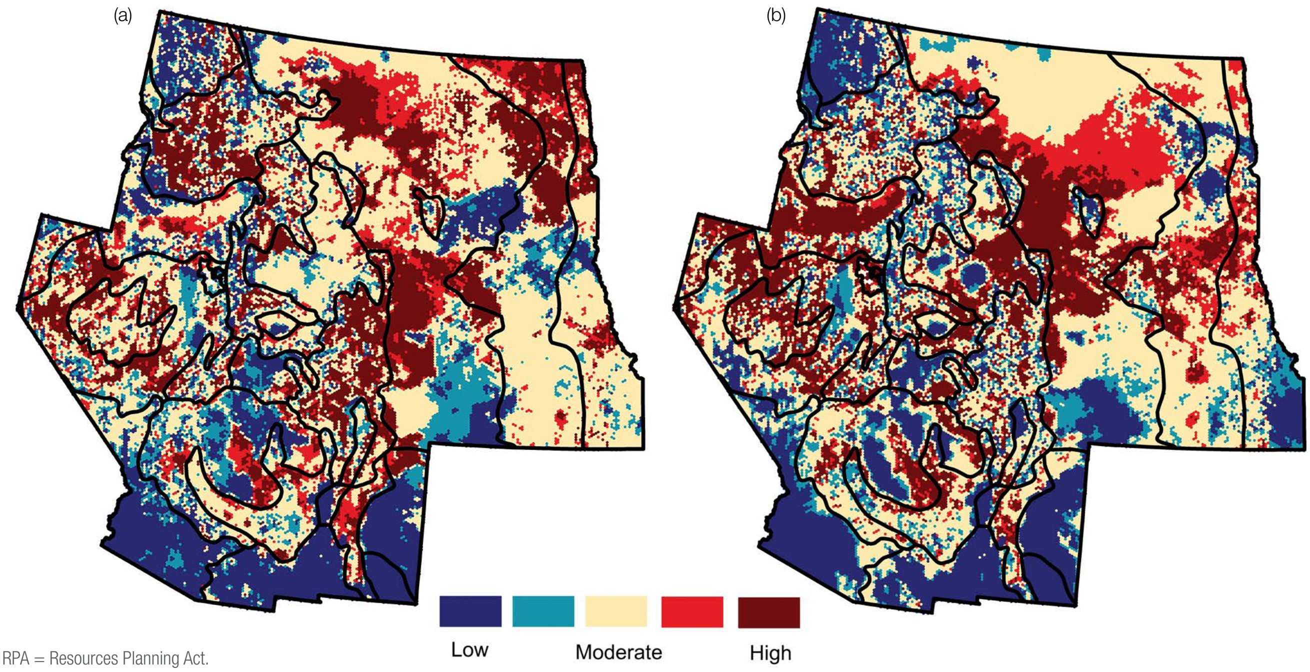
Source: Foti et al. (2012).

➔Finding: Projected climate-induced stress to terrestrial wildlife habitat varies geographically in the RPA Rocky Mountain Region, indicating that strategies for addressing climate change stress to terrestrial wildlife habitats will need to be geographically specific.

The 2010 RPA found that terrestrial wildlife habitats, already affected by fragmentation and conversion of native vegetation to urban and developed areas, will be stressed further by changes to terrestrial habitat attributed to climate change. In the RPA Update, we focused on effects at a smaller spatial scale in the RPA Rocky Mountain Region. Areas of low climate stress to wildlife habitat were projected to occur in southern Arizona and New Mexico, while areas of high climate stress were projected to occur in the desert and semidesert ecosystems of Arizona, Idaho, and Nevada and the temperate steppe ecosystems of Colorado and Wyoming (figure 2-11).

Fire management also affected climate-induced stress to wildlife habitats. Strategies to actively suppress fires resulted in higher climate-induced stress among the Intermountain semidesert and desert ecoregions, where more widespread replacement of historical temperate shrubland vegetation with

Figure 2-11. Terrestrial climate stress index (TCSI) for the RPA Rocky Mountain Region under the A2 emissions scenario and three climate models in which (a) fire is not suppressed and (b) fire is suppressed. High stress is defined as those grid cells with TCSI scores in the top 20 percent; low stress has grid cells with scores in the lower 20 percent. Ecoregion provinces (thick black lines) after Bailey (1995).



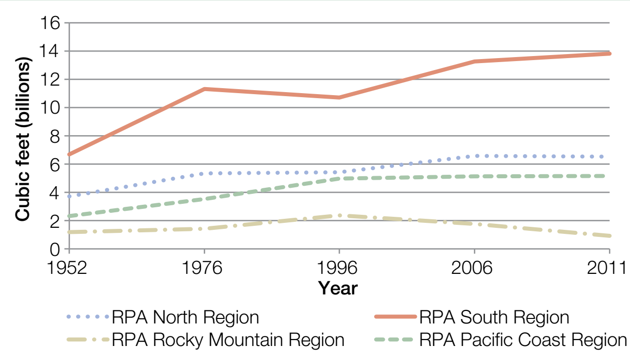
RPA = Resources Planning Act.

temperate forest and woodland types occurred. Management strategies with limited investment in suppressing fires resulted in higher climate-induced stress among the steppe-coniferous and open woodland ecoregions, where the underlying productivity of these systems declined. We do note, however, that a clean interpretation of these patterns is complicated by the interaction with the historical fire regime and our uncertainties associated with attributing vegetation shifts to fire management versus climate.

➔**Finding:** The RPA Rocky Mountain Region declined in net annual growth and increased in mortality between 1996 and 2011.

Forest growth rates continue to vary as they are influenced by patterns of forest management and cycles of insects, disease, wildfire, and other disturbances. Average net growth on growing stock trees across all ownerships nationwide has slowed by about 1 percent annually since 2006. This national trend is driven by growth declines in the RPA Rocky Mountain Region, whereas average annual growth is increasing in all other regions (figure 2-12). Average annual net growth in the Rocky Mountain Region has slowed by 48 percent since 2007, a change that can be attributed to large increases in mortality due to mountain pine beetle (MPB) infestations.

Figure 2-12. Net annual growth of growing stock on timberland, by RPA region, 1952 to 2011.



RPA = Resources Planning Act.
Source: Oswalt et al. (2014).

Softwood mortality in the RPA Rocky Mountain Region increased 92 percent between 1996 and 2011. Mortality was highest in the MPB-affected States of Colorado, Idaho, Montana, Utah, and Wyoming, where MPB affected large stands of mature lodgepole pine trees in the States. Mortality estimates for the RPA Intermountain Subregion also capture mortality that occurred during the peak activity of MPB, which spanned from 2008 through 2010. Although tree mortality has increased significantly in the RPA Intermountain Subregion, average annual mortality rates in the region are still in the range of 0.6 to 2.0 percent of total growing stock volume compared with rates in the RPA South and North Regions, where mortality ranges from 0.4 to 1.4 percent.

➔**Finding:** Mortality caused by insects and diseases has been reported on a declining number of forest acres since 2009; wildfire continues to be a major disturbance.

Mortality caused by insects and diseases has been reported on a declining number of acres since 2009, when mortality was reported on 11.8 million acres. In 2013, mortality was reported on nearly 4.5 million acres nationwide. MPB caused slightly more than 35 percent of the mortality. Defoliation can also significantly affect our forests. The western spruce bud-worm caused nearly 1.7 million acres of defoliation damage in 2013, a 1.8-million-acre decrease from 2012. European gypsy moth defoliation was reported on nearly 574,000 acres in 2013, an increase from 2012.

Insects and disease will also likely have substantial impacts on species composition and health in urban forests across the United States. A study of six insects and diseases showed varying impacts on urban trees across 26 U.S. cities. Potential impacts were greatest for gypsy moth, followed by Dutch elm disease, Asian longhorned beetle, southern pine beetle, emerald ash borer, and hemlock woolly adelgid. These city analyses provide a glimpse of the types of impacts that insects and diseases are having or potentially could have on urban trees, impacts that may be exacerbated by climate change. Maintaining healthy urban tree populations may become more challenging in the future.

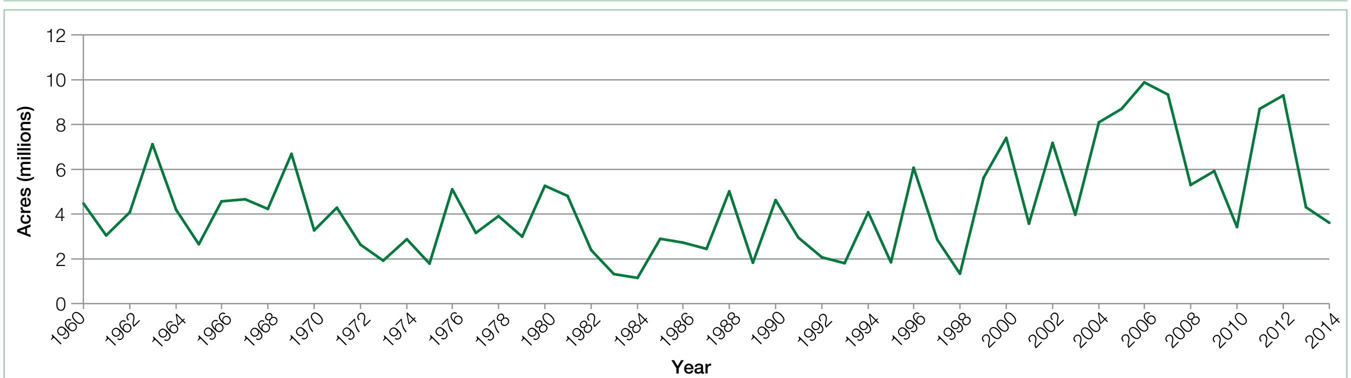
Wildfire continues to be a major disturbance in many forests of the United States. The 2010 RPA reported that acreage burned in 2006 was the largest fire-affected acreage during the period 1960 to 2010. In more recent years, fires in both 2011 and 2012 burned areas close to the 2006 total (figure 2-13). Climate change is increasing the vulnerability of many forests to ecosystem changes and tree mortality through fire, insect infestations, drought, and disease outbreaks. The potential for both warmer temperature and drought is likely to increase tree mortality. Relationships between climate and fire suggest that forests in the Western States are likely to be increasingly affected by large and intense fires. Although forests in the Eastern States are less likely to experience increases in wildfire, a combination of increasing temperatures, seasonal dry periods, protracted drought, and/or insect damage that triggers wildfire could also occur.

The results of the RPA Update analyses reinforce the 2010 RPA findings that climate change and other disturbances will alter natural ecosystems. Our understanding of these effects continues to improve, but much remains to be learned. The ability of the forest lands and rangelands to continue to produce ecosystem services will be affected particularly as climate change affects human population distribution patterns, which in turn will affect patterns of land use change. Examining the consequences of alternative adaptation options will be increasingly important. Consideration of these interactive effects will be important for designing flexible resource-management strategies.

Ecosystem Services From Forests and Rangelands

The United States has abundant natural resources, but a growing population, related land development, and climate change effects will put continuing pressure on these resources. The RPA Update reviews the outlook for the U.S. forest products sector, the market for exporting wood pellets in particular, and prospects for future recreation participation. We highlight ecosystem services from urban trees, the outlook for carbon sequestration on U.S. forests, the role of forested watershed in providing water, and the need for adaptation to address future water shortages. Finally, we consider the potential joint benefits of protecting drinking water and aquatic species. The RPA Update provides evidence of resource situations in which competition is likely, adaptation is critical to meet demands, and resources are sufficient to meet projected demand.

Figure 2-13. Total area of wildfires in the United States, 1960 to 2014.



➔**Finding:** Total wood and paper production has begun to recover since the 2007-to-2009 recession but remains below 2006 levels.

U.S. economic recovery has placed upward pressure on timber demand since 2009. Growth in the housing sector has improved softwood lumber consumption and sawtimber prices. Housing starts have continued to increase since the 2009 low, but single-family housing starts may return only to historical norms of less than 1.1 million rather than the high levels seen in 2004 and 2005, and total starts to the norm of less than 1.5 million (figure 2-14). The outlook for solidwood demand is uncertain, partly because of declines in the wood use per installed square foot during the past 50 years. Growth in overseas paper manufacturing output; shrinkage in U.S. manufacturing, which demands paper for final products and packaging; and substitution of paper publications by electronic media continue to put downward pressure on U.S. paper and paperboard production. As a result, timber growers and derived product manufacturers are likely to experience only weak improvement in markets in the near term.

➔**Finding:** Long-term trends in paper use, trade, and U.S. manufacturing activity indicate that market share in the foreseeable future is unlikely to return to the peak levels observed in the late 1990s.

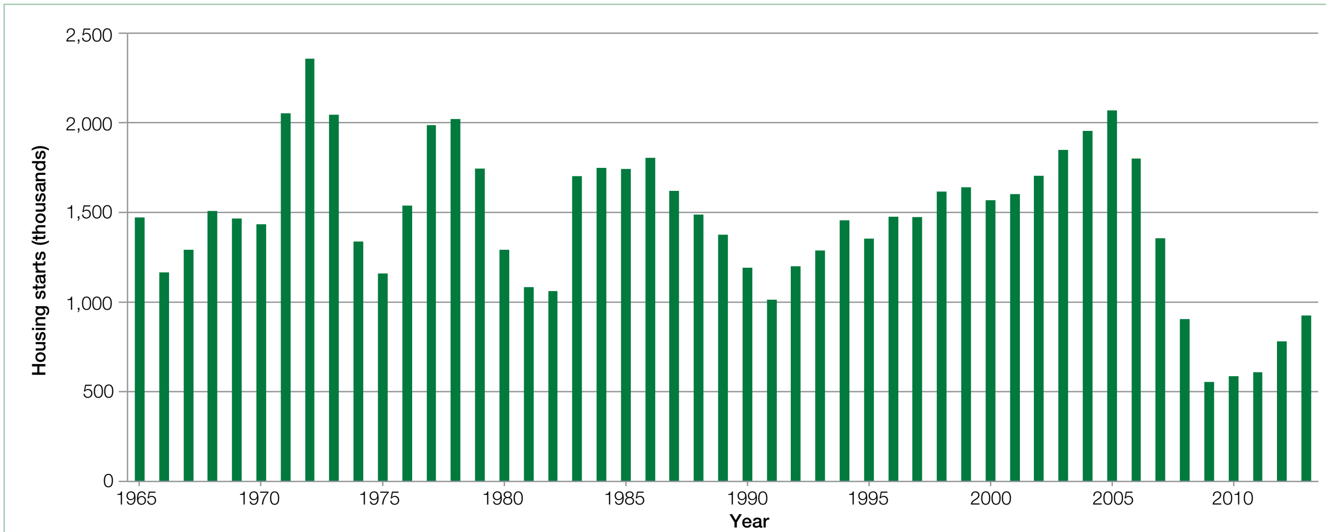
The U.S. share of global output of most timber products has declined since the 1960s, partly because of growth in foreign production and partly because of declines in domestic production. Long-term prospects for some market-share recovery exist in the wood products sector. Ongoing population growth combined with economic growth should raise demands for housing construction. A return to average levels of housing starts in the longer term would likely bring the U.S. share of global wood products markets somewhat closer to prerecession levels. The paper sector is less likely to recover in the short or long term. To illustrate, domestic U.S. consumption of paper used for writing, newsprint, and advertising declined by 46 percent between 2000 and 2013 because electronic media have supplanted these uses.

While domestic economic activity is the dominant force affecting U.S. wood products manufacturing, trade is increasing in importance. Global advances in policies and programs demanding or requiring sustainability certification for forest products traded on global markets also have the potential to affect foreign markets for U.S. forest products. Whether U.S. producers fully embrace certification, how certified producers conform to the sustainability requirements of destination of markets, and whether certification costs trend higher or lower will have implications for domestic U.S. timber growers and forest-product manufacturers. In the longer run, we might expect that the strong resource endowment of the United States and its shift toward production from planted forests will continue to support domestic wood products manufacture, especially if other countries reduce their timber inventories. Observed recent expansion in U.S. timber supply, while not the only requirement, is a step toward some recovery or a slowing of the loss in U.S. market share over the long run.

➔**Finding:** The U.S. wood pellet market will continue to grow, led by production in the South.

Increases in demand for woody biomass in energy production have often been suggested as a major new market, but use in the United States remains limited. Wood pellet production

Figure 2-14. Total U.S. housing starts, 1965 to 2013.

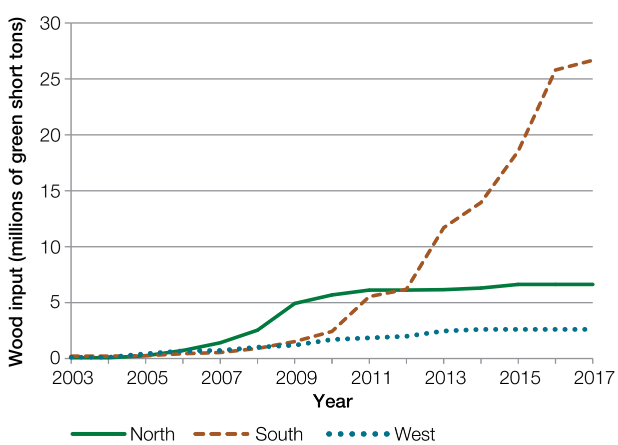


Source: U.S. Census Bureau (2014d).

in the South is the main exception, although production is primarily for export and not domestic use (figure 2-15). To date, the South is the primary provider of pellet exports, which has raised concerns about competition with other users of the southern forest resource. Increases in pellet production will provide short-run gains to forest landowners and short-run losses to nonpellet users of pulpwood inputs.

The South is expected to continue to dominate U.S. wood pellet production. Increases in pellet production could significantly increase the South's share of timber removals and lead to increased timber harvests and increased timber prices. The key driver of U.S. pellet production and export will continue to be demand from the European Union (EU) in the near term. The extent to which pellets from the U.S. South are able to continue to supply European markets depends on EU energy targets, growth in EU energy demands, EU policy targets set for the proportion of energy supplies provided by woody biomass, and the evolution of complementary and competing wood products industries. Export and domestic markets will be affected by ongoing debates about the carbon neutrality of forest biomass and mill residue to produce energy, limitations on greenhouse gas (GHG) emissions, and certification requirements. EU decisions about sustainability requirements for solid biomass, effects of biomass use on indirect land use change, and goals for GHG emission reductions could influence future U.S. pellet production. The GHG reduction potential of woody biomass has been the subject of considerable debate. EU sustainability criteria could limit the supply of Southern U.S. biomass to European renewable energy markets.

Figure 2-15. Growth in wood pellet production capacity by U.S. region, 2003 to 2014, and projected, 2015 to 2017.



Source: Forisk Consulting (2015).

➔Finding: U.S. forests continue to accumulate carbon but at a decreasing rate in the future, primarily because of land use change and forest aging.

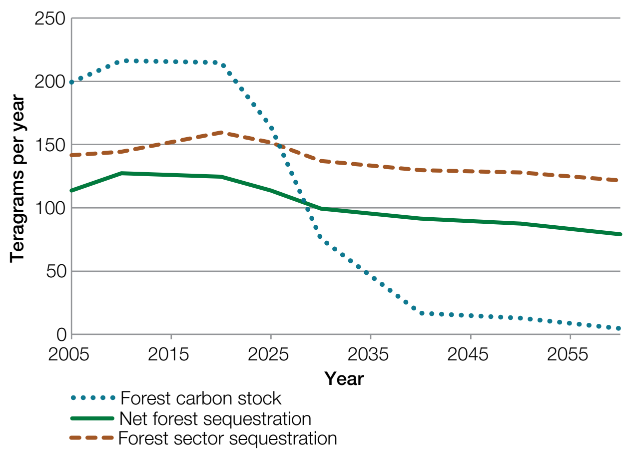
Carbon transfers associated with land use transitions play an important role in rates of forest carbon sequestration. Annual forest carbon flux was about 0.5 percent of the forest carbon stock from 1990 to 2016; increase in forest area accounted for about 41 percent of that annual flux (figure 2-16). Projections of future rates of net sequestration are sensitive to assumptions of forest area; for example, assuming a shift to declining forest area after 2020 leads to a transfer of carbon out of the forest pool and into other land use carbon pools (i.e., the change is a transfer, not an emission). As a result, the forest carbon pool declines from 2015 to 2060 (figure 2-16). Higher rates of forest loss can result in forests becoming an emissions source; low rates of change maintain the sink.

Actual net sequestration of carbon from the atmosphere by forests requires subtracting the land use carbon transfers from forest carbon stock change—defining the net sequestration line in figure 2-16. Actual sequestration of carbon by forests is much less variable than forest carbon stock change across scenarios, and it declines gradually over time. Under the scenario depicted in figure 2-16, net sequestration declines gradually from 2015 to 2060, reflecting the influence of forest aging and disturbance.

➔Regional Finding: When comparing the economic dependence of counties in the National Forest System Northern Region (R1), timber-producing counties in R1 have less social vulnerability than non-timber-producing counties, counties heavily dependent on recreation have less social vulnerability than those with little recreation, and counties dependent on grazing are significantly more vulnerable overall.

The Social Vulnerability Index (SoVI) is designed to measure the vulnerability of U.S. counties to environmental hazards, using variables that are selected to characterize broader dimensions of social vulnerability. The aspects of vulnerability included in the index are primarily related to demographic or socioeconomic features of each county's population. Many counties in the eastern part of Montana and central portions of North Dakota and South Dakota fall into the highly vulnerable category; likewise, counties at the eastern edge of Arizona and central-eastern portion of New Mexico are ranked as highly vulnerable. Counties dependent on grazing are significantly more vulnerable according to the SoVI, possibly a reflection of aging populations, low regional incomes, reliance on a single economic sector, and a large proportion of minorities. In the Southwestern Region, high social vulnerability overlaps with the high-stress pattern associated with climate change, perhaps portending a lower adaptive capacity to climate change in this part of the region.

Figure 2-16. Estimates of changes in U.S. forest carbon stocks, net forest carbon sequestration, and forest sector sequestration of carbon, Reference scenario, 2005 to 2060.



Modeling forest carbon at the regional scale accounts for important differences in aging and disturbance dynamics. Forest carbon stocks were highest in the two eastern RPA regions in 2015, when the South and North[3] Regions constituted 31 and 30 percent of carbon stocks respectively. Annual change in carbon stocks was also greatest in the eastern regions, accounting for roughly 80 percent of net forest carbon sequestration in 2015.

➔**Finding:** Urban trees serve important ecosystem functions by storing carbon and removing air pollutants.

Total carbon storage from trees on urban lands was estimated at 643 million metric tons. Given limitations to tree growth and establishment in urban areas, increases are unlikely in the absence of targeted policy. As tree cover in urban areas in the United States was declining in the mid-2000s to late 2000s, carbon storage in urban areas also likely declined. It is currently unknown if this recent decline in tree cover will continue.

Pollution removal by trees and forests in the United States was estimated at more than 17 million metric tons in 2010. Removal was greater in rural areas because about 96 percent of the land base is rural, but the estimated health benefit was greater in urban areas because more than 80 percent of the population lives in urban areas. Although typical annual air quality improvement due to pollution removal by trees was less than 1 percent, the benefits to health were still substantial.

➔**Finding:** Outdoor recreation participation is projected to continue to grow, with some regional variation.

The number of Americans participating in outdoor recreation will continue to grow through 2060. Overall growth in number of recreation participants and total days of recreation occurs even for those activities in which participation rates are projected to decline because the U.S. population growth rate is expected to exceed the rate of any per capita participation declines. The greatest growth in adult participation rates nationwide will come in developed skiing, challenge activities, day hiking, swimming, horseback riding on trails, and visiting interpretive sites. Activities with lower or declining rates include hunting, snowmobiling, motorized off-roading, fishing, and floating. The largest increases in participants will be for already-popular activities undertaken at a wide array of venues, including visiting developed and interpretive sites, nature viewing, swimming, and day hiking.

Outdoor recreation participation growth will vary across RPA regions. Growth will be less, in general, in the North Region because population growth is lowest there. The fastest growing activities will be developed skiing, day hiking, and horseback riding on trails. For the South Region, the growth in participation will increase the most in hiking, birding, visiting developed sites, and motorboating. The Rocky Mountain Region has some of the highest growth rates for participants because the region has the highest projected population growth rate. Activities with the highest participant growth rates in this region are developed skiing, challenge activities, day hiking, and birding. In the Pacific Coast Region, the activities with the highest participant growth include developed skiing, motorboating, horseback riding on trails, and swimming.

For most activities, population density has a negative effect on participation. With projected increases in urbanization, population density will increase in many areas. Unless recreation behavior changes, the increases in population density will be accompanied by decreases in participation rates for activities most affected by crowding or access limits. At the same time, increasing participation on a static public land base is likely to result in more crowding at some venues and possibly a decreased quality of experience.

➔**Finding:** National forests provide outdoor recreation opportunities to large numbers of visitors, with high levels of visitor satisfaction.

National forests hosted an estimated 146.8 million forest visits in 2014. Most of the use occurred in general forest areas (53 percent), with day use developed sites receiving the next greatest proportion of visits (36 percent). All age groups were

[3] The Eastern Plains States of Kansas, Nebraska, North Dakota, and South Dakota are included in the North Region in these analyses.

represented, with the under-16-year-old and 40-to-49-year-old groups the most frequent visitors. Males accounted for 65 percent of the visits, and about two-thirds of the visits came from recreationists living within 100 miles of the forest. Minorities are underrepresented relative to the general population in their use of national forests. Racial minorities in total accounted for about 5 percent of national forest visits, with Asian visitors being the most represented group, at 3 percent. Some variation existed across RPA regions, with the Pacific Coast Region having the largest share of minority forest visits, at about 11 percent, and the North Region having the smallest portion, at 3 percent. The South Region had the largest share of African-American forest visits, at 2 percent. Native American visits consistently ranged from 2 to 3 percent across all regions. Hispanic/Latino ethnicity for forest visitors averaged 6 percent nationally, ranging from slightly more than 1 percent in the North Region to 6 and 8 percent, respectively, in the Rocky Mountain and Pacific Coast Regions. Changes in participation rates or the types of opportunities provided may be required to encourage more minorities to visit national forests.

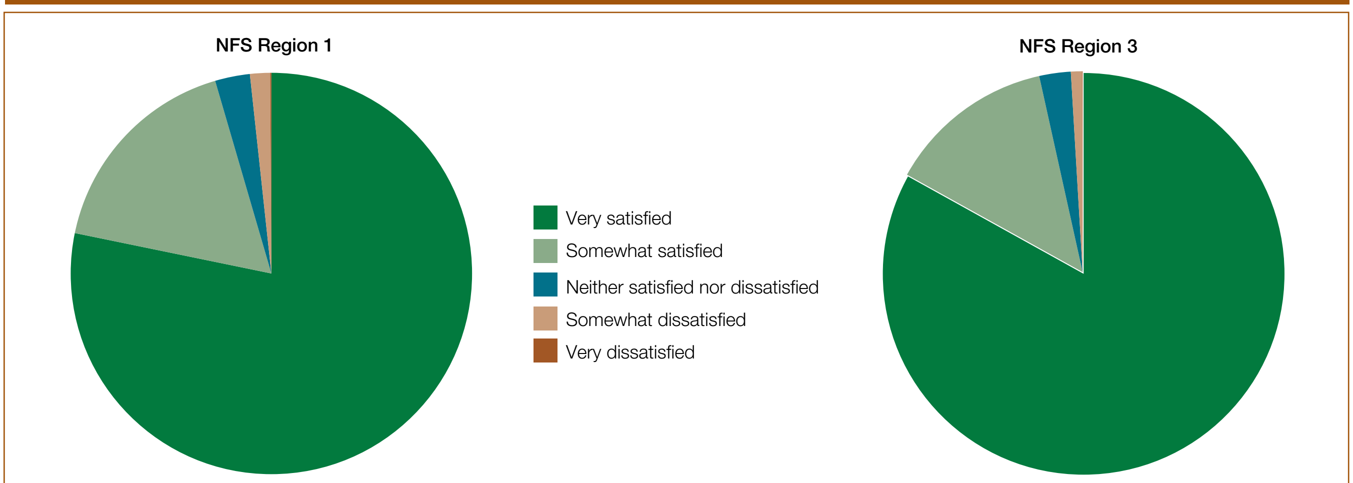
National forest visitors engaged in a variety of recreation activities. The five most popular were viewing natural features, viewing wildlife, relaxing, hiking/walking, and driving for pleasure. In the RPA Pacific Coast and Rocky Mountain Regions, skiing was also very popular. Across nearly all regions and site types, national forest visitors expressed satisfaction with recreation setting attributes they deemed important, including condition of the environment, natural scenery, signage adequacy, trail conditions, and value for any fees paid. In fact, only about 1.5 percent of all region/site-type/attribute combinations showed evidence that visitors felt significant improvement was warranted. Such improvements included restroom cleanliness for developed sites and general forest areas, parking availability for developed sites, and recreation information for wilderness areas. Personal safety was among the most highly rated attributes across all regions and site types. The level of crowding generally was considered satisfactory across most sites at most times of the year.

➔**Regional Finding:** Overall, recreation visitors to national forests and grasslands in the National Forest System Northern and Southwestern Regions were satisfied with their recreation experience.

Similar to the findings across the RPA regions, recreation visitors to national forests in both the Northern (R1) and Southwestern (R3) NFS Regions judged their recreation experience positively across all recreation site types. One example is visitor satisfaction with the condition of the natural environment across all site types (figure 2-17) for each region. Visitor perception of crowding increased over time for general forest areas in both regions, whereas declines in crowding were perceived by visitors using wilderness in R1 and overnight use developed sites in R3.

Given projected increases in recreation use for the larger RPA Rocky Mountain Region, national forest visitation is likely to increase in the future. Increasing demand for outdoor recreation opportunities may stress recreation facilities that are easily accessed and in close proximity to areas of high population growth, potentially reducing visitor satisfaction. Visitor choices of where to recreate in summer and winter may also be affected by climate change: increased temperature in R3 reducing preferred recreation conditions, more interest in recreating at higher and cooler elevations in the summer, and more limited opportunities overall for winter recreation. These choices could put increasing pressure on the limited water resources (rivers, springs, lakes) and aquatic resources.

Figure 2-17. Distribution of visitor satisfaction ratings for conditions of the natural environment in National Forest System (NFS) Region 1, Northern Region (left), and Region 3, Southwestern Region (right), from 2010 to 2012 for all site types.



More than 7 percent of national forest visits included a group member with a disability. About three-fourths of groups nationwide with a disabled member claimed that site facilities were accessible. At the RPA regional level, the highest satisfaction level for disabled accessibility was in the Pacific Coast Region (85 percent) and the lowest was in the South Region (58 percent). Access to outdoor recreation opportunities will continue to be challenged with an aging population, led by a large segment of retiring baby boomers, and with a sizeable number of families having a disabled member.

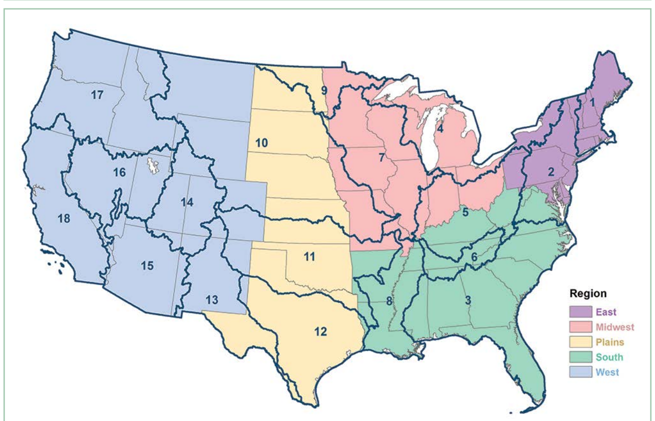
➔**Finding:** Forested watersheds provide about two-thirds of the water supply of the East, South, and West U.S. regions.

Forest areas are the source of roughly two-thirds of the annual renewable water supply of the East, South, and West U.S. regions, and roughly one-third of the water supply of the Midwest and Plains water supply regions (figure 2-18), where forest land is a much smaller proportion of the total land base. Because forests, in general, are the source of the highest quality runoff, they play an extremely important role in the provision of water in the United States. To the extent that public forest lands are less prone to development than private lands, public forest lands will likely increase in importance as sources of clean water in the future.

➔**Finding:** Adaptation options can reduce vulnerability to water shortage, but no single option eliminates the likelihood of shortage in all basins.

Climate change was projected to have substantial effects on water demand and supply in the 2010 RPA. The combined effects of population growth and climate change put increased pressure on renewable water supplies. On average, and in the

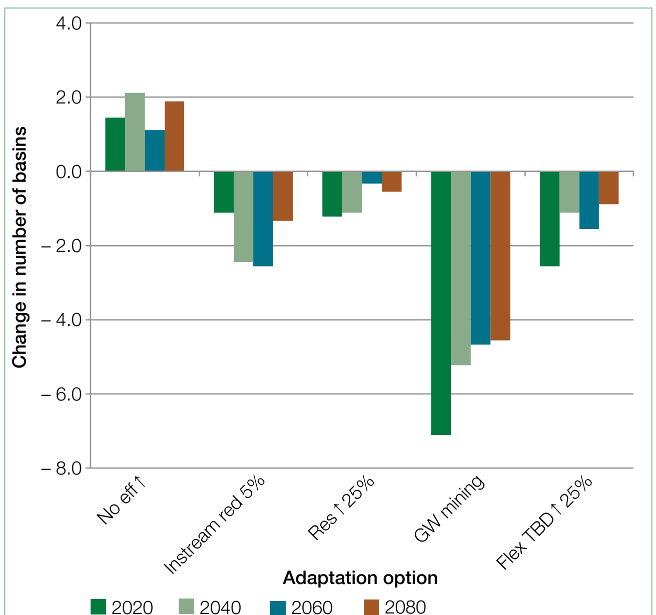
Figure 2-18. Eighteen water resource regions (numbered) and five water supply regions.



absence of further adaptation efforts, the number of water basins with at least 1 year of shortage was projected to increase about four-fold from the recent past to 2060. Water shortages occur because of increases in water demand and/or decreases in water supply, with demand increases tending to be more important than supply decreases in most basins.

Continued improvements in water withdrawal efficiency and continuation of the past rate of decrease in western irrigated areas will not be sufficient to avert future water shortages. A number of adaptation options were tested to determine how many basins could be removed from the projected shortage list compared with the base condition defined by the results of the 2010 RPA. Lack of continued improvements in water withdrawal efficiency (which were assumed in the base condition) would increase the number of basins facing shortage (figure 2-19). Of all the measures of adaptation examined, allowing continued groundwater mining has the biggest impact on projected shortages, resulting in a 20- to 50-percent reduction in the number of basins with shortages, on average. Groundwater mining, however, is not a long-term solution to water scarcity—it imposes costs on future water users and can exhaust the recoverable groundwater supply. All other adaptations tend to reduce the number of basins with shortages of about 5 to 10 percent. Reducing the instream flow requirement from 10

Figure 2-19. Change from the base condition in the number of basins with at least 1 year of shortage for five selected adaptations (average of results of all nine futures). In the base condition, 15, 18, 20, and 20 basins incur ≥1 year of shortage in periods 2020, 2040, 2060, and 2080, respectively.



No eff ↑: Lack of assumed increases in water use efficiency.
Instream red 5%: Reduction in the instream flow constraint from 10 to 5% of mean annual flow.
Res ↑ 25% : Increase reservoir storage capacity by 25%.
GW mining: Continued reliance on groundwater mining.
Flex TBD ↑ 25%: A 25% increase in transbasin diversion capacity combined with an increase in the flexibility with which such diversions occur.

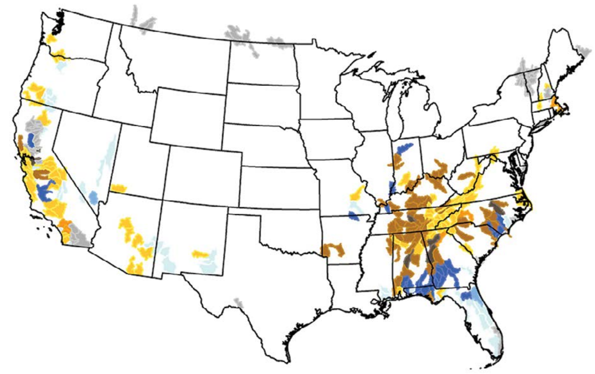
to 5 percent of mean annual yield and expected improvements in withdrawal efficiency tend to have the next greatest impact. Of course, reducing instream flow would tend to harm aquatic life and lower the quality of instream recreation. A common past adaptation, increasing reservoir storage capacity, had some effects on the shortage in the beginning of the 21st century, but the effects diminish later in the century as water yields diminish in key regions. A combination of removing the constraint to always fully satisfy transbasin diversion (TBD) requests and increasing TBD capacity by 25 percent also reduces the incidence of shortage from one to two basins. As would be expected, the effectiveness of the adaptations differs considerably by location (i.e., basin). For example, groundwater mining is most effective in basins with ample groundwater supplies, and reducing irrigated area is most effective where irrigation accounts for a large percentage of total water use. Thus, in practice, selection of adaptations—both the kind and size or extent—must be sensitive to local circumstances. Basins under water stress will need to implement a varied mixture of adaptations, aiming to both decrease water demand and increase the flexibility with which water is stored and delivered to meet those demands. But even combinations of the adaptations examined here would probably be insufficient to eliminate shortages from all basins, suggesting that additional measures, such as reductions in water use beyond those examined here, may be necessary.

➔Finding: Two-thirds of watersheds that supported a high proportion of at-risk aquatic biodiversity have a collateral stake in drinking water protection.

Some ecosystem services may benefit from complementary actions. One example of potential joint benefits is protecting at-risk aquatic biodiversity while simultaneously protecting drinking water quality. An RPA Update analysis reported that two-thirds of watersheds that support a high proportion of at-risk aquatic biodiversity have a collateral stake in drinking water protection. These watersheds are concentrated in the Southeast and the Mediterranean climates of California (figure 2-20). Joint benefit watersheds that also have low levels of land protection and high rates of urbanization can serve as targets for land use and conservation planning. Explicit identification of watersheds with joint benefits has the potential to leverage scarce conservation funding resources and facilitate action among traditionally competing stakeholders.

The effect of water demands on instream flow for aquatic species is one example in which demands on one resource often influence conditions of other resources. Consideration could be given to the complementary production of other goods and services as well as tradeoffs and interactions in production to design more effective policy and management strategies.

Figure 2-20. Watersheds that support a relatively high proportion of at-risk aquatic biodiversity (in the 90th percentile) categorized by whether the watershed has drinking water intakes, whether the percentage of protected areas is limited, and whether the watershed has relatively high urban development. # DWI is the number of drinking water intakes. Count is the number of watersheds in each set.



	# DWI	% Protected	% Urban change	Count
	0	> 9	< 1	40
	0	> 9	≥ 1	2
	0	≤ 9	< 1	26
	0	≤ 9	≥ 1	0
	≥ 1	> 9	< 1	73
	≥ 1	> 9	≥ 1	7
	≥ 1	≤ 9	< 1	52
	≥ 1	≤ 9	≥ 1	7
	No species data			

Source: Wickham and Flather (2013).

In summary, the findings of this RPA Update are largely consistent with the 2010 RPA. The United States has abundant natural resources, but demands on forest, rangeland, and water resources will increase in the future. Land development and urbanization, climate change, and natural disturbances will continue to reshape the extent and character of our forests and rangelands. The combination of human and biophysical stressors will affect their ability to provide some ecosystem services.

The outcomes portrayed in the RPA Update are not inevitable—they are based on a continuation of current policies. Many policies and management strategies can be used to change the direction of future trends. Changes in markets, technology, trade flows, Government policies, and public values will all play key roles in shaping responses to changing resource conditions. Although markets are quite effective at providing incentives for commodity products, incentives to provide other ecosystem services are limited. Increased use of payments for ecosystem services could provide incentives to landowners to maintain a wide array of services, but much progress remains to be made in this area. Other types of programs, such as land retirement programs, conservation easements, and tradable development permits are all options that can contribute to sustaining forest lands and rangelands. Social and political perceptions are as important in enabling change as are technical solutions. General social acceptability sometimes limits management options, particularly on public lands. For example, public views of harvest from public lands or use of biomass for energy can be as limiting as market situations.

Maintaining and improving data and information collection and synthesis allow for continued identification of emerging challenges and development of innovative strategies to address resource management needs. Very different economic, ecological, and environmental outcomes are possible, depending on management strategies and policies. The results from this RPA Update help provide a scientific foundation for evaluation of alternative strategies and policies.

Chapter 3. Land Resources

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) provided an overview of the land and water resources of the United States. Land use/cover trends in the conterminous United States were based on the National Resources Inventory (NRI) through 2007, and NRI data were also the basis for the 2010 RPA land use projections through 2060. In this RPA Update, we present a summary of NRI data on land use/land cover trends through 2012.

Highlights

- Non-Federal developed land area increased 34 percent between 1992 and 2012.
- Urban land area increased 44 percent between 1990 and 2010.
- Urban area would account for 8.6 percent of the conterminous U.S. land area by 2060, an increase of 141 percent, if 1990-to-2010 average growth rates were to continue.
- Improved maps of protected areas show 16 percent of the total area of the United States was protected under International Union for Conservation of Nature (IUCN) standards.
- In the conterminous United States, 18 percent of total forest cover area was protected under IUCN standards; 58 percent of the total area protected under IUCN standards had forest cover.

Land development was noted as an ongoing threat to the integrity of natural ecosystems in the 2010 RPA. We focus in this chapter on developed land use and cover change trends based on NRI data (1982 to 2012) and the National Land Cover Database (NLCD) (1992 to 2011) and on urbanization trends based on the U.S. Census (1990 to 2010). The status of protected areas in the United States using the Protected Areas Database of the United States (PAD-US) is also updated from the 2010 RPA.

The U.S. Department of Agriculture, Natural Resources Conservation Service released an update to NRI (USDA 2015) that includes historical corrections to earlier NRI data and can be used to detect change for previous NRI data from 1982 to 2012. The data from 1982 to 2012 do not indicate any significant change in land use trends except for cropland and the Conservation Reserve Program (CRP). Table 3-1 shows the changes in land use and cover from 2007 to 2012 on non-Federal lands in the conterminous United States.

The 2012 NRI data indicate that cropland acreage increased by nearly 4 million acres (1.6 million hectares [ha]) from 2007 to 2012, which reversed a trend of steady decline during the previous 25 years. Most of the cropland increase came from CRP. Between 2007 and 2012, CRP acreage was reduced by nearly 27 percent, from 32.5 to 24.2 million acres (13.1 to 9.8 million ha) (not shown in table 3-1). About one-half of that acreage became cropland, and another one-third became pastureland. Non-Federal forest land remained virtually unchanged during the same period.

Table 3-1. Changes in major non-Federal land cover and uses in the conterminous United States, 2007 to 2012.[a]

2007 land cover/uses (thousand acres)	2012 land cover/uses (thousand acres): Cropland	Pastureland	Rangeland	Forest land	Developed land	Other rural land	2007 total
Cropland	351,672	4,793	103	249	697	389	**358,866**
Pastureland	4,586	112,060	143	1,859	562	272	**119,744**
Rangeland	486	200	404,855	391	555	453	**407,231**
Forest land	258	563	123	410,028	1,407	334	**413,123**
Developed land	83	48	22	162	110,739	23	**111,080**
Other rural land	113	345	168	215	137	43,950	**44,935**
2012 total	**362,726**	**121,138**	**405,777**	**413,337**	**114,113**	**45,449**	
Net change	3,860	1,394	– 1,454	214	3,032	514	

[a] To read this table: The 2007 land cover/use totals are listed in the right-hand vertical column, titled "2007 total." The 2012 land cover/use totals are listed in the bottom horizontal row, titled "2012 total." The number at the intersection of rows and columns with the same land cover/use represents acres that were in the same land cover/use category in both 2007 and 2012. The numbers to the left or right of this number represent acres lost to another land use during the period. The numbers above or below this number represent acres gained from another land use during the period. Comparing the "2007 total" column to the "2012 total" row represents the new acres gained or lost over the period. Estimates in red are not reliable because the margins of error are equal to or greater than the estimate, so the confidence interval includes zero. The data for 2007 and 2012 are not summed across all categories because not all National Resources Inventory land use/cover categories are included in this table.

Source: USDA (2015).

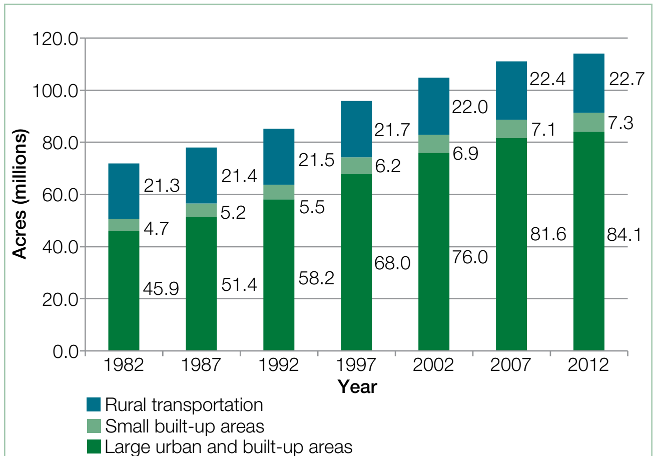
Developed Land Trends

❖ Developed land area increased in the past two decades; absolute rates of growth are relatively small, but relative change varies greatly across the United States.

NRI provides a perspective on developed land that includes (1) large tracts of urban and built-up land, (2) small tracts of built-up land of less than 10 acres, and (3) land outside these built-up areas that is in a rural transportation corridor (roads, railroads, and associated rights-of-way) (USDA 2015). According to the 2012 NRI results, from 2007 to 2012, developed land on non-Federal lands increased 2.7 percent, an increase of about 3 million acres (1.2 million ha) (figure 3-1). All 48 conterminous States had statistically significant increases in developed land. Over the entire NRI timeframe, the greatest growth in developed land area occurred in large urban and built-up areas, which increased 83 percent between 1982 and 2012 (figure 3-1) (USDA 2015).

The NLCD was used to assess developed land cover change between 1992 and 2011 (Fry et al. 2009; Homer et al. 2015; USGS 2014a). Developed land defined in the NLCD is the land cover significantly modified by human activity with constructed materials, excluding most agricultural activities. Four NLCD classes were used to quantify developed land trends: (1) developed, open space with less than 20 percent impervious surfaces; (2) developed, low intensity with 20 to 49 percent impervious surfaces; (3) developed, medium intensity with 50 to 79 percent impervious surfaces; and (4) developed, high intensity with 80 to 100 percent impervious surfaces. The developed category generally includes human settlements of variable population, from highly populated cities to suburban, exurban, and rural communities.

Figure 3-1. Trends in area of National Resources Inventory-defined developed lands, 1982 to 2012.



Source: USDA (2015).

From 1992 to 2011, NLCD-defined developed land cover of the conterminous United States increased 15 percent, from 5.2 percent of the land base (97.7 million acres [39.5 million ha]) to 5.9 percent (112.2 million acres [45.4 million ha]) (table 3-2). This percentage increase is lower than the NRI estimate for the comparable time period (34 percent between 1992 and 2012), partially because the NLCD percentage is based on the entire conterminous U.S. land area, not just non-Federal lands.

The States with the smallest and largest percent of NLCD-defined developed land cover in 2011 were Wyoming (0.9 percent) and New Jersey (31.9 percent); the District of Columbia had 88.3 percent developed land cover. The absolute change in percent developed land cover by State, in general, was small, ranging from 0.1 percent in Wyoming and Vermont to 9.0 percent in Delaware. The relative growth of developed land

Table 3-2. Trends in NLCD-defined developed land cover, 1992 to 2011, and census-defined urban land area by State and RPA region, 1990 to 2010.

State	1992	2001	2006	2011	1992–2011	1990	2000	2010	1990–2010
	percent developed land cover—NLCD				*percent change*	*percent urban land—census*			*percent change*
Connecticut	23.5	24.0	24.6	25.1	6.8	30.6	35.5	37.7	23.3
Delaware	10.1	17.3	18.6	19.1	90.0	10.9	15.0	20.9	91.4
Maine	3.4	3.6	3.7	3.7	7.5	1.0	1.1	1.2	20.7
Maryland	11.6	18.3	18.8	19.2	65.2	14.3	17.3	20.7	44.4
Massachusetts	24.0	24.4	25.4	25.9	7.9	29.2	34.2	38.0	30.1
New Hampshire	7.6	7.7	7.9	8.2	6.6	4.4	6.1	7.2	64.9
New Jersey	24.5	30.3	31.3	31.9	30.1	31.2	36.2	39.8	27.6
New York	9.1	9.3	9.5	9.6	6.1	7.2	8.1	8.7	20.8
Ohio	13.8	14.3	14.6	14.8	7.8	8.3	9.7	10.8	29.7
Pennsylvania	10.5	12.0	12.3	12.5	18.2	7.5	9.4	10.5	40.4
Rhode Island	29.5	29.4	30.4	30.7	4.1	30.2	35.9	38.7	28.3
Vermont	5.6	5.6	5.6	5.7	1.8	1.3	1.5	1.7	28.5
West Virginia	6.7	7.0	7.1	7.1	6.6	1.9	2.3	2.7	41.7
Northeast	10.5	11.5	11.7	11.9	14.0	8.1	9.6	10.7	31.8
Illinois	11.5	11.6	11.9	12.1	5.9	5.4	6.4	7.1	32.3
Indiana	10.1	10.5	10.8	11.0	8.5	4.9	6.1	7.0	43.5
Iowa	7.1	7.3	7.5	7.5	5.8	1.3	1.5	1.7	31.2
Michigan	10.3	10.6	10.7	10.8	4.8	4.8	5.8	6.4	32.7
Minnesota	5.3	5.8	6.0	6.1	15.8	1.6	1.9	2.2	35.6
Missouri	6.5	6.9	7.0	7.1	9.0	2.3	2.6	3.0	32.5
Wisconsin	6.8	7.3	7.6	7.7	13.6	2.4	3.0	3.5	42.6
North Central	7.9	8.3	8.5	8.6	8.6	3.0	3.6	4.1	35.4
RPA North	**8.9**	**9.5**	**9.7**	**9.8**	**11.0**	**4.9**	**5.9**	**6.6**	**33.2**
Florida	13.2	14.1	14.6	15.0	13.2	8.3	10.8	13.7	64.4
Georgia	8.2	9.3	10.0	10.2	24.9	4.5	6.4	8.3	83.9
North Carolina	9.1	10.4	10.8	11.1	22.0	5.0	7.1	9.5	87.8
South Carolina	7.8	9.1	9.7	9.9	27.1	4.6	6.0	7.9	73.7
Virginia	7.2	9.5	9.9	10.0	38.4	4.8	5.9	6.8	40.2
Southeast	9.4	10.7	11.2	11.5	22.4	5.6	7.4	9.5	70.2
Alabama	6.4	7.0	7.3	7.5	17.4	2.8	3.4	4.4	58.9
Arkansas	5.5	5.9	6.0	6.1	11.0	1.4	1.7	2.1	53.3
Kentucky	6.8	7.3	7.5	7.6	11.3	2.5	3.0	3.6	43.4
Louisiana	6.5	7.3	7.5	7.6	16.8	3.0	3.5	4.6	53.8
Mississippi	5.7	6.3	6.5	6.6	15.4	1.6	2.0	2.4	47.7
Oklahoma	5.4	6.1	6.2	6.3	16.5	1.4	1.7	1.9	31.6
Tennessee	8.3	9.3	9.7	9.9	19.0	4.4	5.8	7.0	58.5
Texas	5.0	6.2	6.4	6.6	30.8	2.2	2.7	3.3	53.1
South Central	5.7	6.6	6.8	6.9	21.3	2.3	2.8	3.4	51.9
RPA South	**6.7**	**7.7**	**8.0**	**8.2**	**21.7**	**3.2**	**4.1**	**5.1**	**60.8**
Kansas	4.7	5.1	5.2	5.3	11.5	0.9	1.1	1.2	35.3
Nebraska	3.5	3.6	3.7	3.7	6.5	0.5	0.6	0.7	34.2
North Dakota	3.9	4.1	4.1	4.2	6.7	0.2	0.2	0.3	50.9
South Dakota	2.7	2.9	2.9	3.0	7.7	0.2	0.2	0.3	55.8
Great Plains	3.7	4.0	4.0	4.0	8.6	0.5	0.5	0.6	38.5
Arizona	1.8	2.1	2.2	2.4	30.7	1.0	1.5	1.9	83.3
Colorado	2.4	2.7	2.8	2.8	16.4	1.0	1.2	1.5	51.0
Idaho	1.6	1.7	1.7	1.7	9.7	0.4	0.5	0.6	60.0
Montana	1.3	1.4	1.5	1.5	12.9	0.2	0.2	0.2	35.2
Nevada	0.8	0.9	1.0	1.0	24.0	0.3	0.5	0.7	128.6
New Mexico	1.0	1.1	1.2	1.2	17.1	0.5	0.6	0.7	50.9
Utah	1.5	1.6	1.7	1.7	15.7	0.6	0.8	1.1	70.7
Wyoming	0.8	0.9	0.9	0.9	12.3	0.2	0.2	0.2	30.2
Intermountain	1.4	1.5	1.6	1.6	17.9	0.5	0.7	0.8	67.5
RPA Rocky Mountain	**2.0**	**2.2**	**2.2**	**2.3**	**13.2**	**0.5**	**0.6**	**0.8**	**60.5**

Table 3-2. Trends in NLCD-defined developed land cover, 1992 to 2011, and census-defined urban land area by State and RPA region, 1990 to 2010. (continued)

State	1992	2001	2006	2011	1992–2011	1990	2000	2010	1990–2010
	percent developed land cover—NLCD				percent change	percent urban land—census			percent change
Alaska						0.0	0.0	0.0	39.4
Oregon	2.5	2.7	2.7	2.7	7.7	0.9	1.1	1.2	32.8
Washington	5.6	5.9	6.0	6.0	8.7	2.5	3.1	3.6	42.7
Pacific Northwest	3.8	4.0	4.1	4.1	8.3	0.4	0.5	0.5	39.4
California	6.3	6.6	6.8	6.9	8.5	4.3	5.0	5.3	22.9
Hawaii						4.5	5.4	6.1	34.2
Pacific Southwest	6.3	6.6	6.8	6.9	8.5	4.3	5.0	5.3	23.4
RPA Pacific Coast	**5.0**	**5.3**	**5.4**	**5.4**	**8.4**	**1.1**	**1.3**	**1.4**	**27.8**
District of Columbia	82.1	88.0	88.1	88.3	7.6	89.9	89.9	100.0	11.3
Conterminous United States	**5.2**	**5.7**	**5.8**	**5.9**	**15.0**	**2.5**	**3.0**	**3.6**	**44.6**
United States Total						**2.1**	**2.6**	**3.0**	**44.5**

NLCD = National Land Cover Database. RPA = Resources Planning Act.

cover in the same time period, however, is considerably higher. The smallest relative increase in developed land occurred in Vermont (1.8 percent), and the largest increase occurred in Delaware (90.0 percent). As table 3-2 shows, the largest regional increase occurred in the RPA South Region, at 21.7 percent.

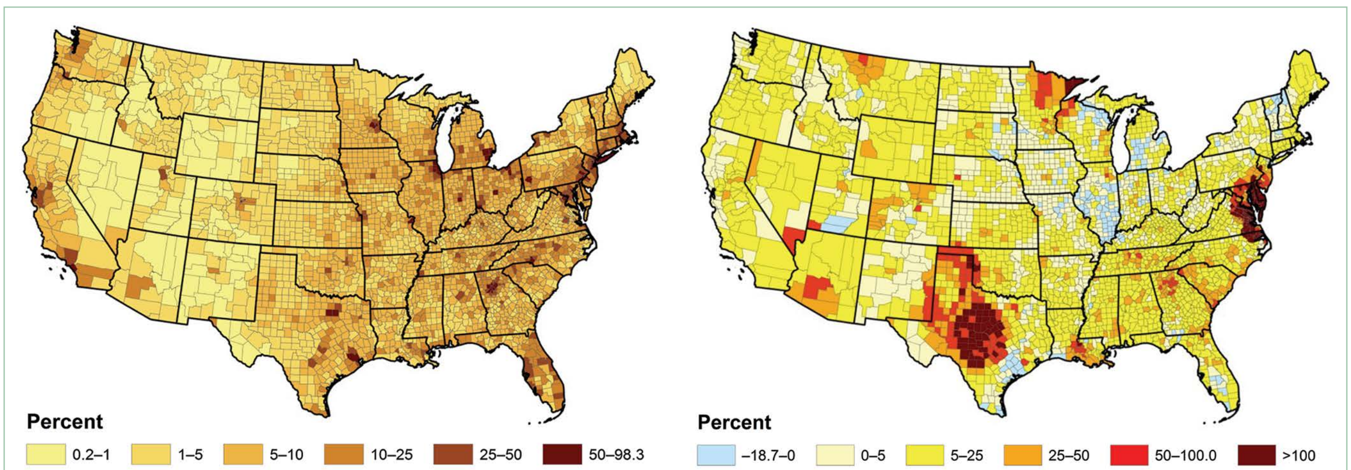
While the variation in percent change in developed land cover is considerable across States, it is even greater at the county level. Figure 3-2 shows the distribution of NLCD-defined developed land cover in 2011 at the county level and the percent change of developed land cover between 1992 and 2011. Those States with the highest percent change (table 3-2) also tend to have high rates of change at the county level. The range is even greater, however, because some counties lost developed land cover and others gained at rates higher than the State average. For example, Texas has one of the largest State increases, but increases are even higher in a large number of counties, offset by slower development in other counties.

Urbanization Trends and Projections

- ❖ Urban land area increased 44 percent between 1990 and 2010; the rate of growth slowed in the 2000-to-2010 decade compared with the rate in the previous decade.
- ❖ If urban growth continued at the average rate from 1990 to 2010, urban area would account for 8.6 percent of the conterminous U.S. land area by 2060, an increase of 141 percent.

The U.S. Census Bureau defines *urban land* as all territory, population, and housing units located within urbanized areas or urban clusters, which are defined by population density. Urbanized areas are the areas of high population density containing 50,000 or more people, and urban clusters are areas of high population density of more than 2,500 but less than 50,000

Figure 3-2. Distribution of National Land Cover Database (NLCD)-defined developed land cover by county, 2011 (left), and percent change of NLCD-defined developed land cover by county, 1992 to 2011 (right).

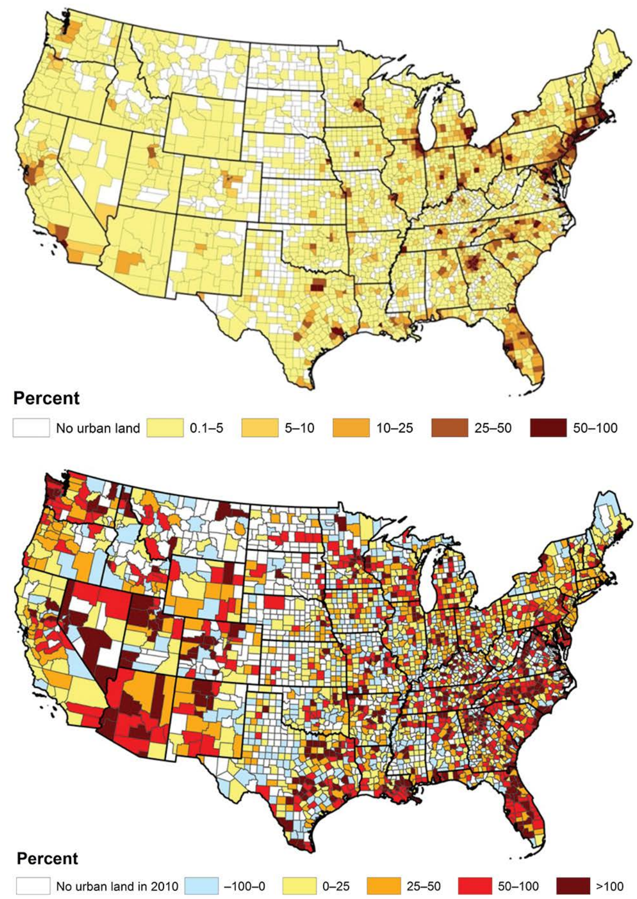


Sources: Fry et al. (2009); Homer et al. (2015).

people. In the 2000 census, urbanized areas and urban clusters were derived from census blocks and block groups with population densities of 1,000 people per square mile (386.1 people per square kilometer) in the core and 500 people per square mile (193.1 people per square kilometer) in the surrounding area. In addition, surrounding areas were included within a distance of 2 1/2 miles along a connected corridor (i.e., a road), they included less densely populated blocks or block groups less than 1/2 mile between more densely populated blocks or block groups, and they included blocks or block groups with large airports but little to no population (U.S. Census Bureau 2013). Because the census urban definition substantially changed between 1990 and 2000, 1990 urban land was redefined using the 2000 definition to facilitate the analysis in this section.

In the 2010 census, the urban land was redrawn and redefined. While the 2000 general definition of urbanized area and urban cluster was maintained, census tracts and not blocks or block groups were used to delimit the urban core; institutional populations (i.e., correctional facilities and military installations) were limited within the urban designation; smaller airports were included; more limitations were added on how far noncontiguous areas are included within the surrounding areas; and areas of high impervious surfaces but with smaller population density were incorporated with surrounding areas and included with the urban designation. No adjustment was made to the 1990 and 2000 census data to account for these changes, which were considered minor for the purpose of the analysis. While the term urban land may be perceived as an area typically associated with large cities, the current census definition includes suburban, exurban, and rural communities.

Figure 3-3. Percent census-defined urban land by county, 2010 (top), and percent change in urban land, 1990 to 2010 (bottom), for the conterminous United States.



Source: U.S. Census Bureau (2013).

Urban Land Trends

By 2010, more than 80 percent of the U.S. population lived in urban areas, an increase from 75 percent in 1990 (figure 3-3). Urban land also expanded during that time. Between 1990 and 2010, urban land area in the United States increased from 2.1 percent (47 million acres [19 million ha]) in 1990 to 3.0 percent in 2010 (68 million acres [28 million ha]) (table 3-2). This growth averaged 1.1 million acres per year (446,000 ha per year) in the 1990s and 1.0 million acres per year (405,000 ha per year) in the 2000s. Comparing percent developed land and percent urban land in table 3-2 clearly shows that urban land occupies less of the land area, but the relative percent change of the 20-year period is usually higher than for developed land growth because the percent increases tend to be from a much smaller base. Urban land in 2010 still accounted for a relatively small proportion of the total U.S. land base, despite overall growth.

Urban growth comes at the expense of other land covers and uses. Between 2000 and 2010, the urban expansion mostly occurred within NLCD classes of developed land (36.2 percent), agricultural land (22.7 percent), forest land (21.0 percent), shrub/scrub and grassland (12.0 percent), wetlands (7.0 percent), and barren land (1.0 percent). This expansion was somewhat different from the urban growth between 1990 and 2000, when most of the urban expansion occurred within forest land (33.4 percent), followed by agricultural land (32.7 percent), developed land (15.1 percent), other lands (14.0 percent), and wetlands (4.9 percent) (Nowak et al. 2005).

The greatest urban growth typically occurred in States with the largest amount or percent of urban land. Growth at the county level was highest in and around the most urbanized areas (table 3-2; figure 3-3). States with the greatest amount of urban land in 2010 were the larger States of Texas (5.6 million acres [2.3 million ha]), California (5.3 million acres [2.1 million ha]), and Florida (4.7 million acres [1.9 million ha]). States with the greatest percent of urban land are in the Northeast: New Jersey (39.8 percent), Rhode Island (38.7 percent), and Massachusetts (38.0 percent). The greatest amount of urban land growth from 1990 to 2010 occurred in Texas (1.9 million acres [784,000 ha]), Florida (1.8 million acres [745,000 ha]), and Georgia (1.4 million acres [564,000 ha]), while the greatest growth in percent urban occurred in Nevada (128.6 percent), Delaware (91.4 percent), and North Carolina (87.8 percent).

Across the NRI, NLCD, and census urban data sources, the continuing trend of increasing development and urbanization is evident and consistent. In particular, the growth of urbanization and development is more pronounced in the regions already high in developed and urban lands such as the megalopolis region extending along the Northeast coast and throughout the South.

Urban Land Projections

Urban land expansion is associated with population and economic growth. A previous RPA Assessment (USDA Forest Service 2007) presented a projection of urban growth from 2000 to 2050 based on county growth patterns between 1990 and 2000 (Nowak et al. 2005). We present projections using similar methods to project urban growth from 2010 to 2060 based on average percent urban growth in counties between 1990 and 2010 (table 3-3; figure 3-4).

Table 3-3. Percent urban land cover by State and RPA region, 2010, and projected, 2020 to 2060.

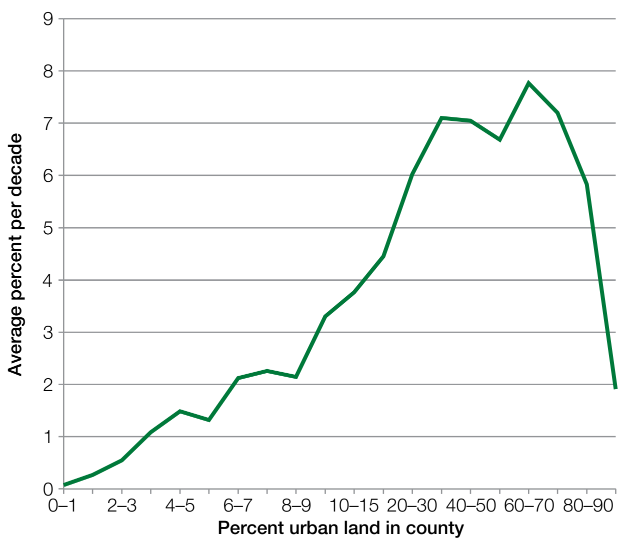
State	2010	2020	2030	2040	2050	2060	2010–2060
	percent urban land cover						*percent change*
Connecticut	37.7	43.6	49.6	55.6	60.9	65.3	73.3
Delaware	20.9	25.4	30.3	36.7	43.0	50.1	140.2
Maine	1.2	1.5	1.9	2.4	3.0	3.7	222.4
Maryland	20.7	24.3	28.5	33.0	37.8	42.5	105.9
Massachusetts	38.0	43.5	48.1	52.3	56.5	60.7	59.6
New Hampshire	7.2	8.9	10.7	12.8	15.1	17.7	145.8
New Jersey	39.8	44.7	49.6	54.4	58.6	62.4	56.9
New York	8.7	10.3	12.1	14.1	16.2	18.6	113.1
Ohio	10.8	12.8	15.1	17.6	20.4	23.5	117.6
Pennsylvania	10.5	12.6	15.0	17.7	20.6	23.9	126.5
Rhode Island	38.7	46.0	52.6	59.3	66.6	73.5	90.0
Vermont	1.7	2.1	2.6	3.3	4.0	5.0	195.2
West Virginia	2.7	3.4	4.4	5.5	6.9	8.4	216.5
Northeast	10.7	12.6	14.7	17.0	19.4	22.1	105.8
Illinois	7.1	8.2	9.6	11.0	12.8	14.8	107.5
Indiana	7.0	8.5	10.3	12.4	14.8	17.5	149.0
Iowa	1.7	2.1	2.7	3.3	4.0	5.0	193.1
Michigan	6.4	7.7	9.1	10.7	12.4	14.4	125.4
Minnesota	2.2	2.6	3.1	3.6	4.2	4.9	128.5
Missouri	3.0	3.6	4.3	5.1	6.1	7.2	141.4
Wisconsin	3.5	4.3	5.2	6.3	7.6	9.2	163.6
North Central	4.1	4.9	5.9	7.0	8.2	9.7	135.2
RPA North	**6.6**	**7.8**	**9.1**	**10.7**	**12.4**	**14.2**	**117.4**
Florida	13.7	17.2	20.5	24.0	27.8	31.6	130.9
Georgia	8.3	9.7	11.3	12.9	14.8	16.9	104.2
North Carolina	9.5	11.5	13.9	16.6	19.7	23.1	144.0
South Carolina	7.9	9.9	12.3	15.0	18.1	21.6	172.6
Virginia	6.8	7.9	9.1	10.5	12.0	13.8	104.0
Southeast	9.5	11.6	13.7	16.1	18.8	21.8	129.1
Alabama	4.4	5.5	6.9	8.5	10.3	12.5	187.0
Arkansas	2.1	2.7	3.3	4.2	5.2	6.4	203.4
Kentucky	3.6	4.4	5.4	6.5	7.8	9.4	164.1
Louisiana	4.6	5.7	7.0	8.6	10.5	12.8	179.0
Mississippi	2.4	3.0	3.8	4.8	6.0	7.4	213.0
Oklahoma	1.9	2.3	2.8	3.4	4.1	4.9	155.9
Tennessee	7.0	8.6	10.4	12.4	14.8	17.4	147.7
Texas	3.3	4.1	4.8	5.7	6.7	7.8	132.9
South Central	3.4	4.2	5.1	6.2	7.4	8.8	156.7
RPA South	**5.1**	**6.2**	**7.5**	**8.9**	**10.6**	**12.4**	**142.6**
Kansas	1.2	1.5	1.8	2.2	2.6	3.1	162.4
Nebraska	0.7	0.9	1.1	1.3	1.6	1.9	172.4
North Dakota	0.3	0.4	0.5	0.6	0.8	1.0	271.5
South Dakota	0.3	0.4	0.6	0.7	0.9	1.1	276.6
Great Plains	0.6	0.8	1.0	1.2	1.5	1.8	189.3

Table 3-3. Percent urban land cover by State and RPA region, 2010, and projected, 2020 to 2060. (continued)

State	2010	2020	2030	2040	2050	2060	2010–2060
	percent urban land cover						*percent change*
Arizona	1.9	2.5	3.0	3.9	4.8	5.9	206.7
Colorado	1.5	1.9	2.4	3.0	3.7	4.5	208.3
Idaho	0.6	0.8	1.0	1.3	1.6	2.0	229.4
Montana	0.2	0.3	0.4	0.5	0.7	0.8	296.3
Nevada	0.7	0.9	1.2	1.6	1.9	2.1	198.2
New Mexico	0.7	0.9	1.1	1.3	1.6	2.0	193.2
Utah	1.1	1.4	1.7	2.1	2.5	2.9	162.8
Wyoming	0.2	0.3	0.4	0.4	0.5	0.6	208.6
Intermountain	0.8	1.1	1.4	1.7	2.1	2.6	204.4
RPA Rocky Mountain	**0.8**	**1.0**	**1.3**	**1.6**	**2.0**	**2.4**	**201.2**
Oregon	1.2	1.4	1.8	2.3	2.8	3.4	194.9
Washington	3.6	4.5	5.6	6.9	8.4	9.9	176.8
Pacific Northwest	2.1	2.7	3.4	4.1	5.1	6.1	182.5
California	5.3	6.6	8.2	9.9	12.0	14.4	173.4
Pacific Southwest	5.3	6.6	8.2	9.9	12.0	14.4	173.4
RPA Pacific Coast	**3.7**	**4.6**	**5.7**	**7.0**	**8.5**	**10.2**	**176.1**
District of Columbia	100.0	100.0	100.0	100.0	100.0	100.0	0.0
Conterminous United States	**3.6**	**4.4**	**5.2**	**6.2**	**7.4**	**8.6**	**141.2**

RPA = Resources Planning Act.

Figure 3-4. Average absolute growth in percent urban land per decade by percent urban land categories for the conterminous United States, 1990 to 2010.



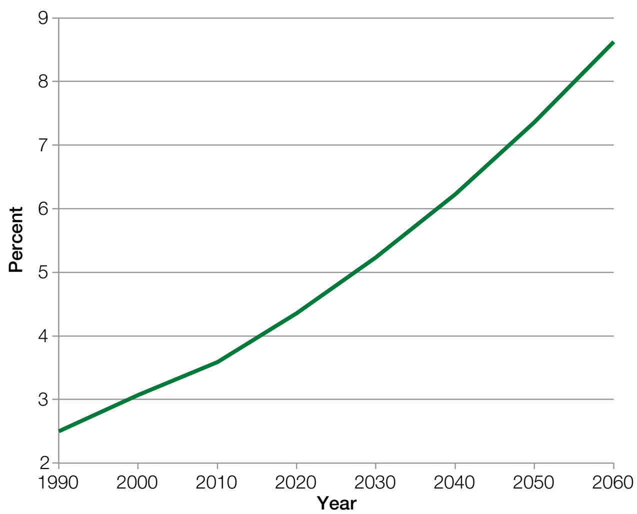
Source: U.S. Census Bureau (2013).

Urban land in 1990, 2000, and 2010 was mapped to analyze the percent of urban growth by county. Patterns of urban growth reveal that the increase in percent urban land within counties (1990 to 2010) tended to increase with percent of the county classified as urban (figure 3-4). The steep decline after 80 percent urban may indicate a threshold for urban land, although it should be noted that urban area includes open areas such as parks (e.g., Central Park in New York City). This average growth pattern for the 1990-to-2010 period was applied to individual counties across the United States based on the percent of the county classified as urban to project urban growth in 10-year increments for the period 2010 to 2060.

These projections are based on national average urban growth within counties with varying levels of urbanization, and assume the growth trends of the 1990-to-2010 period will continue, by decade, until 2060. Using a national average to project urban growth will underpredict growth in areas that develop rapidly (above average growth relative to their percent urban) in the next several decades and overpredict growth in areas with below average development relative to their percent urban. The projections also increase in uncertainty the further the projections go into the future. The projections, however, reveal the likely pattern of development across the landscape if past growth trends continue. These trends may vary in the future, given changes in land development policies (e.g., SmartGrowth initiatives); changes in land value, interest rates, and fuel prices; ecosystem limitations (e.g., water shortages); and other social, economic, or environmental factors. Although various factors may alter the projections of urban growth, increasing rates and amounts of urban development and associated transformation of forest and other land cover types will occur in the future to accommodate a growing population.

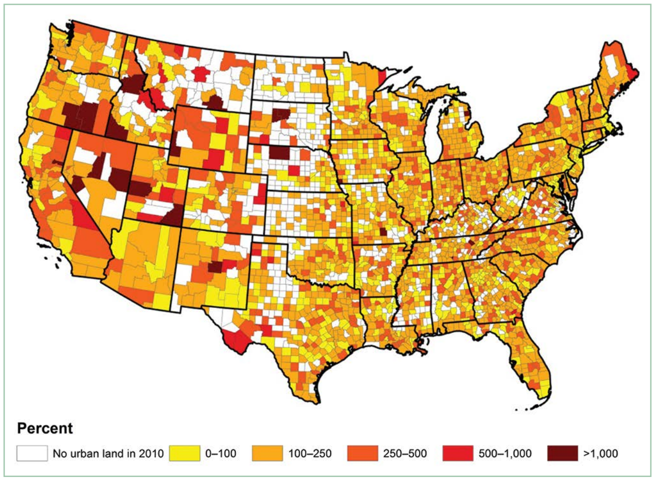
Based on the average urban land growth (table 3-2), the percent of urban land in the conterminous United Stated is projected to increase from 3.6 percent (68 million acres [27 million ha]) in 2010 to 8.6 percent (163 million acres [66 million ha]) in 2060 (table 3-3; figure 3-5). The greatest amount of projected urban land growth (2010 to 2060) will occur in California (9.1 million

Figure 3-5. Increase in percent urban land for the conterminous United States, actual, 1990 to 2010, and projected, 2010 to 2060.



Source: U.S. Census Bureau (2013).

Figure 3-6. Projected percent change in percent urban land by county, 2010 to 2060.



acres [3.7 million ha]), Texas (7.4 million acres [3.0 million ha]), and Florida (6.0 million acres [2.4 million ha]). The greatest projected relative change in percent urban will occur in Montana (296 percent), South Dakota (279 percent), and North Dakota (276 percent), but these percent increases are from a very small urban land base (table 3-3). The growth was not uniform within States and varied among counties (figure 3-5). Growth is concentrated within and around the more urbanized counties in 2010.

Including two decades of historic data resulted in a slight decline in projected growth compared with applying the same methods using only data from 1990 to 2000 (Nowak et al. 2005). The decade of 2000 to 2010 had a lower rate of growth that was influenced by the economic recession in the second half of the decade. The differences are not large. Using only 1990-to-2000 data, urban land in 2050 was projected to be 8.1 percent instead of 7.4 percent in the conterminous United States. In general, the projected increases are lower using both decades of data at both the State and regional levels. One exception is Delaware, where urban land growth is higher in the updated analysis by about 10.0 percent.

Similar to the situation with historical changes, projected percentage changes at the county level are much more variable than projected State-level changes (figure 3-6). The highest rates of percent change tend to be a function of very small urban acreages in 2010. The relative changes can seem extremely large, but those numbers should be considered in relation to the absolute change in urban area.

Protected Areas in the United States

- Improved maps of protected areas showed 16 percent of the total area of the United States was protected under IUCN standards.
- In the conterminous United States, 18 percent of total forest cover area was protected under IUCN standards, and 58 percent of the total area protected under IUCN standards had forest cover.
- Most of the increase of protected area with designated protection since the 2010 RPA is attributable to improved maps and additional classification of the existing protected areas, not to the addition of more protected area.

The status of protected areas in the United States was reported in the 2010 RPA. This section summarizes the most recent update of the Nation's protected areas by owner type and IUCN designation. For consistency with the 2010 RPA, the summary used version 2.0 of PAD-US (Conservation Biology Institute 2012). PAD-US includes detailed maps of the known protected areas for all 50 States, along with the status of each protected area according to guidelines developed by IUCN (see the sidebar, Definition of International Union for Conservation of Nature Categories for the Protected Areas Database of the United States, with IUCN categories and definitions). The summary included legally decreed ("designated") conservation land and did not include proposed or potential conservation land.

Forests and rangelands of the United States are in protected status for a variety of purposes, but primarily to preserve functioning natural ecosystems, provide refuges for species, and maintain ecological processes (Henifin 2012). Public ownership generally offers protection from conversion to more developed uses. According to PAD-US, the Federal Government holds 667 million acres (270 million ha) of land (27.5 percent of the country's total area), which includes national parks, national forests, national wildlife refuges, and other Federal agency ownerships. Most of the Federal total is administered by four agencies: Bureau of Land Management (262 million acres [106.0 million ha]), Forest Service (197 million acres [79.7 million ha]), Fish and Wildlife Service (98 million acres [39.7 million ha]), and National Park Service (80 million acres [32.4 million ha]). State governments administer a total of 187 million acres (75.7 million ha) in State parks, State forests, and other holdings. PAD-US also identifies protected areas owned by Native Americans (99 million acres [40.1 million ha]) and local governments (8 million acres [3.2 million ha]), as well as about 7 million acres (2.8 million ha) of privately owned conservation land and 4 million acres (1.6 million ha) in joint ownership. Because most of the designated IUCN class I through VI area is in Federal or State ownership, all of the other ownership types were grouped together for this analysis.

Considering all IUCN categories except "unassigned," PAD-US reveals an area of 398 million acres (161 million ha) of protected lands in the United States, or 16.4 percent of total area (table 3-4). Approximately 94.0 percent of the designated area is either Federal land (291 million acres [118 million ha]) or State land (84 million acres [34 million ha]). An additional 480 million acres (194 million ha; 19.8 percent of total U.S. area) is held in Federal and State ownership in the unassigned category. Overall, the protected lands in the East are not as extensive as in the West, primarily reflecting the distribution of Federal ownership. Of the total IUCN-protected area of 398 million acres (161 million ha), approximately 47.3 percent is in Alaska, 25.3 percent in the RPA Rocky Mountain Region, 12.6 percent in the RPA Pacific Coast Region (excluding Alaska), 8.5 percent in the RPA North Region, and 6.3 percent in the RPA South Region. Many of the statistics in table 3-4 are noticeably different from statistics shown in the 2010 RPA. Almost all of the differences arose from improved mapping and classification of existing protected areas and not from the protection of additional area. Some differences also arose because of changes to the IUCN designations of some individual protected areas.

PAD-US does not identify the specific land use or land cover that is contained in the protected areas. We used the same process as for the 2010 RPA analysis to derive comparable statistics for protected forest cover area: the PAD-US map was combined with a map of forest cover for the conterminous

Table 3-4. Protected areas from PAD-US, by ownership and RPA region.

RPA region	Owner	IUCN category (thousand acres; excludes unassigned area)							Row total
		Ia	Ib	II	III	IV	V	VI	
Alaska	Federal	216	56,875	6,840	1,785	67,270	28,349	57	161,391
	State	7	485	2,502	0	3,101	3,950	2,158	12,203
	Other	2	460	542	77	12,765	856	61	14,763
	Region total	225	57,819	9,884	1,862	83,136	33,155	2,276	188,357
North	Federal	15	1,868	865	11	1,221	650	207	4,837
	State	457	1,472	2,771	0	5,949	3,082	12,031	25,761
	Other	22	0	38	0	85	2,756	148	3,049
	Region total	494	3,340	3,674	11	7,254	6,488	12,386	33,647
Pacific Coast[a]	Federal	400	25,657	1,354	834	1,456	11,145	22	40,868
	State	146	3	1,021	16	1,257	5,309	784	8,537
	Other	0	177	2	4	81	120	151	535
	Region total	546	25,836	2,377	854	2,794	16,575	957	49,939
Rocky Mountain	Federal	568	35,108	6,008	4,501	5,176	12,732	7,781	71,874
	State	3	6	471	27	2,906	22,915	221	26,548
	Other	15	1	112	0	2,050	184	0	2,362
	Region total	585	35,115	6,590	4,527	10,132	35,832	8,002	100,784
South[b]	Federal	9	2,743	2,264	130	3,946	2,444	5	11,541
	State	192	11	975	0	6,743	1,570	1,078	10,568
	Other	53	16	236	0	1,718	608	341	2,971
	Region total	254	2,769	3,474	130	12,407	4,622	1,424	25,080
National	Federal	1,207	122,250	17,331	7,261	79,069	55,320	8,072	290,510
	State	805	1,976	7,740	43	19,955	36,827	16,272	83,617
	Other	91	654	929	81	16,699	4,524	701	23,679
	National total	2,103	124,880	26,000	7,384	115,723	96,671	25,045	397,807

IUCN = International Union for Conservation of Nature. PAD-US = Protected Areas Database of the United States. RPA = Resources Planning Act.

[a] Excludes Alaska; includes Hawaii.

[b] Excludes Puerto Rico.

Note: Entries may not sum to row or column totals because of rounding.

Source: Conservation Biology Institute (2012).

Land Definition of International Union for Conservation of Nature Categories for the Protected Areas Database of the United States

IUCN category	Definition
Ia	Strict Nature Reserve: protected area managed mainly for science.
Ib	Strict Nature Reserve: protected area managed mainly for wilderness protection.
II	National Park: protected area managed mainly for ecosystem protection and recreation.
III	Natural Monument: protected area managed mainly for conservation of specific natural features.
IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention.
V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation.
VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems.
Unassigned	In the PAD-US database, this category includes public and private lands that have been designated[a] according to IUCN protocols for further classification into one of the above categories. It includes, for example, a large share of National Forest System land and nearly all Native American land.

IUCN = International Union for Conservation of Nature. PAD-US = Protected Areas Database of the United States.

[a] Designated land does not include potential or recommended land.

Source: European Environment Agency, EIONET Data Dictionary: http://dd.eionet.europa.eu/data_element.jsp?mode=view&delem_idf=IUCNCAT&pns=47.

United States for the year 2001 (Ruefenacht et al. 2008; USDA Forest Service 2004). The forest cover area within each protected area identified by PAD-US was summarized in the same way as for total protected areas shown in table 3-4. Note that these statistics refer to forest cover area, which is defined differently from forest land area reported elsewhere in this RPA Update. These statistics also do not include Alaska or Hawaii, which complicates comparisons with table 3-4.

The forest cover map identified a total of 655 million acres (265.1 million ha) of forest cover in the conterminous United States. Of that area, 120 million acres (50.6 million ha) occurred in an IUCN category (table 3-5), which represents 57.3 percent of the total IUCN area in the conterminous United States. An additional 152 million acres (61.5 million ha) of forest cover was in the IUCN unassigned category.

Table 3-5. Area of protected forest cover from PAD-US, by ownership and RPA region in the conterminous United States.

RPA region	Owner	IUCN category (thousand acres; excludes unassigned area)							Row total
		Ia	Ib	II	III	IV	V	VI	
North	Federal	13	1,556	285	5	449	557	12	2,877
	State	360	1,449	2,574	0	3,927	2,046	11,223	21,578
	Other	12	0	37	0	67	2,575	126	2,818
	Region total	384	3,006	2,895	5	4,444	5,177	11,361	27,272
Pacific Coast[a]	Federal	260	22,091	859	822	1,129	7,773	22	32,955
	State	33	1	951	16	782	4,297	784	6,863
	Other	0	67	1	1	24	15	151	260
	Region total	293	22,159	1,811	839	1,935	12,086	957	40,078
Rocky Mountain	Federal	367	19,072	3,331	1,344	959	1,900	5,844	32,815
	State	1	3	181	2	781	2,404	213	3,584
	Other	6	1	8	0	276	100	0	391
	Region total	374	19,075	3,519	1,345	2,016	4,403	6,057	36,790
South[b]	Federal	9	1,625	810	105	2,679	1,736	5	6,971
	State	97	11	393	0	4,885	997	1,026	7,408
	Other	36	16	107	0	756	300	272	1,486
	Region total	141	1,651	1,310	105	8,321	3,033	1,303	15,865
National	Federal	649	44,344	5,285	2,275	5,216	11,966	5,883	75,618
	State	489	1,463	4,098	17	10,375	9,744	13,246	39,433
	Other	54	84	153	1	1,124	2,989	549	4,955
	National total	1,193	45,891	9,536	2,294	16,715	24,699	19,678	120,005

IUCN = International Union for Conservation of Nature. PAD-US = Protected Areas Database of the United States. RPA = Resources Planning Act.

[a] Excludes Alaska and Hawaii.

[b] Excludes Puerto Rico.

Sources: Protected areas were defined by the Conservation Biology Institute (2012); forest cover was defined by USDA Forest Service (2004).

Approximately 95.9 percent of the protected forest cover in the conterminous United States is either Federal (76 million acres [30.8 million ha]) or State (39 million acres [15.8 million ha]) land. An additional 133 million acres (53.8 million ha; 20.3 percent of total forest cover area) is held in Federal and State ownership in the unassigned category. Overall, the total protected forest cover in the East (43 million acres [17.4 million ha]) is less than the total in the West (77 million acres [31.2 million ha]). Of the total IUCN-protected forest cover area of 120 million acres (48.6 million ha), 33.4 percent is in the RPA Pacific Coast Region, 30.7 percent in the RPA Rocky Mountain Region, 22.7 percent in the RPA North Region, and 13.2 percent in the RPA South Region. These percentages differ from the percentages of all land area because a higher percentage of land area in the East is naturally forested than is in the West; protected areas are more extensive in the West, but those areas contain larger shares of nonforest land cover.

Future Work

The 2010 RPA emphasized the importance of understanding the impact of current and projected development trends on natural resources. We will continue to track trends in development and urbanization in the next RPA Assessment. Improvements in the land use modeling portion of the RPA modeling framework are being designed to model land use and land cover change at higher spatial resolution and to incorporate climate change effects. We will also continue to track trends in protected areas in the United States and better understand how their extent and spatial configuration influence the condition of forest and rangelands and their associated natural resources.

Conclusions

Because of urbanization, the U.S. national landscape is changing, and the landscapes within urban areas are also changing. Urbanization, whether measured by U.S. Census Bureau definitions or developed land definitions, has increased in the past 20 years. In the conterminous United States, between 1990 and 2010, the amount of census-defined urban land increased from 2.1 to 3.6 percent and developed land from 5.2 to 5.9 percent. During the 50-year projection period (2010 to 2060), urban land is projected to increase to 8.6 percent if urban expansion trends from the 1990-to-2010 period continue. Past and projected increases tend to be concentrated in and around existing urban areas. The role of protected areas in preserving functioning natural ecosystems, providing refuges for species, and maintaining ecological processes is likely to increase as unprotected land continues to be developed to accommodate a growing population.

Chapter 4. Forest Resources

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) reported on the extent and ownership of forest lands in the United States based on the national summary of Forest Inventory and Analysis (FIA) data to 2007 (Smith et al. 2009). In this RPA Update, we provide the most recent U.S. forest resource data, based on the national summary of FIA data to 2012 (Oswalt et al. 2014). As mentioned in Chapter 3, Land Resources, we updated the analysis of forest cover by comparing results from the 2001, 2006, and 2011 National Land Cover Database (NLCD). This analysis examines temporal changes in forest cover and landscape pattern and trends in interior forests from 2001 to 2011. We then expand the treatment of intact forest introduced in the 2010 RPA on eastern forests to all forests of the conterminous United States as of 2006. We continue to use both land use and land cover information to understand the trends in forest resources, as described in the sidebar Land Use and Land Cover: Complementary Perspectives on Forest Trends.

Highlights

- U.S. forest area increased slightly between 2007 and 2012, continuing a trend that began in the 1980s.
- Softwood growing stock continues to increase, but average net growth on growing stock trees across all ownerships has slowed by about 1 percent per year since 2006. Wildfire losses are responsible for some of the slowing growth rates.
- Forest cover fragmentation increased from 2001 to 2011, with fragmentation rates higher on private land than on public land. Interior forest cover was most heavily impacted, with a net percent loss two to seven times larger than the net percent loss of total forest cover.

Land Use and Land Cover: Complementary Perspectives on Forest Trends

Forest extent and change in forest extent are key indicators reported in the 2010 RPA and other national and international reports. Efforts to maintain and/or enhance the flow of goods and services from forest ecosystems must start with a clear understanding of the forest land base that provides these services and how that land base is changing. In the United States, many estimates of forest extent and forest change exist across a range of spatial and temporal scales. For example, some broad-scale monitoring and assessment efforts rely on forest extent as defined by land use, while other assessments rely on forest extent as defined by land cover. The 2010 RPA reported trends in both forest land use and forest land cover because each perspective offered unique information. Understanding the differences in these measures is essential for understanding the implications of observed changes in the range of goods and services forests provide. The exploration of these different but complementary metrics may yield further insights into the effects of an evolving landscape on U.S. forest conditions and service flows.

Forest land use is a function of the social, cultural, and economic purposes for which land is managed, while **forest land cover** refers to the biophysical cover observed on the land. The differences between cover-based and use-based definitions of forest can be illustrated by the two primary databases used in the 2010 RPA to track forest trends: forest land use defined by the Forest Service, Forest Inventory and Analysis (FIA) program and forest land cover as defined by the National Land Cover Database (NLCD).

The main points of divergence between these "forest" definitions are time and intent (Coulston et al. 2014). Regarding time, a **forest cover**-based definition generally relies on observed tree cover at a single time, and because these definitions are typically implemented via remote sensing, information about intent is generally not available. A **forest use**-based definition requires a human interpretation of the conditions on the ground at a single point in time regarding intended use over a broader time period. These divergences can lead to different estimates of both the extent of forest and the change in forest area reported by monitoring and assessment activities.

A suite of drivers causes estimates of forest land use and forest land cover extent to diverge and/or converge; these drivers depend on the classification scheme used, human activities, and natural disturbances. The explicit notion of intent in use-based definitions often creates divergences in comparing use and cover at a point in time. Forest management practices, such as harvest and replanting, and natural disturbances such as hurricanes and insect outbreaks, do not usually change the management intent, and therefore the forest use. They do cause short-term fluctuations in tree cover, however, which is considered a change from a land cover perspective. On the other hand, some land conversions (e.g., forest to urban) usually represent a change in both land use and land cover.

Localized divergence between land use and land cover measures may further inform our understanding of landscape change. Declines in forest cover coupled with increases in use may signal an intensification of management activity. Persistent declines in forest cover following wildfire may foretell a shift in biome/use associated with regeneration failure. Forest cover patterns associated with urban and developed land uses signal the quality of ecosystem services in expanding cities.

The 2010 RPA recognized the unique perspectives provided by the FIA and NLCD databases. FIA provides official forest land statistics for the Nation, and because it is made up of an extensive field sampling system, it can provide a wealth of detail about forests—tree species and sizes, land ownership, and other details—when humans actually visit the field plots to record data. Most of the forest analyses in this assessment are based on FIA and forest land use. By comparison, the NLCD is derived primarily from satellite images and can describe the places, albeit without the detail from human interpretations. The strength of the NLCD is that it provides complete geographic coverage, which is a desirable feature for analysis of landscape patterns, forest fragmentation, and other spatial attributes of the forest. With the recent redevelopment of the FIA program into a nationally consistent inventory system, and the recent deployment of the NLCD as a national land cover monitoring program, it is increasingly possible to merge the data sources in creative ways, to leverage the unique potential of each type of data, and thereby improve forest assessments.

Forest Land Base

- ❖ U.S. forest area increased slightly between 2007 and 2012.
- ❖ The proportion of timberland area occupied by sawtimber-sized trees has increased consistently in the North and South since the 1950s.
- ❖ Nationwide, the amount of softwood growing stock has increased modestly—about 3 percent—since 2007, but the increase was tempered by losses from wildfire.

Total forest area increased roughly 1 percent between 2007 and 2012, to a total of 766 million acres (310 million hectares [ha]). This increase is a continuation of the upward trend reported in the 2010 RPA Assessment. (The forest area definitions in this RPA Update follow international definitions that distinguish between forest and woodlands; see the sidebar Changes in Definitions for RPA Forest Database). Although the national trend is upward, considerable regional variation exists. Most States gained or lost less than 5 percent of forest area. The Great Plains States experienced the largest percent gains, but, because these States tend to have relatively little forest area in proportion to the size of the State, the absolute change is small. Only Delaware and New Jersey experienced losses of more than 5 percent, but the total affected acreage is also small. Regional changes were within 1 percent of 2007 forest area estimates in all RPA regions except the North Region, which experienced a 2-percent change (Oswalt et al. 2014).

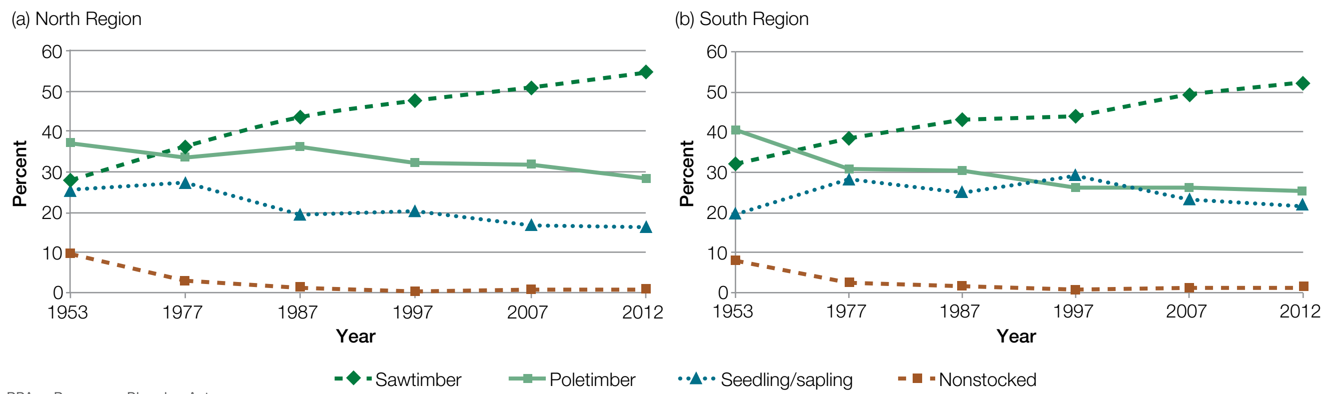
Timberland area also has increased about 1 percent since 2007. Although the area increase is small, the characteristics of timberland are changing. The proportion of timberland area occupied by sawtimber-sized trees has increased consistently in the RPA North and South Regions since the 1950s, accompanied by a slow but steady decline in the proportional area occupied by poletimber, seedlings, and saplings (figure 4-1). This structural change has been a source of concern about the habitat of wildlife species that depend on early-successional forest characteristics for portions of their life cycles. By comparison,

Changes in Definitions for RPA Forest Database

Trends in forest area and characteristics for the 2010 RPA are based on international definitions to maintain consistency with U.S. reporting to organizations such as the Food and Agriculture Organization. The most recent compilation of forest statistics from the Forest Inventory and Analysis (FIA) database reassigns portions of what FIA currently calls "forest" to a class called "woodlands." This new class also returns chaparral to the RPA statistics as other land. Chaparral was removed from RPA reporting in 1997 because it did not meet the minimum standards of forest land and was not recognized by the Society of American Foresters as a forest type (Eyre 1980). Future reports will more fully populate and describe the woodlands land class as well as urban treed land and other land. It is important to note that this classification change of some FIA forest areas to woodlands does not affect current or historic timberland area or volume statistics. In general, it affects wooded areas in the arid regions of the Southwestern United States (predominantly portions of Arizona, southern Colorado, Nevada, New Mexico, west Texas, and Utah) where tree species are not expected to achieve a minimum height at maturity in situ (Oswalt et al. 2014).

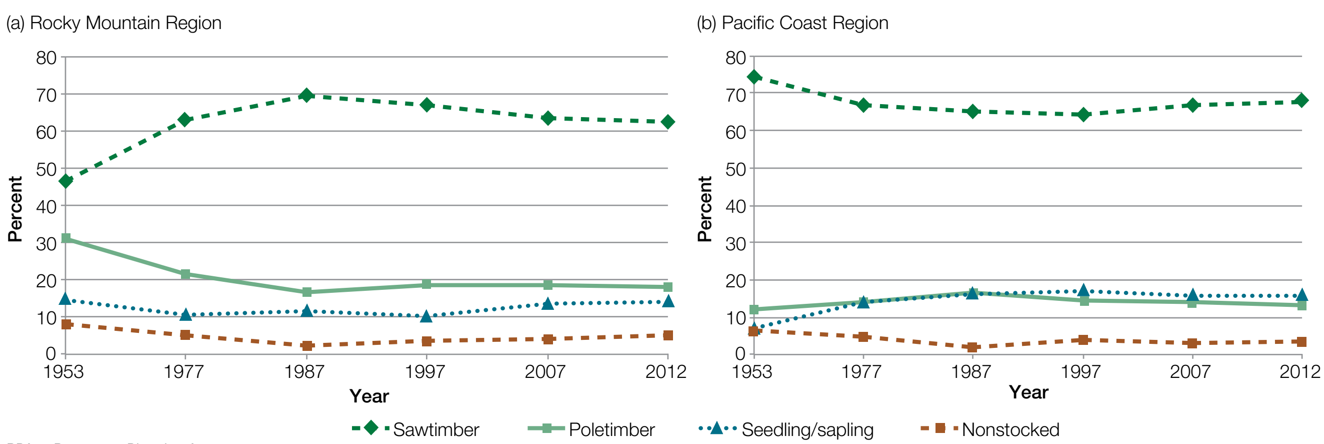
western and Pacific coast forests do not have consistent trajectories (figure 4-2). In the RPA Rocky Mountain Region, the proportional sawtimber component increased through the 1970s and then began to decline slowly, whereas the seedling/sapling area slowly increased. Forests in the RPA Pacific Coast Region, including those in Hawaii and Alaska, have remained proportionally similar since the 1960s (Oswalt et al. 2014).

Figure 4-1. Percent of timberland by stand-size class in RPA (a) North and (b) South Regions, 1953 to 2012.



RPA = Resources Planning Act.
Source: Oswalt et al. (2014).

Figure 4-2. Percent of timberland by stand-size class in RPA (a) Rocky Mountain and (b) Pacific Coast Regions, 1953 to 2012.



RPA = Resources Planning Act.
Source: Oswalt et al. (2014).

The 766 million acres (310 million ha) of U.S. forest land are owned by an array of private and public entities. The distribution of forest land by ownership has not changed appreciably since the 2010 RPA, nor has the geographic distribution of ownership. Most forest land—58 percent—continues to be privately owned, and the remainder is under the control of Federal, State, and local governments. Private ownership dominates in the RPA North and South Regions (74 and 87 percent of the forest land, respectively), and public ownership dominates in the RPA Rocky Mountain Region (74 percent) and the RPA Pacific Coast Region, including Alaska and Hawaii (67 percent) (figure 4-3 and table 4-1).

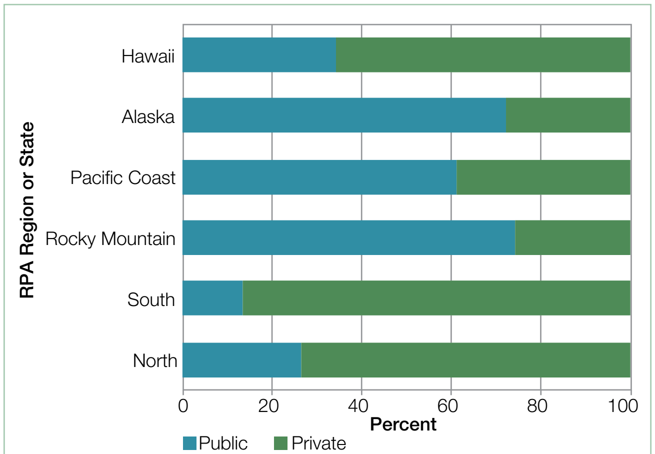
The forests of the United States are diverse in type, stature, and function according to the climates and biophysical settings they inhabit. In the Eastern United States, oak/hickory forests constitute the largest forest-type group (34 percent of forest land area), followed by the pine forests of the Deep South and the mixed maple/beech/birch forests of the North. In the conterminous Western United States, Douglas-fir forests occupy the largest proportion of land area (18 percent), followed by mixed western hardwoods and pinyon/juniper forests (17 and 15 percent, respectively). Alaska's extensive boreal forests are dominated by mixed western softwoods and fir/spruce (45 and 34 percent, respectively) (Oswalt et al. 2014).

Softwood growing stock volume continued to increase and total timberland volume continued to exceed 1 trillion cubic feet (28 billion cubic meters). Nationwide, softwood growing stock has experienced a modest increase of about 3 percent since 2007, but that increase has been tempered by losses from wildfire. The RPA North and South Regions contain 61 percent of the Nation's timberland volume. In both those regions, hardwoods comprise the majority of timber volume. Conversely, in the Rocky Mountain Region and the Pacific Coast Region (including Alaska and Hawaii), softwoods comprise the majority of timber volume (figure 4-4) (Oswalt et al. 2014).

The vast majority of forest land in the United States regenerates naturally. Only 9 percent of total forest land (13 percent of timberland) is planted, an area that has increased by about 4 percent since 2007. The RPA South Region accounts for 72 percent of planted timberland in the Nation. The ownership of planted forests differs markedly by region. Of planted forest land, 95 percent is privately owned in the RPA South Region, predominately by corporate interests. By contrast, 63 percent of planted forests in the RPA North Region are privately owned, predominately by noncorporate interests. In the RPA Rocky Mountain Region, 61 percent of planted forest is publicly owned, predominately by the National Forest System, but, in the RPA Pacific Coast Region, 59 percent of planted forest land is privately owned, primarily by corporate interests (Oswalt et al. 2014).

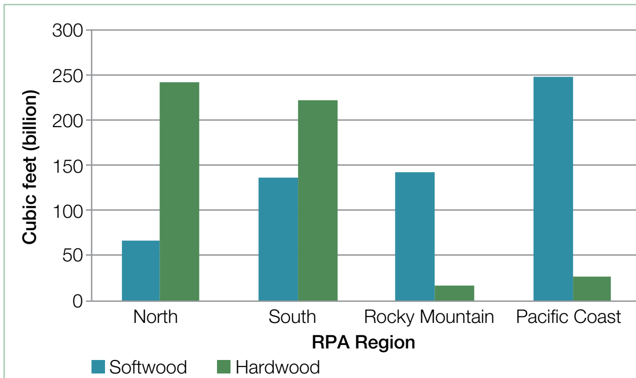
Private forests provide more than 90 percent of the Nation's wood and paper products. By contrast, national forests provide less than 2 percent of the country's wood and paper products. In general, private forests are more productive than comparable publicly owned forests. Private forests tend to be located on

Figure 4-3. Forest ownership patterns, by RPA region,[a] 2012.



RPA = Resources Planning Act.
[a] Alaska and Hawaii are not included in the RPA Pacific Coast acreage.
Source: Oswalt et al. (2014).

Figure 4-4. Total volume of timberland, by RPA region and major species group, 2012.



RPA = Resources Planning Act.
Source: Oswalt et al. (2014).

Table 4-1. U.S. forest land area by ownership and RPA region, 2012.

Ownership	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region[a]	Alaska	Hawaii
	acres (millions)					
Public	46.5	32.7	97.5	51.4	92.5	0.6
Private	129.1	212.0	33.8	32.9	36.1	1.2

RPA = Resources Planning Act.
[a] Alaska and Hawaii are not included in the RPA Pacific Coast Region acreage.

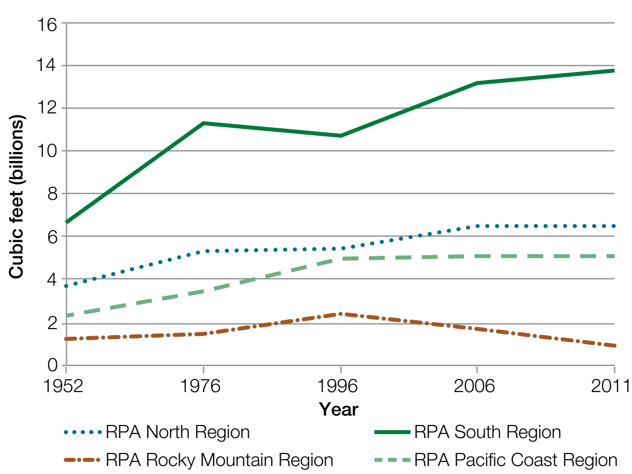
higher quality sites and have annual growth potentials that, on average, are 17 percent higher than the growth potential on public forests. Further, private forests are achieving 56 percent of their potential annual growth compared with only 28 percent for public forests. Overall, private forest owners control 56 million acres (23 million ha) of planted forests—mostly pine, spruce, and fir (Oswalt et al. 2014).

Forest Health

- ❖ Nationwide, average net growth on growing stock trees across all ownerships has slowed by about 1 percent annually since 2006.
- ❖ Mortality caused by insects and diseases has been reported on a declining number of forest acres since 2009.

The 2010 RPA provided a broad overview of major trends and issues related to forest health. In this RPA Update, we provide the most current data from FIA on forest mortality and more recent information from the Forest Service, Forest Health Monitoring (FHM) program. The latest FIA data indicate that softwood mortality increased during the reporting period in the Intermountain West and hardwood mortality increased in the Northeast. Average net growth on growing stock trees across all ownerships nationwide has slowed by about 1 percent annually since 2006. This national trend is driven by growth declines in the RPA Rocky Mountain Region, whereas average annual growth is increasing in all other regions (figure 4-5). Average annual net growth in the RPA Rocky Mountain Region has slowed by 48 percent since 2007, a change that can be attributed to large increases in mortality due to mountain pine beetle (MPB) infestations (Oswalt et al. 2014).

Figure 4-5. Net annual growth of growing stock on timberland, by RPA region, 1952 to 2011.



RPA = Resources Planning Act.
Source: Oswalt et al. (2014).

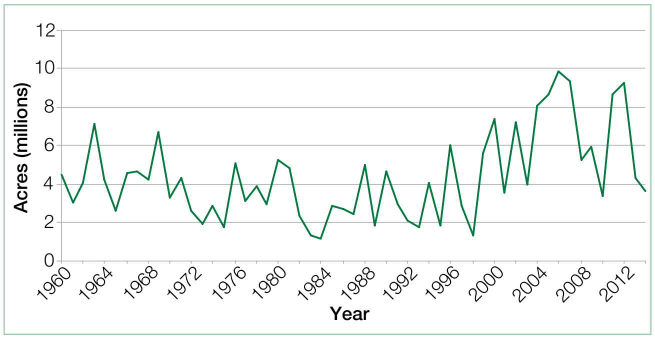
Softwood mortality in the RPA Rocky Mountain Region increased by 57 percent between 2006 and 2011; the increase between 1996 and 2011 was 92 percent. Hardwood mortality in the region has decreased. Within the region, mortality is highest in the MPB-affected States of Colorado, Idaho, Montana, Utah, and Wyoming, affecting large stands of mature lodgepole pine trees in the States. Mortality estimates for the RPA Intermountain Subregion also capture mortality that occurred during the peak activity of the MPB, which spanned from 2008 through 2010. Although tree mortality has increased significantly in the RPA Intermountain West Subregion, average annual mortality rates in the subregion are still in the range of 0.6 to 2.0 percent of total growing stock volume. That value is compared with values in the RPA North and South Regions, where mortality ranges from 0.4 to 1.4 percent. The overall average tree mortality rate in the United States is currently 0.9 percent of total growing stock volume (Oswalt et al. 2014).

Current reports from the FHM program indicate that mortality has tapered off in recent years. Mortality caused by insects and diseases has been reported on a declining number of acres since 2009, when mortality was reported on 11.7 million acres (4.7 million ha) (Potter 2013). In 2013, mortality was reported on nearly 3.8 million acres (1.5 million ha) nationwide. The MPB caused slightly more than 42 percent of the mortality. In addition to the 1.6 million acres (648,000 ha) of mortality from MPB (a decrease of 779,000 acres [315,400 ha] from 2012), the western spruce budworm caused nearly 1.7 million acres (688,000 ha) of defoliation damage in 2013, a 1.9-million-acre (754,000 ha) decrease from 2012. European gypsy moth defoliation was reported on nearly 574,000 acres (232,000 ha) in 2013, an increase from the 39,193 acres (15,868 ha) reported in 2012 (Potter and Paschke 2015a, 2015b). A single defoliation event does not usually cause tree mortality; however, taken together with continued attacks or severe abiotic factors, such as weather and drought, trees can succumb to these defoliating insects (Jenkins 2015). Additional information on forest health is available at http://www.fs.fed.us/foresthealth/monitoring/index.shtml.

Wildfire continues to be a major disturbance in many forests of the United States. In the 2010 RPA, forested area burned in 2006 was the largest fire-affected acreage during the period from 1960 to 2010. More recently, fires in both 2011 and 2012 burned areas close to the 2006 total (figure 4-6). Growing scientific evidence indicates that climate change will increase the number and size of wildfires, globally and in North America (Dale et al. 2001; Liu et al. 2014b).

The most recent National Climate Assessment synthesized current scientific knowledge about climate change and forest disturbances (Joyce et al. 2014b). A key message was that climate change is increasing the vulnerability of many forests to ecosystem changes and tree mortality through fire, insect

Figure 4-6. Total area of wildfires in the United States, 1960 to 2014.



infestations, drought, and disease outbreaks. The potential for both warmer temperature and drought is likely to increase tree mortality. Relationships between climate and fire suggest that western forests are likely to be increasingly affected by large and intense fires. Although eastern forests are less likely to experience increases in wildfire, a combination of increasing temperatures, seasonal dry periods, protracted drought, and/or insect damage that triggers wildfire could also occur.

Temporal Changes in Forest Cover Fragmentation

- Forest cover fragmentation increased from 2001 to 2011.
- The net percent loss of interior forest cover was two to seven times larger than the net percent loss of total forest cover, depending on the scale at which interior forest was measured.

Many of the ecological values that come from forested landscapes depend on how the forest area is arranged throughout the landscape—on forest spatial patterns and fragmentation (Forman and Alexander 1998; Harper et al. 2005; Laurance 2008; Murcia 1995; Ries et al. 2004). For example, most forests are naturally extensive, and, as they become fragmented, their ability to support ecological values is reduced by the loss of interior forest conditions. The isolation of disconnected forest parcels reduces ecological continuity between them, and the juxtaposition of forest with human land uses increases the risk of forest degradation from nearby human activities. Thus, spatial-temporal trends in forest patterns are often taken as leading indicators of subordinate ecological conditions (Council on Environmental Quality 1993; Heinz Center 2008; Millennium Ecosystem Assessment 2005; USDA Forest Service 2011).

Forest patterns usually vary with the spatial scale over which they are measured. For example, a highly fragmented large landscape may contain smaller areas that are not fragmented. While knowledge of fragmentation at a single scale is required to understand ecological processes at that scale, a multiple-scale analysis can inform a wider range of ecological questions by identifying the scales over which forest fragmentation can be said to exist. Thus, the RPA Assessment uses multiple-scale analysis, because the goal is to assess potential impacts of forest fragmentation on many ecological values.

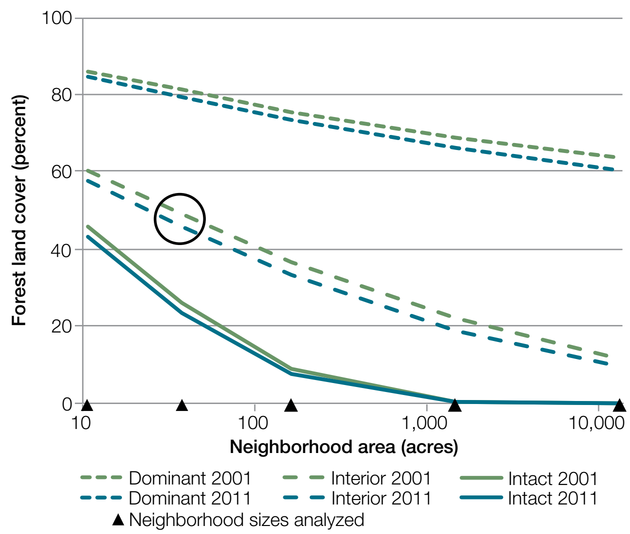
The 2010 RPA reported the fragmentation of the Nation's forest based on analysis of national land cover maps from 2001 (USDA Forest Service 2012a). At that time, forest cover tended to be the dominant land cover type where it occurred, yet fragmentation was so pervasive that only 9.5 percent of all forest cover existed within a fully forested 162-acre (65.6 ha) neighborhood, and 28 percent of it was within 100 feet (30 m) of a different type of land cover. For this report, new land cover maps permitted analysis of forest fragmentation changes over time. Included in the new analysis were the 2001 and 2011 NLCD land cover maps for the conterminous United States (Homer et al. 2007; Jin et al. 2013).

Following the same general procedures that were used in the 2010 RPA (Riitters 2011), the 2001 and 2011 NLCD land cover maps (USGS 2014b, 2014d) were analyzed to identify and map forest fragmentation. Forest was assumed to consist of four NLCD land cover types: (1) deciduous forest, (2) evergreen forest, (3) mixed forest, and (4) woody wetlands. A pattern metric known as "forest cover density" was used to describe 0.22-acre (0.09-ha) parcels on the 2001 and 2011 land cover maps by the proportion (P) of a surrounding neighborhood that was forest cover. The analyses were repeated using five neighborhood sizes: 11 acres (4.41 ha), 38 acres (15.21 ha), 162 acres (65.61 ha), 1,460 acres (590.49 ha), and 13,100 acres (5,314.41 ha). The 2001 and 2011 maps of forest cover density were then intersected with the original land cover maps to extract values of forest cover density for the forest parcels in 2001 and 2011. The extracted values were then expressed as the percentages of total forest cover in 2001 and 2011 that met the criteria for intact ($P = 1.0$), interior ($P \geq 0.9$), and dominant ($P \geq 0.6$) forest cover density (figure 4-7).

Between 2001 and 2011, the percentages of forest cover area meeting the criteria for intact, interior, and dominant forest decreased for all five neighborhood sizes, which implies that a higher percentage of forest cover occurred in less forested neighborhoods ($P < 0.6$) in 2011 compared with 2001. According to the NLCD land cover maps, the total forest cover in 2001 was 581.3 million acres (235.3 ha). Forest cover gains and losses between 2001 and 2011 resulted in a net loss of 17.2 million acres (7.0 million ha) or 1.1 percent of total forest cover in 2001. Figure 4-7 shows more fragmentation of the extant forest in 2011 compared with 2001 over a wide range of spatial scales and for three fragmentation criteria.

Trends in interior forest conditions are of particular concern because of the ecological values that relatively unfragmented forests support (Riitters and Wickham 2012). Such trends are more interpretable when changes of interior forest cover are compared with changes of total forest cover. By comparison with the net loss of 17.2 million acres (7.0 million ha) (3.0 percent) of total forest cover since 2001, the net loss of interior forest cover was at least 13.4 million acres (5.4 million ha), with a maximum loss of 26.1 million acres (10.6 million ha) for the 162-acre (65.61-ha) neighborhood size (table 4-2). The percentage loss of interior forest cover was approximately two to seven times larger than the percentage loss of total forest cover. The rate of loss increased with neighborhood size, because larger neighborhoods had less interior forest cover in 2001.

Figure 4-7. Summary of forest cover fragmentation in the conterminous United States for five neighborhood sizes in 2001 and 2011. The circle indicates conditions highlighted in the 38-acre scale in figure 4-8.



Note: Except for the exclusion of Alaska, Hawaii, and Puerto Rico, this chart is comparable to the forest statistics shown in figure 23 in the 2010 RPA (USDA Forest Service 2012a).
Sources: National Land Cover Database, 2001 and 2011.

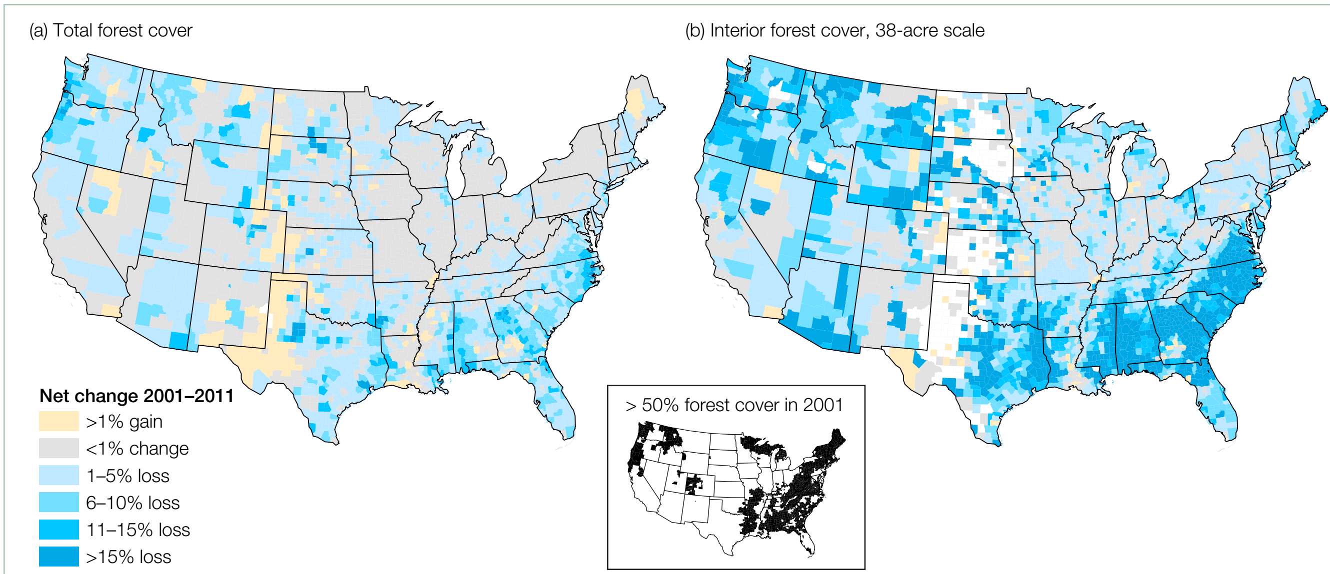
Figure 4-8 illustrates the geography of net changes of both total and interior forest cover. Most of the forest-dominated counties in the conterminous United States exhibited a net loss of total forest cover, while net gains were concentrated in counties where forest was not the dominant land cover in 2001 (figure 4-8a). By comparison, the 38-acre (15.21-ha) neighborhood size had a net loss of interior forest cover in 2,665 of 3,109 counties; 1,425 counties exhibited losses of greater than 5 percent and

Table 4-2. Scale-dependent change in interior forest cover in the conterminous United States, 2001 to 2011. Interior forest was measured at five spatial scales defined by neighborhood size and was summarized for the conterminous United States.

Neighborhood size	Interior forest cover			
	2001	2011	Change from 2001 to 2011	
acres	*acres (millions)*			*percent*
11	350.2	325.9	– 24.3	– 7.0
38	283.9	257.7	– 26.1	– 9.2
162	213.3	187.6	– 25.7	– 12.0
1,460	127.8	107.8	– 20.0	– 15.7
13,100	67.0	53.6	– 13.4	– 20.0

Sources: National Land Cover Database, 2001 and 2006.

Figure 4-8. Net change in forest cover for (a) total forest and (b) interior forest in a 38-acre-scale neighborhood, 2001 to 2011. Counties are shaded and State boundaries are shown for comparison. Counties without color had none of the indicated forest cover in 2001 and/or 2011. In the inset map, forest-dominated counties are those that contained more than 50 percent forest in 2001.



Sources: National Land Cover Database, 2001 and 2011.

652 counties had losses of greater than 15 percent (figure 4-8b). In forest-dominated areas of the Nation, interior forest cover losses greater than 10 percent were typical in the RPA Pacific Northwest Subregion and the northern portion of the RPA Intermountain Subregion, while losses greater than 15 percent were typical in the RPA South Region. Smaller percentages of loss (less than 5 percent) were common in the central RPA Intermountain Subregion and the RPA North Region. The RPA Intermountain and Great Plains Subregions had relatively low total forest cover, and the interior forest cover changes in those subregions had relatively little influence on national statistics. The nearly national extent of differences between total forest cover loss (figure 4-8a) and interior forest cover loss (figure 4-8b) suggests a widespread increase in fragmentation, including in regions exhibiting relatively small net changes in total forest cover.

Why did the net loss of interior forest cover exceed the net loss of total forest cover? When assessing temporal changes in fragmentation, trends depend on more than just changes in the total forest cover in a landscape. At any given time, forest patterns are the result of the spatial patterns of forest losses and gains as they were superimposed on an initial forest pattern. Fragmentation can change even if the total forest area remains constant because the same amount of forest area can be arranged in different patterns and because the patterns of losses and gains may be different.

Thus, the disproportionate loss rates are explained by the patterns of original forest cover, forest cover loss, and forest cover gain in relation to forest cover density in 2001 and 2011 (Riitters and Wickham 2012). Overall forest cover losses tended to follow the distribution of all forest cover in relation to forest cover density in 2001, but the losses exceeded the gains at the high forest cover density values corresponding to "interior" forest. As a result, a smaller percentage of the extant forest cover was interior forest in 2011. Because forest cover losses followed the original distribution, it is plausible that forest spatial pattern was not typically considered when removing forest; as a result, preservation of interior forest was not achieved. Because interior gains did not replace the losses, it is likely that creation of interior forest was typically either not practical or not considered when forest was added.

Trends of forest fragmentation are coarse-scale indicators of dependent ecological changes. It is difficult to interpret specific impacts on ecological values because actual impacts depend on local circumstances, such as forest type (see next section on intact forests), the proximate causes of the fragmentation, anthropogenic land uses in the vicinity, and the degree of fragmentation that is a natural condition. This analysis did not distinguish between natural and anthropogenic forest loss and gain, nor did it compare conditions with natural forest patterns absent human influences. Knowledge of natural patterns is helpful for understanding specific impacts of fragmentation, but it is not essential when evaluating trends within the human-dominated era. More information is needed to evaluate quantitatively the relative importance of the causes of fragmentation in different parts of the United States. The principal drivers of change appear to be human activities in the East and biotic and abiotic disturbances in the West (Riitters and Wickham 2012).

In summary, analysis of forest cover from 2001 to 2011 in the conterminous United States indicated trends toward higher overall rates of fragmentation over a wide range of spatial scales from 11 acres (4.41 ha) to 13,100 acres (5,314.41 ha). Those trends occurred even in regions exhibiting small net changes in total forest cover. The geographically dispersed and noncompensating patterns of forest cover losses and gains resulted in rates of net change of interior forest cover that were at least twice as large as the rate of net change of total forest cover. Land cover maps provide a synoptic perspective to identify indicators of fragmentation consistently over large regions. Ongoing monitoring and analysis of land cover are expected to provide better trend estimates and to improve the interpretation of the observed trends.

Trends in Intact Forest

- ❖ Fragmentation rates were higher on private land than on public land, but most intact forest area is still privately owned.
- ❖ Three-fourths of total intact forest cover area is in eastern forest types.

The forest fragmentation measurements described in the previous section do not account for differences among forest types or ownerships. Those differences may be important when translating assessment findings to land management policy and action. In the 2010 RPA, the national analysis of forest fragmentation was refined for eastern forests in 2001 by incorporating field plot observations of forest types and ownerships from the FIA Program (USDA Forest Service 2010a). For this report, that analysis was updated to 2006 and extended to the conterminous United States. The analysis was not updated to 2011 because the available FIA data represented a circa 2005 snapshot of the forest inventory that was taken to be comparable with the 2001 and 2006 NLCD data.

Intact forest, defined as an 11-acre (4.41-ha) neighborhood containing only forest cover, was mapped for the years 2001 and 2006 using the NLCD (Fry et al. 2011; Homer et al. 2007; USGS 2014b, 2014c; Xian et al. 2009). Using those maps, individual FIA plot locations were assigned a new plot-level attribute (intact forest) in each year if they were located at the center of an intact forest neighborhood. FIA statistical estimators were then used to calculate total area of intact forest by FIA forest type and FIA owner class (Riitters et al. 2012). Recognizing differences in the definition of forest between the two data sources, the strict interpretation of this method is that it evaluates forest cover fragmentation (from NLCD data) in the vicinity of specific forest types and land ownerships (from FIA data).

This analysis considered a subset of all FIA-defined forest land, including 112 forest types (39 western and 73 eastern types) on 539 million acres (218.2 million ha) of forest land (79 percent of total forest land area). Not included were 8 woodland forest types (82.8 million acres [33.5 million ha]), forest land with unassigned forest type (28.4 million acres [11.5 million ha]), nonstocked forest land (20.1 million acres [8.2 million ha]), 7 exotic or miscellaneous types (7.3 million acres [3.0 million ha]), and 22 types that occupied less than 100,000 acres (40,469 ha) each (0.8 million acres [0.3 million ha]). In 2001, the Nation had 231.3 million acres (93.6 million ha) of intact forest (43 percent of total area). From 2001 to 2006, the gross losses and gains of intact forest were 12.1 and 2.8 million acres (4.9 and 1.1 million ha), respectively. The resulting 9.2-million-acre (3.7-million-ha) net loss reduced the area of intact forest to 222.1 million acres (89.9 million ha) (41 percent of total area) in 2006.

Which Forest Types Are Intact?

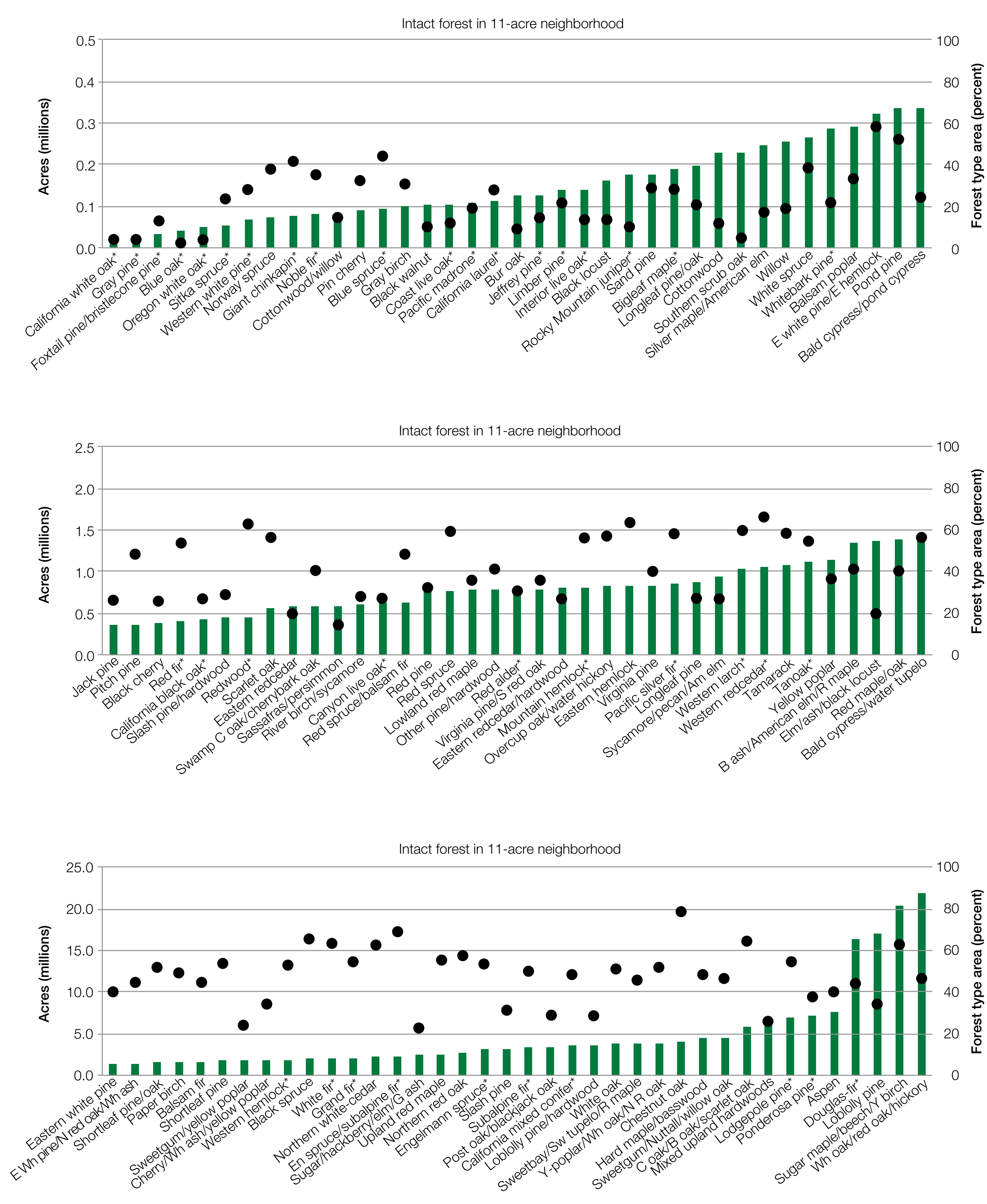
Fragmentation varies naturally among forest types because of the biophysical differences where those types occur and because human land uses tend to fragment some forest types more than others. That variation makes it more difficult to quantify and manage the benefits of intact forest on forest-dependent goods and services that are tied to specific forest types. For example, an intact black spruce forest offers habitat for species that are different from the ones found in an intact longleaf pine forest, and the quality of intact forest habitat depends on which species are found in a given type of forest. Information about the current extent of intact forest can inform land management policy by identifying forest types of special concern for conservation or remediation (for example, the ones that do not have a high proportion of intact forest).

Figure 4-9 summarizes the area of intact forest types in 2006 and the corresponding percentage of forest type area that is intact. Note that the vertical axis scale is different for the three graphs in figure 4-9 because of the wide variation in forest extent of different forest types. In 2006, the overall percentage of total forest land area that was intact forest was higher for the western forest types (44 percent) than for the eastern forest types (40 percent), but eastern forest types accounted for 74 percent of total intact forest area (164 million acres [66.4 million ha]) because 76 percent of all forest land was in the Eastern United States. The percentage of intact forest varied from 2 percent (blue oak) to 78 percent (chestnut oak) of individual forest type areas, with the median forest type having 37 percent of its area as intact (figure 4-9). As expected, lower percentages were obtained for some naturally fragmented forest types (e.g., Oregon white oak, Rocky Mountain juniper, and cottonwood), and higher percentages were obtained for some forest types that tend to be inaccessible because of steep slopes or protected status (e.g., chestnut oak and Engelmann spruce/subalpine fir) or hydric soils (e.g., black spruce and northern white-cedar). Eleven forest types, including six eastern and five western types, exhibited intact area percentages exceeding 60 percent.

Policy concerns may be driven more by estimates of total area of intact forest than of percentages of intact forest. It should be noted that the intact area associated with a forest type is the product of its intact percentage and total forest type area. Because total forest type area varies substantially among forest types (Smith et al. 2009), some forest types exhibited a large absolute area of intact forest even if the percentage of intact area was low (figure 4-9). The nine forest types with more than 5 million acres (2.0 million ha) intact (figure 4-9) together accounted for 49 percent of the total intact area because those nine types comprised approximately 46 percent of total forest type area, even though the percentage of intact forest was less than 50 percent for six of them.

Between 2001 and 2006, 5 of the 112 forest types had net gains of intact area, 16 had no change, and 91 had net losses of intact area. For the 91 types with net losses, the median loss was 36,000 acres (14,569 ha) and the median percentage loss was 3.9 percent of the intact area in 2001. Approximately two-thirds of the total net loss occurred in the 12 forest types that exhibited net losses larger than 200,000 acres (80, 937 ha) (table 4-3). The net loss exceeded 5 percent of the intact area in 2001 for 7 of those 12 types and for 28 additional forest types that were in the “All others” category (table 4-3).

Figure 4-9. The area of intact forest types (vertical bars) and the corresponding percentage of forest type area that is intact (circles), 2006. Forest types are sorted by intact area: note the scale changes between the three charts. Forest types are as defined in USDA Forest Service (2010); western forest types are indicated by asterisks; and some types are abbreviated using Am (American), B (black), C (chestnut), E (eastern), En (Engelmann), G (green), N (northern), R (red), S (southern), Sw (swamp), Wh (white), or Y (yellow).



Sources: National Land Cover Database, 2006; USDA Forest Service, Forest Inventory and Analysis.

Table 4-3. Net loss of intact area for 112 forest types in the conterminous United States, 2001 to 2006.[a]

Forest type	Net loss of intact area from 2001 to 2006	
	acres (millions)	*percent*
Loblolly pine	1.29	7.1
Douglas-fir	0.89	5.2
Loblolly pine/hardwood	0.66	15.5
Mixed upland hardwoods	0.57	8.6
Sugar maple/beech/yellow birch	0.48	2.3
White oak/red oak/hickory	0.43	1.9
Ponderosa pine	0.27	3.7
Aspen	0.26	3.4
Slash pine	0.25	7.6
Sweetgum/yellow poplar	0.25	11.9
Sweetbay/swamp tupelo/red maple	0.24	6.0
Lodgepole pine	0.24	3.4
Subtotal	5.85	4.8
All others	3.37	3.1
All forest types	9.21	4.0

[a] The 12 forest types with losses larger than 0.2 million acres are identified and the remaining are combined into the "All others" category. Percent loss is calculated from the base year of 2001.

Sources: National Land Cover Database, 2001 and 2006; USDA Forest Service (2010).

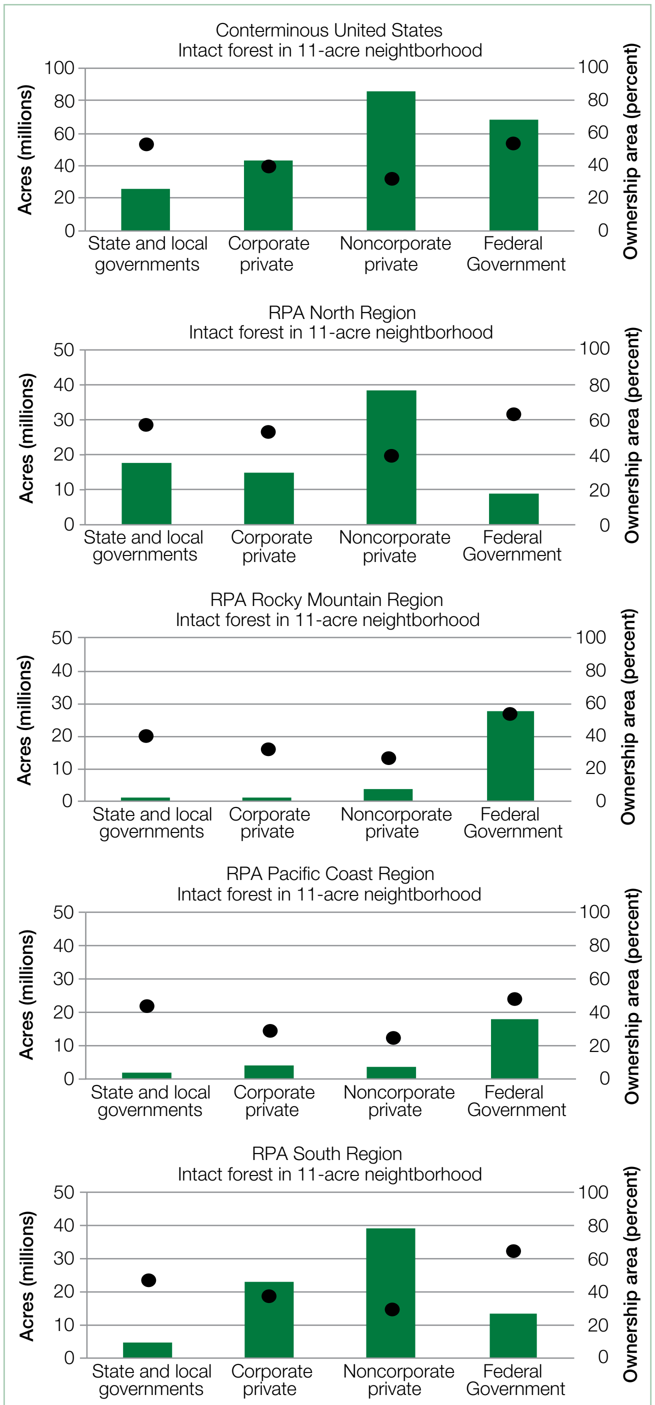
Who Owns the Intact Forest?

Fragmentation varies among ownerships primarily because of differences in the land uses that occur on different ownerships. The summary of intact forest in 2006 by ownership (figure 4-10) considers four ownership classes defined by the FIA inventory: (1) corporate private, (2) noncorporate private, (3) State and local government, and (4) Federal Government (USDA Forest Service 2010a). The summary is organized by region, because most western forest land is publicly owned and most eastern forest land is privately owned (Smith et al. 2009).

In 2006, more than one-half (129 million acres [52.0 million ha]) of all intact forest was privately owned, and two-thirds of that area (85 million acres [34.5 million ha]) was in noncorporate private ownership. Public ownership accounted for 94 million acres (37.9 million ha) of intact forest, with the Federal Government owning three-fourths of that area. Reflecting the regional differences in private versus public forest land ownership, most of the privately owned intact forest was in the two eastern regions (RPA North and South Regions) and most of the publicly owned intact forest was in the two western regions (RPA Rocky Mountain and Pacific Coast Regions). Nationwide and within each region, the percentage of group total forest area that was intact forest was consistently highest for the Federal Government group and lowest for the noncorporate private group.

The changes in total intact forest area from 2001 to 2006 were driven primarily by private land use, particularly in the RPA South Region. Compared with the 59 percent of total intact area that was privately owned in 2001, 82 percent of total gross loss, 92 percent of total gross gains, and 79 percent of total net loss occurred on privately owned land (table 4-4). While the South

Figure 4-10. National and regional forest ownerships characterized by the percentage of group forest land that is intact (circles) and the total area of intact forest (vertical bars). Note scale change after the first chart. Forest ownership groups are as defined in USDA Forest Service (2010), circa 2006.



RPA = Resources Planning Act.

Sources: National Land Cover Database, 2006; USDA Forest Service, Forest Inventory and Analysis.

Region contained 37 percent of total intact forest in 2001, that region accounted for 64 percent of gross losses, 89 percent of gross gains, and 57 percent of net losses to 2006 (table 4-4). At the same time, ratios of gross gains to gross losses indicated

Table 4-4. Changes in intact area for 112 forest types in the conterminous United States, by owner class and RPA region, 2001 to 2006.[a]

	2001	Gross loss	Gross gain	Net change	2006
			acres (millions)		
Owner class					
State and local government	26.3	– 0.8	0.1	– 0.6	25.7
Corporate private	47.4	– 5.7	1.5	– 4.2	43.2
Noncorporate private	88.4	– 4.2	1.1	– 3.1	85.3
Federal Government	69.1	– 1.4	0.1	– 1.3	67.9
All owner classes	231.3	– 12.1	2.8	– 9.2	222.1
RPA region					
North	81.8	– 1.6	0.2	– 1.4	80.4
Pacific Coast	29.6	– 1.7	0.1	– 1.6	28.0
Rocky Mountain	34.4	– 1.1	0.1	– 1.0	33.4
South	85.5	– 7.7	2.5	– 5.2	80.3
All regions	231.3	– 12.1	2.8	– 9.2	222.1

RPA = Resources Planning Act.

[a] Values shown for 2006 may not equal values for 2001 minus net change due to rounding error.

Sources: National Land Cover Database, 2001 and 2006; USDA Forest Service Forest (2010).

replacement of a larger fraction of intact forest on private land (26 percent) compared with public land (11 percent) and in the South Region (33 percent) compared with other regions (7 percent).

Future Work

Future work will use the most recent NLCD land cover maps to assess trends of forest cover fragmentation. This RPA Update considered the 2001, 2006, and 2011 NLCD data. The 2016 NLCD will be used to update the national summary of forest cover fragmentation in the conterminous United States in the 2020 RPA Assessment. That information will be analyzed along with the most recent, available FIA field plot data to evaluate fragmentation in relation to forest types and owners.

An important limitation when using NLCD to assess forest fragmentation has been an inability to identify the proximate causes of fragmentation, or whether fragmentation was due to temporary disturbances (e.g., fire, harvest) or permanent land cover conversions. It is expected that the longer time series of NLCD data (2001 through 2016) will improve interpretations in the 2020 RPA Assessment. In addition, a major current research focus is on identifying the proximate causes of fragmentation by overlaying recently produced national maps of disturbances attributable to fires, insects, diseases, and other agents. That research will greatly enhance our abilities to interpret the practical significance of forest fragmentation and loss of intact forest cover in different regions of the country.

The longer time series of both FIA and NLCD data, combined with improvements in the land use forecasting portion of the RPA modeling system, has also created research opportunities for projecting forest fragmentation statistics into the future. Focused work on modeling these changes at very high spatial resolution and tying them to climate projections is also underway for the 2020 RPA Assessment.

The new forest modeling structure developed for the 2010 RPA Assessment is being revised to improve our ability to address dynamics associated with RPA scenarios (including climate change, global trade, and land use change) and their implications for ecosystem services in the United States. We are particularly focused on modeling disturbance regimes linked to fire and extreme weather events (e.g., hurricanes) and type transitions linked to climate conditions and forest aging. In addition, we are investigating methods for increasing the efficiency of model solutions to reduce the time required for analysis of scenarios and develop new ways to display the results of stochastic simulations to investigate the implications of forecast variance.

Because RPA models and projections are often used to inform management and policy questions raised within the USDA and the Forest Service, we are also enhancing the linkage between forest projections and the analysis of other resource areas. We are working toward a spatially refined interpretation of model outputs to have companion (30-meter resolution) spatial products for projections from the land use and forest dynamics models.

Conclusions

The most recent FIA data indicate that forest area in the United States has increased slightly since 2006. Timberland also has increased, although the distribution by size class has shifted in some regions. Most notably, sawtimber-sized trees are accounting for a steadily increasing proportion of forest area in the East, with accompanying declines in area occupied by poletimber, seedlings, and saplings. Overall growing stock volume continued to increase; however, both softwood and hardwood mortality increased in the RPA Intermountain Subregion and RPA Northeast Subregion from 2006 to 2011. During that same period, average net growth of growing stock trees across all ownerships slowed nationwide.

The most recent land cover data indicate that forest cover fragmentation increased almost everywhere in the conterminous United States. Substantial differences exist between landowners, and most of the increase in fragmentation is attributable to private land uses. Substantial differences also exist between forest types, and the total area of fragmented forest is driven by forest disturbances in the most abundant forest types. Significant limitations prevent full interpretation of the observed trends. Ongoing monitoring and analysis of land cover are expected to provide better trend estimates and to improve the interpretation of the observed trends.

One strength of the RPA Assessment is its use of diverse information to inform resource management issues from several perspectives. Regarding forest area estimation, a major challenge is to develop the techniques to fully integrate data from plot-based and remotely sensed databases. The section described how such databases can be partially integrated to draw on the strengths of each source of information. That type of analytical integration will likely be improved because of the programmatic integration of the FIA and NLCD programs, such that the FIA-produced maps of tree cover are now used for both FIA sampling design and NLCD mapping purposes. Ongoing monitoring and analysis of both data streams, along with additional ancillary data and maps, are expected to improve our ability to address fundamental questions about the status and trends of forest resources.

Chapter 5. Urban Forests

In the 2010 Resources Planning Act (RPA) Assessment (2010 RPA), we reviewed trends in urbanization, reported on the percent tree cover in urban areas circa 2005, reviewed urban forest ecosystem services, provided preliminary estimates of carbon stored in urban forests, and reviewed threats to urban forest health. The most recent trends in urbanization are reported in chapter 3. In this chapter, we examine planting and natural regeneration in urban forests and evaluate risk to urban forests from insects and invasive tree species. We also report updated and expanded information about ecosystem services from urban forests, providing estimates of carbon storage and sequestration, and results of an analysis of the effects of trees on air quality in both urban and rural areas.

Highlights

- Tree planting in urban areas is more common on residential and commercial properties.
- Natural regeneration tends to dominate in cities in forested regions.
- Invasive species and insects and disease currently affect urban forest species composition; climate change will likely affect future distributions of invasive species and insects and disease and their associated effects on urban forests.
- Because tree cover in urban areas in the United States is on the decline, carbon storage in urban areas is also likely on the decline.
- Pollution removal by trees and forests in the United States was substantially greater in rural areas because about 96 percent of the land base is rural, but the estimated health benefit was substantially greater in urban areas because more than 80 percent of the population lives in urban areas.

Urban trees and forests in the United States provide important ecosystem services that influence human health and well-being and sustain quality of life. The term *urban forest* refers to all publicly and privately owned trees within an urban area—including individual trees along streets and in backyards and also stands of remnant forest (Nowak et al. 2001). We use the Census Bureau definition of *urban land* to delimit the areas that contain urban trees and forests, as described in chapter 3.

Urban growth in the future will have an increasingly important effect on forest management, environmental quality, and human well-being. Numerous forces for change will alter urban forests in the coming years and affect the quality and quantity of this vital resource. Understanding these forces and their potential impact is essential to developing appropriate management plans to create sustainable and desirable urban forests for future generations.

Planting and Natural Regeneration in Urban Forests

- ❖ About one-third of existing urban trees were planted in sampled cities.
- ❖ Tree planting is more common on residential and commercial properties.
- ❖ Natural regeneration tends to dominate in cities in forested regions but can increase the prevalence of invasive species.

Two dominant forces can lead to increased tree cover in urban areas: tree planting and natural regeneration. Although relatively little is known about how urban forests have changed, field data from several cities provide some clues about the relative impact of tree planting versus natural regeneration in cities in the United States and Canada.

The proportion of existing tree population that was planted or occurred through natural regeneration was estimated in 12 cities throughout the United States and Canada, based on random sampling of field plots in each city (Nowak 2012). In addition, remeasurements of field plots in two cities (Baltimore, MD, and Syracuse, NY) were used to estimate regeneration and planting rates (Nowak 2012) and document changes in species composition (Nowak et al. 2013b).

Data from these cities reveal that, on average, in the United States, only about one in three of the existing urban trees came from tree planting (Nowak 2012). Land uses with the highest proportion of trees planted were residential (74.8 percent of trees planted) and commercial/industrial (61.2 percent) lands (table 5-1). The percentage of the tree population planted is greater in cities developed in grassland areas than in cities developed in forests, and tree planting tends to increase with increased population density and percent impervious cover in cities.

Table 5-1. Overall percent of tree population planted, by land use within 12 U.S. or Canadian cities. Data were collected between 2007 and 2009.

Land use	Percent planted
Residential	74.8
Commercial/industrial	61.2
Institutional	19.7
Utilities/transportation	15.1
Other	13.8
Park/cemetery/golf	10.7
Open space/vacant	7.1
Agriculture	2.0
Wetland/water	0.8

Source: Nowak (2012).

New tree influx rates ranged from 1.6 trees per acre per year (4.0 trees per hectare [ha] per year) in Baltimore to 3.5 trees per acre per year (8.6 trees per ha per year) in Syracuse. About 1 in 20 trees (Baltimore) and 1 in 12 trees (Syracuse) were planted in newly established tree populations, indicating that natural regeneration is the dominant force in establishing new tree populations in these cities in recent years. Natural regeneration rates were greater than planting rates on all land uses in Baltimore and Syracuse and were highest on vacant land in Syracuse (11.8 trees per acre per year [29.2 trees per ha per year]) and in forest/open spaces in Baltimore (5.6 trees per acre per year [13.8 trees per ha per year]).

Although these data are limited in extent due to sparse urban forest monitoring data, the data indicate that natural regeneration is an important force for enhancing tree cover in many cities, particularly in cities in forested regions and those with limited tree planting. The proportion of the tree population that is planted tends to increase as city population density increases, in cities with drier climates, and in land uses with higher levels of direct management (e.g., residential lands). In forested regions, efforts to encourage natural regeneration (e.g., by limiting mowing, reducing impervious surfaces) could be used to enhance urban tree cover at relatively low costs. Natural regeneration, however, could lead to changes in species composition and associated ecosystem services.

In Syracuse, natural regeneration is dominated by buckthorn and other invasive or pioneer species (Nowak et al. 2013b). Although native forest species are regenerating, only 35 percent of new trees in Syracuse (from 2001 to 2009) are native species. In addition, 52 percent of the new trees are classified as invasive species in Syracuse: buckthorn, tree of heaven, Norway maple, black locust, and Russian olive (Nowak 2012). As a result, invasive species could alter natural species composition in cities and pose problems associated with their spreading into the surrounding landscape, displacing native species and altering local ecosystems (e.g., Pimentel et al. 2000). Natural regeneration dominated by invasive species will alter future urban forest composition and ecosystem services.

In a survey of current efforts to expand and protect the urban tree canopy, 84 percent of the 135 cities that responded view their activities relating to trees as part of their overall sustainability and/or climate protection efforts, with 47 percent of the cities having increased tree canopy cover as a stated goal of their overall tree resource management plan or as an ordinance (City Policy Associates 2008). Information regarding urban forest planting and regeneration can help cities meet desired tree canopy goals in a more cost-effective manner.

Risks to Urban Forests

- ❖ The percent and number of invasive tree species vary widely across cities in the United States.
- ❖ Gypsy moth and Dutch elm disease potentially affect the largest number of trees in 26 selected U.S. cities.
- ❖ Invasive species and insects and disease currently affect urban forest species composition, but climate change will affect species distribution and likely affect the distribution of insects and diseases in the coming years.

A national assessment of risks from insects, diseases, and invasive tree species could not be conducted because data on specific tree species in urban areas throughout the United States do not currently exist. Instead, local urban tree population data from select cities throughout the United States were used in this analysis, based on random sampling of tree populations in urban areas and analyses using the i-Tree model (Nowak et al. 2008). City data were compiled for 26 cities across the United States (Nowak et al. 2013b).

State invasive species lists were used to determine the amount and proportion of the sample tree population that was classified as invasive. All of the 26 sampled cities had some degree of invasive species influence on the urban forest population. This influence ranged from 33 percent of the total tree population in Milwaukee, WI, being classified as invasive to 1 percent in Gainesville, FL, and Arlington, TX (table 5-2). Some of the invasive species variation is due to differences in State invasive species lists.

In addition to the potential risk to urban tree population created by invasive tree species, several insects and diseases provide significant potential to alter urban forest composition and ecosystem services. To estimate the potential impact of various insect and disease infestations in cities, city tree population data were compared with tree host data for six major insects and diseases (Asian longhorned beetle [ALB], Dutch elm disease, emerald ash borer [EAB], gypsy moth, hemlock woolly adelgid [HWA], and southern pine beetle) and range maps of where the insects and diseases are located (Krist et al. 2014). The proportion and amount of urban forest at risk by the insect and disease were calculated for cities where the insect or disease is already present.

Table 5-2. Number of invasive tree species; percent of city tree population that is invasive; and percent of city tree population at risk by six insects and diseases in 26 U.S. cities. City data collection dates varied among cities and ranged between 1996 and 2010.

City and State	Invasive species		Gypsy moth	Dutch elm disease	Asian longhorned beetle	Southern pine beetle	Emerald ash borer	Hemlock woolly adelgid
	number	*percent*	*percent of city tree population at risk*					
Arlington, TX	4	1.1		25.9				
Atlanta, GA	6	1.6		3.0		16.5	0.4	
Baltimore, MD	4	7.2	15.3	8.5		3.4	9.5	0.2
Boston, MA	5	22.6	28.6	3.5	45.1		2.7	3.7
Casper, WY	3	5.1		9.6				
Chicago, IL	10	16.1	17.6	7.2	33.6		11.9	
Freehold, NJ	7	29.4	14.0	2.4		12.4	1.9	4.1
Gainesville, FL	2	1.1		1.1		26.6		
Golden, CO	1	3.6						
Hartford, CT	4	10.7	17.9	8.1			2.0	1.0
Jersey City, NJ	7	28.0	24.3	2.5	27.0		0.0	0.3
Lincoln, NE	3	11.7		14.1				
Los Angeles, CA	2	1.6						
Milwaukee, WI	12	33.3	14.2	7.5			18.5	
Minneapolis, MN	2	5.9		19.1			21.9	
Moorestown, NJ	8	8.8	26.3	1.3		8.8	2.0	1.0
Morgantown, WV	1	3.4	10.3	6.2		4.7	5.8	1.7
New York, NY	2	15.0	27.4	1.2	26.6		0.6	0.5
Omaha, NE	2	10.0		17.0				
Philadelphia, PA	6	13.8	15.5	2.4		4.7	6.5	1.1
Roanoke, VA	8	17.6	15.5	2.4		4.7	1.5	1.1
San Francisco, CA	1	15.9						
Scranton, PA	7	5.8	48.7	0.7		3.7	2.6	0.9
Syracuse, NY	5	29.8	11.5	0.8			1.9	
Washington, DC	7	6.8	15.7	6.6		3.7	2.1	1.0
Woodbridge, NJ	9	12.8	34.2	1.2	24.2	2.4	5.4	0.1

Notes: Not all insects and diseases are present in all cities; table illustrates potential risk if the insect or disease is present and if it attacks known hosts. Blank cells indicate pest is not present in city.
Source: Nowak et al. (2013b).

Of the 26 sampled cities, 24 are impacted by at least one of the six insects and diseases analyzed. Only Los Angeles and San Francisco, CA, are currently not affected. The insect and disease potential impacts were greatest for gypsy moth, affecting more than 5 million trees in 16 of the 26 cities. The next most potentially impactful insect and diseases were Dutch elm disease (3.3 million trees, 23 of 26 cities), ALB (3.2 million trees, 5 of 26 cities), southern pine beetle (2.9 million trees, 11 of 26 cities), EAB (1.9 million trees, 18 of 26 cities), and HWA (152,000 trees, 13 of 26 cities) (table 5-2).

It is important to note that these 26 cities were not selected at random and tend to be biased toward the Eastern United States, where much of the U.S. population resides. The pattern of cities relative to the insect and disease distribution affects the results. As these insects and diseases spread, the impacts will change. For example, the ALB has the greatest potential for devastation because of the large number of species it can kill, but this insect is currently limited in geographic spread. These city analyses provide a glimpse of the types of impacts that invasive species and insects and diseases are having or potentially could have on urban forests in selected cities. These forces for change will likely have substantial impacts on species composition and health in urban forests across the United States. Not only will invasive species and insects and disease affect urban forest species composition, but climate change will also affect species distribution and importance values in the coming years (Iverson et al. 1999) and likely affect the distribution of insects and diseases.

Urban Forest Ecosystem Services

As urban forests change in the coming decades, so will the ecosystem services and values provided by urban forests. Although urban forests provide myriad ecosystem services (Millennium Ecosystem Assessment 2005; Nowak and Dwyer 2007), two ecosystem services were recently assessed at the national scale: (1) carbon storage and sequestration and (2) air pollution removal and associated health values.

Carbon in Urban Trees

- ❖ Total carbon storage from trees on urban lands was estimated at 643 million metric tons.
- ❖ Given limitations to tree growth and establishment in urban areas, increases are unlikely without changes to current management procedures.
- ❖ Because tree cover in urban areas in the United States is on the decline, carbon storage in urban areas is also likely on the decline.

Carbon storage and sequestration affect levels of atmospheric carbon dioxide (CO_2) and, consequently, many of the issues associated with global climate change (IPCC 2014). Like many ecosystem services derived from trees, these services are related to the amount of tree cover, along with other forest or environmental variables, and vary across the United States. To estimate urban forest carbon storage and annual sequestration rates, National Land Cover Database tree cover data were combined with carbon storage and sequestration rates per unit of tree cover derived from field data-based assessments of various cities using the i-Tree model (Nowak et al. 2013a). Carbon values were based on the U.S. Interagency Working Group (2010).

Carbon sequestration is the gross annual amount of carbon removed by the urban forest through tree growth. The 2010 RPA included preliminary results of carbon storage and sequestration by urban trees. Nowak et al. (2013a) provided final estimates that vary slightly from the preliminary estimates. Total carbon storage from trees on urban lands was estimated at 643 million metric tons of carbon. Sequestration on urban areas was estimated at 25.6 million metric tons of carbon per year (table 5-3).

Net sequestration after accounting for estimated annual tree mortality and decomposition is estimated at 74 percent of gross sequestration (Nowak et al. 2013a). Texas, Florida, and Georgia had the greatest amount of carbon stored in urban forests and the greatest urban forest gross annual sequestration (table 5-3) due to the large amount of tree cover and relatively fast growth rates in those States. The greatest annual sequestration rates per hectare of urban tree cover were in Hawaii, Florida, and Louisiana, as a result of relatively fast growth rates (Nowak et al. 2013a).

This updated estimate of trees and forests in U.S. urban areas storing 643 million metric tons of carbon is within the range of past estimates, but with a reduced bound of error. Given the potential available space (pervious land) in urban areas of 43.7 million acres (17.7 million ha), carbon storage could increase in urban areas. Given limitations to tree growth and establishment in urban areas imposed by humans (e.g., mowing) and nature (e.g., lack of precipitation), however, any increases are unlikely without changes to current management procedures. Because tree cover in urban areas in the United States is on the decline (Nowak and Greenfield 2012), carbon storage in these urban areas is also likely on the decline (Nowak et al. 2013a).

In addition to affecting direct carbon storage and sequestration in urban areas, as reported in this chapter, urban trees can also affect carbon emissions in urban areas. Planting trees in energy-conserving locations around buildings (e.g., Heisler 1986) can reduce building energy use and, consequently, emissions from power plants. Transpirational cooling and changes in albedo because of trees alter urban microclimates that can also reduce carbon emissions from cities (e.g., reduced

Table 5-3. Estimated carbon storage and gross annual sequestration from trees in urban areas (total and per km² land area), by State in metric tons (t) of carbon (C), circa 2005. Storage and sequestration values per m² of trees are given in Nowak et al. (2013a).

State	Storage		Sequestration	
	$tC \times 10^6$	tC/km^2	$tC \times 10^3$/ year	tC/km^2/year
Alabama	18.7	4,081	836	182
Arizona	5.5	1,264	253	58
Arkansas	7.7	3,308	331	142
California	31.4	1,532	1,591	78
Colorado	4.4	1,341	112	34
Connecticut	23.3	5,113	724	159
Delaware	2.3	2,923	99	127
Florida	42.9	2,699	2,650	167
Georgia	38.5	4,003	1,770	184
Idaho	1.1	1,010	25	24
Illinois	18.7	2,034	688	75
Indiana	9.7	1,718	317	56
Iowa	3.8	1,787	117	56
Kansas	4.8	2,154	176	79
Kentucky	6.5	2,071	241	77
Louisiana	10.6	2,480	544	128
Maine	3.8	4,154	109	119
Maryland	11.9	2,533	497	106
Massachusetts	35.9	4,965	1,187	164
Michigan	22.9	2,662	654	76
Minnesota	9.3	2,386	275	71
Mississippi	7.4	3,108	333	139
Missouri	11.2	2,392	417	89
Montana	0.5	692	11	17
Nebraska	1.6	1,399	51	43
Nevada	1.3	923	35	25
New Hampshire	7.1	4,923	202	139
New Jersey	28.0	3,878	1,069	148
New Mexico	1.8	932	62	32
New York	32.1	3,170	1,005	99
North Carolina	34.0	3,706	1,378	150
North Dakota	0.4	1,154	12	33
Ohio	22.9	2,234	739	72
Oklahoma	4.3	1,454	187	63
Oregon	8.1	3,077	255	97
Pennsylvania	28.7	2,618	911	83
Rhode Island	4.1	4,154	139	139
South Carolina	17.3	3,620	760	159
South Dakota	0.7	1,615	21	49
Tennessee	18.9	3,012	744	119
Texas	45.2	2,460	2,165	118
Utah	2.1	1,154	58	32
Vermont	1.5	4,040	42	112
Virginia	16.6	2,679	632	102
Washington	13.8	2,525	463	85
West Virginia	5.1	3,574	161	112
Wisconsin	9.4	2,244	275	66
Wyoming	0.3	692	7	16
United States (48)*	**638.8**	2,692	**25,347**	107
Alaska	2.0	2,938	44	64
Hawaii	2.2	2,338	167	177
United States	**643.2**	2,693	**25,559**	107

* Conterminous United States.

Note: Carbon storage in above- and below-ground biomass on U.S forest land averages 7,421 metric tons of carbon per km² land area (Heath et al. 2011), based on 2008 data.

Source: Nowak et al. (2013a).

evaporative emissions with lower air temperatures). In addition, urban tree management practices need to be considered when estimating the net effects of urban trees on atmospheric CO_2, because various maintenance activities emit carbon back to the atmosphere via fossil-fuel combustion (e.g., from chain saws, trucks, chippers) (Nowak and Crane 2002). As urban areas produce substantial emissions of carbon, tree effects on carbon emissions through altering of microclimates, albedo, energy use, and maintenance emissions need to be incorporated with tree carbon storage and sequestration estimates to develop a more complete assessment of the role of urban forests on climate change (Nowak et al. 2013a).

Air Quality and Human Health

- ❖ Trees and forests in the United States removed an estimated 17 million metric tons of air pollutants in 2010.
- ❖ Improved air quality due to pollution removal by trees was estimated to have reduced human mortality by more than 850 incidences in 2010.
- ❖ Removal was substantially greater in rural areas because about 96 percent of the land base is rural, but the estimated health benefit was substantially greater in urban areas because more than 80 percent of the population lives in urban areas.

Trees affect air quality positively through the direct removal of air pollutants and cooling air temperatures, but they can have positive or negative effects on air quality by altering local microclimates and building energy use (i.e., reduced energy use can improve air quality while increased energy use can worsen air quality). Trees can also have negative effects on air quality by reducing dispersion, emitting pollen, and emitting volatile organic compounds (VOCs), which can contribute to ozone (O_3) and particulate matter (PM) less than 2.5 microns ($PM_{2.5}$) formation. Integrative studies have revealed, however, that trees, particularly low-VOC-emitting species, can be a viable strategy to help reduce urban O_3 levels (e.g., Nowak et al. 2000; Taha 1996). Nowak et al. (2014) estimated the amount of air pollution (nitrogen dioxide [NO_2], O_3, $PM_{2.5}$, and sulfur dioxide [SO_2]) removed by trees and forests within urban and rural areas of the conterminous United States in 2010 and the associated impacts of that removal on human health.

Total tree cover varies in the United States, ranging from a low of 2.6 percent in North Dakota to a high of 88.9 percent in New Hampshire (Nowak and Greenfield 2010). Just as people and trees exist in varying densities across the landscape, pollution removal and effects on local pollution concentrations vary, as do human health impacts. Estimates of avoided health impacts and associated dollar benefits of air pollution removal required four types of analyses conducted at the county level for all urban and rural areas: (1) estimate the total tree cover and leaf area index on a daily basis, (2) estimate the hourly flux of pollutants to and from the leaves, (3) estimate the effects of hourly pollution removal on pollutant concentration in the atmosphere, and (4) estimate the health impacts and monetary value of the change in NO_2, O_3, $PM_{2.5,}$ and SO_2 concentration using information from the U.S. Environmental Protection Agency (EPA) Environmental Benefits Mapping and Analysis Program (BenMAP) model (U.S. EPA 2012). Urban and rural areas were delimited using 2010 census data, with rural land defined as land not classified as urban (U.S. Census Bureau 2013).

Pollution removal by trees and forests in the United States was estimated at more than 17 million metric tons in 2010, with a human health value of $6.8 billion. Removal was substantially greater in rural areas because about 96 percent of the land base is rural; however, the estimated health benefit was substantially greater in urban areas (68 percent of the total estimated value) because over 80 percent of the population lives in urban areas (table 5-4). Highest removal rates were for O_3 (14.3 million metric tons); lowest rates were for $PM_{2.5}$ (696,000 metric tons). The greatest health values were associated with $PM_{2.5}$ ($4.6 billion) and O_3 ($2.2 billion). Health impacts included the avoidance of more than 850 incidences of human mortality and 670,000 incidences of acute respiratory symptoms. The effects of reducing human mortality dominated the value of health benefits, but substantial benefits also accrued to reductions in acute respiratory symptoms, hospital admissions, and incidences of chronic bronchitis and asthma exacerbation (Nowak et al. 2014).

Primary air quality standards focus on public health protection, and the air quality effects of trees on public health are greater in urban areas because of their high population densities relative to rural areas. Secondary air quality standards are focused on public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. Including estimates of tree benefits associated with secondary standards, particularly damage to animals, crops, and vegetation, would likely change the distribution of air quality benefits between rural and urban areas (Nowak et al. 2014).

Typical annual air quality improvement due to pollution removal by trees was less than 1 percent. In general, the greater the tree cover, the greater the removal. Trees, however, also affect air quality in ways not analyzed in this study. This national-scale modeling focused on broad-scale estimates of pollution removal by trees. At the local scale, pollution concentrations can be increased if tree canopies trap pollutants near emission sources, limit dispersion by reducing wind speeds, and/or lower mixing heights by reducing wind speeds. Under stable atmospheric conditions (limited mixing), pollution removal by trees could lead to greater reductions in pollution concentrations at ground level. Local-scale design of trees and forests can affect local-scale pollutant concentrations. More research is needed that accounts for vegetation configuration and source-sink relationships to maximize beneficial tree effects on pollutant concentrations and human exposure to air pollution (Nowak et al. 2014).

Although these estimates have various limitations, the results give a first order approximation of the magnitude of pollution removal by trees and their effects on human health. Modeling broad-scale effects of pollution removal by trees on air pollution concentrations and human health reveals that, although the percent reduction in pollution concentration averages less than 1 percent, trees remove substantial amounts of pollution and can produce substantial health benefits and monetary values across the Nation, with most of the health values derived from urban trees (Nowak et al. 2014).

Even though air pollution removal and carbon sequestration are just two of many ecosystem services derived from urban trees and forests, these two services total to an annual value of $6.7 billion or $293 per acre of urban tree cover ($723 per ha of urban tree cover). Numerous other services (e.g., air temperature reduction, building energy savings, ultraviolet radiation reduction, other human health impacts) will increase this value, and other costs (e.g., maintenance costs, possible increased energy use, pollen, VOC emissions that can lead to pollutant formation) will decrease the value. These additional services and costs need to be assessed to determine the overall net benefits of urban forests in the United States.

Table 5-4. Estimated annual removal of pollutants and associated health value due to urban and rural trees in the conterminous United States, by State and the District of Columbia, 2010.

State	All land		Urban land		Rural land	
	metric tons (thousands)	*dollars (millions)*	*metric tons (thousands)*	*dollars (millions)*	*metric tons (thousands)*	*dollars (millions)*
Alabama	639.8	227.1	18.8	104.2	621.0	122.9
Arizona	446.6	24.9	6.0	20.9	440.5	4.0
Arkansas	548.6	95.8	7.0	37.7	541.6	58.2
California	1,035.3	446.2	36.4	404.3	999.0	41.9
Colorado	534.3	15.7	2.0	5.0	532.4	10.6
Connecticut	49.0	120.3	15.6	102.3	33.4	18.0
Delaware	15.7	21.1	2.7	15.8	13.0	5.3
District of Columbia	0.3	7.7	0.3	7.7	NA	NA
Florida	638.9	569.2	61.5	465.5	577.5	103.7
Georgia	731.7	352.3	50	226.2	681.7	126.1
Idaho	565.7	42.8	1.4	18.7	564.4	24.1
Illinois	140.3	149.4	11.2	133.0	129.2	16.4
Indiana	164.0	96.2	8.4	63.1	155.5	33.0
Iowa	86.5	28.2	2.1	18.5	84.4	9.7
Kansas	85.8	16.7	2.1	11.7	83.8	5.0
Kentucky	334.9	99.9	6.9	42.1	328.0	57.7
Louisiana	447.7	142.6	15.7	85.5	431.9	57.0
Maine	401.0	78.3	3.6	23.2	397.4	55.1
Maryland	95.2	134.9	16.8	111.8	78.5	23.1
Massachusetts	89.7	250.1	30.2	222.8	59.4	27.3
Michigan	496.3	177.4	21.8	107.1	474.5	70.3
Minnesota	335.5	46.9	4.6	26.7	330.9	20.1
Mississippi	564.2	156.8	10.5	60.4	553.7	96.4
Missouri	502.7	127.7	10.4	70.2	492.4	57.5
Montana	727.7	28.1	0.5	5.6	727.2	22.5
Nebraska	44.0	5.4	0.5	3.9	43.5	1.5
Nevada	210.1	9.0	1.7	8.1	208.4	0.9
New Hampshire	115.5	44.1	5.9	17.3	109.6	26.7
New Jersey	69.1	181.3	21.9	165.5	47.2	15.7
New Mexico	452.7	8.5	2.1	4.3	450.6	4.2
New York	422.5	433.4	31.9	345.9	390.6	87.5
North Carolina	564.7	315.4	42.0	176.5	522.7	138.9
North Dakota	21.2	1.4	0.1	0.8	21.1	0.6
Ohio	233.3	268.0	24.5	205.3	208.8	62.6
Oklahoma	302.9	58.6	3.9	26.9	299.0	31.6
Oregon	676.1	159.9	5.0	102.8	671.1	57.1
Pennsylvania	437.0	543.5	30.8	368.8	406.2	174.7
Rhode Island	10.5	33.6	2.9	27.9	7.6	5.7
South Carolina	371.2	204.3	23.6	118.5	347.6	85.8
South Dakota	45.7	3.7	0.2	1.9	45.4	1.8
Tennessee	402.5	183.2	19.9	103.1	382.6	80.1
Texas	1,011.9	317.2	36.5	222.0	975.4	95.2
Utah	331.4	15.0	2.4	11.5	329.0	3.5
Vermont	96.4	22.2	1.0	6.1	95.4	16.1
Virginia	446.1	171.6	21.4	103.9	424.7	67.7
Washington	535.5	241.1	13.9	168.6	521.5	72.5
West Virginia	262.8	77.7	4.5	28.9	258.2	48.8
Wisconsin	333.1	84.8	7.0	47.7	326.1	37.1
Wyoming	296.6	4.3	0.4	1.9	296.2	2.4
Conterminous United States	**17,370.3**	**6,843.2**	**650.5**	**4,658.4**	**16,719.8**	**2,184.9**

NA = Not applicable.

Source: Nowak et al. (2014).

Future Work

We will continue to update trends in urban forests as new data are available. As we develop scenarios for the 2020 RPA Assessment, new socioeconomic assumptions and climate data can be used to project tree cover at the State and county levels and also to develop estimates of how urban tree cover varies across the Nation, based on potential natural vegetation to aid in predicting urban tree cover. We will integrate climate change projections with assessments of urban forests within cities to illustrate how services and risks might change under future climates. A focus on ecosystem services of urban trees will continue, including examining the national effects of urban trees on energy use and property values. The State-level urban reports with the latest tree cover, tree cover change, number of trees, and ecosystem services and values will also be updated.

Conclusions

The U.S. landscape is changing because of urbanization; the landscapes within urban areas are also changing. Within urban areas, tree cover and natural regeneration vary based on geographic location and land use. Within naturally forested regions, urban tree cover and natural regeneration, on average, are substantially higher than in natural grassland or desert regions. The environment conducive to forest growth (e.g., precipitation greater than evaporation, local seed sources) greatly affects tree growth, survival, and regeneration in urban areas. Actions of humans through landscape management (e.g., mowing, planting, creating impervious surfaces), however, can substantially alter forest extent and composition.

Trees and forests in urban areas provide considerable environmental and health benefits through air pollution removal and carbon storage, among other yet-to-be-quantified services. These forests and services, however, are at risk from various forces for change. Data from the late 2000s indicate that urban tree cover is on the decline in many cities. Significant forces for change include urban development, climate change and storms, insects and diseases, and invasive plant species. By understanding and managing these forces for change at the local scale, sustainable urban forests can be created that will continue to provide desired services for current and future generations.

Chapter 6. Forest Products

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) reviewed historical trends in forest product consumption and production, and it projected trends under the four 2010 RPA scenarios. In this RPA Update, we focus on the status of economic recovery of the U.S. forest products industry, providing the most recent trends in solidwood products and the pulp and paper sector. We highlight recent trends in the housing market because of its importance in solidwood product markets. We also describe the historical U.S. role in international forest products markets and reflect on potential effects of current and expected trends on the future U.S. role. We then revisit projections of the forest sector with a revised scenario that accounts for the 2007-to-2009 recession, and finally examine trends and projections in forest sector employment.

Highlights

- The United States experienced a sharp drop in harvesting and production of most categories of forest products from 2006 through 2009, but outputs partially rebounded by 2013 as a result of the housing market recovery.
- Manufacturing shifts to other countries since 2000 have likely driven down demand for and supply of paper used in packaging in the United States, while U.S. demand for paper used in the media has been declining steadily and is projected to continue declining into the foreseeable future.
- Timber harvest to supply the energy sector has expanded rapidly since the late 2000s, particularly in the form of wood pellets for export. Encouragement of the use of wood to produce energy depends in part on domestic policies that will determine whether the accounting of biomass-based emissions is carbon neutral.
- The U.S. share of global output of most timber products has declined since the 1960s, partly because of growth in foreign production and partly because of declines in domestic production. Long-term prospects for market-share recovery exist in the wood products sector, but the paper sector is less likely to recover in the short or long term.
- These divergent trends are reflected in employment projections for the wood products and paper sectors, with prospects for some recovery in the former and a continued overall decline in the latter. Steady improvements in production efficiency provide long-run downward pressure on employment, however, regardless of product demand futures.

Recent Trends in the U.S. Forest Products Industry

❖ The Nation's forest resources support a large wood and paper products sector that supports the highest forest product-consuming country in the world.

The United States historically has and today remains the economy with the highest intensity of industrial roundwood consumption (FAO 2014; U.S. Census Bureau 2014a, 2014c, 2014e), producing and consuming more forest products than any other country. The size and organization of the forest products industry have changed during the past decade, however, reflecting changes in consumer demands, manufacturing activity, and global economic growth.

Solidwood products and pulp and paper comprise the vast majority of the U.S. forest products sector and both have been affected by a combination of trends and cyclical factors. The solidwood products sector serves demands from manufacturing, housing upkeep and repair, and, most strongly, new construction. Paper and paperboard output is strongly correlated with manufacturing output in the United States. Fluctuations in both the manufacturing and the housing sectors during the past decade have affected markets for U.S. forest products, especially during the 2007-to-2009 recession. Accompanying these cyclical fluctuations, however, are longer term trends attributable to technology changes and shifts in consumer preferences.

Trends in Removals and Timber Products

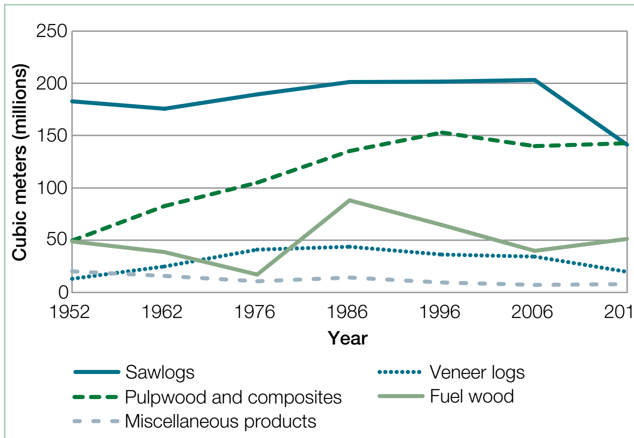
❖ Total production has increased since 2009 but remains below 2006 levels.

The 2010 RPA reported on trends through 2006; the latest summary of Forest Inventory and Analysis data provides trends through 2011. The 5-year trends still show production below 2006 levels. At the national level, growing-stock removals declined 17 percent from 2006 to 2011. Softwoods accounted for 65 percent of growing-stock removals in 2011 and hardwoods accounted for 35 percent. Both species groups showed declines in removals from 2006, with softwoods down by 16 percent and hardwoods down by 20 percent. The South led growing-stock removals in 2011, accounting for 63 percent of the Nation's total growing-stock removals (Oswalt et al. 2014).

In 2011, timber harvested for industrial products and domestic fuel wood totaled 454 million cubic meters, nearly a 15-percent decline since 2006. Slightly more than 80 percent of the harvest came from growing stock, while the remainder came from nongrowing stock sources, including rough and rotten trees, dead trees, tops, and stumps. Sawlog production dropped nearly 31 percent between 2006 and 2011 and accounted for 39 percent of the Nation's total product output in 2011. Pulpwood and composite panel output increased nearly 2 percent and accounted for 39 percent of total product output. Veneer production, accounting for 5 percent of product output for the Nation, has dropped more than 42 percent since 2006. Volume used for other industrial products, such as poles, posts, mulch, and other miscellaneous products, increased 11 percent from 2006. Domestic fuel wood increased 28 percent (figure 6-1) (Oswalt et al. 2014). Wood used to make pellets for energy is obtained primarily from pulpwood, but fiber for wood pellets also comes from the residues generated by the processing of sawlogs, veneer logs, and miscellaneous products in the manufacture of secondary forest products such as lumber and wood-based panels.

During 2011, timber-processing facilities in the United States produced nearly 53.8 million dry metric tons of wood residues; more than 99 percent of that residue was used for fuel or other forest products. About 43 percent of wood residue was used for commercial fuel, 40 percent for fiber products, and about 16 percent for other products. Softwoods accounted for 71 percent of mill residue (Oswalt et al. 2014).

Figure 6-1. Trends in production in the United States, by primary forest product, 1952 to 2011.



Source: Converted to metric based on Oswalt et al. (2014).

Trends in Solidwood Products

- ❖ **Solidwood production continued to increase between 2012 and 2014.**
- ❖ **Growth in the housing sector since 2009 has resulted in increased softwood lumber and structural wood panel consumption.**

The U.S. solidwood industry produced 72.8 million cubic meters of lumber in 2014, up from 67.5 million cubic meters in 2013. The growth in the housing sector had a positive effect on softwood lumber consumption through 2014. Total softwood lumber consumption totaled 72 million cubic meters in 2014, a 6.9-percent increase from 2013 (WWPA 2014).

New residential construction continued to strengthen throughout 2013 and into 2014. Housing and other construction markets started off strong in 2014 but slowed in the third quarter, largely because of fewer single-family starts (Howard and McKeever 2015; NAHB 2014). The National Association of Home Builders Remodeling Market Index climbed above record levels in the third quarter of 2014, surpassing the highest level reached in 2004 before the housing market downturn. Since 2000, expenditures for maintenance and repairs to all existing residential properties have averaged about 25 percent of total expenditures, with the remaining 75 percent for improvements. The high levels of home foreclosures in the United States in recent years have subsided; residential improvements and repairs during that time may have been a bigger part of the economy than usual. Expectations are for continued but declining investments in existing residential properties as low mortgage rates keep new homebuying attractive (Howard and McKeever 2015) (see the sidebar Housing Sector Outlook.).

Structural panel production was 19.5 million cubic meters in 2014, a slight increase from 2013 levels. U.S. structural panel consumption in 2014 increased 3.5 percent between 2013 and 2014, from 22.3 to 23.1 million cubic meters. U.S. oriented strandboard (OSB) production in 2014 increased 6 percent from 2013 levels, to 11.5 million cubic meters. OSB consumption in 2014 was 15.2 million cubic meters, a 6.9-percent increase from 2013 (APA – The Engineered Wood Association 2015).

U.S. softwood plywood production and consumption both decreased between 2013 and 2014. Production in 2014 declined 3.9 percent, to 7.9 million cubic meters, and U.S. softwood plywood consumption declined 4.8 percent in 2014, to 7.9 million cubic meters (APA – The Engineered Wood Association 2015).

Roundwood production for pulp and wood-based panel mills was down slightly in 2013 compared with production in 2012. Roundwood pulpwood consumption is expected to decrease during 2014 as indicated by a slight decline (0.2 percent) in paperboard production in the first 8 months of 2014. Pulpwood supplied from residues continued to decrease relative to roundwood as a result of declining residuals production and competition for residuals for pellets and biomass. The residual portion of pulpwood increased slightly in 2013 (Howard and McKeever 2015).

The U.S. forest products industry's annual harvest was 371 million cubic meters in 2012, exceeding the 361 million cubic meters harvested in 2011. Domestic roundwood timber harvest that supports domestic consumption was 385 million cubic meters in 2013, 14 million cubic meters more than consumption in 2012 (Howard and McKeever 2014).

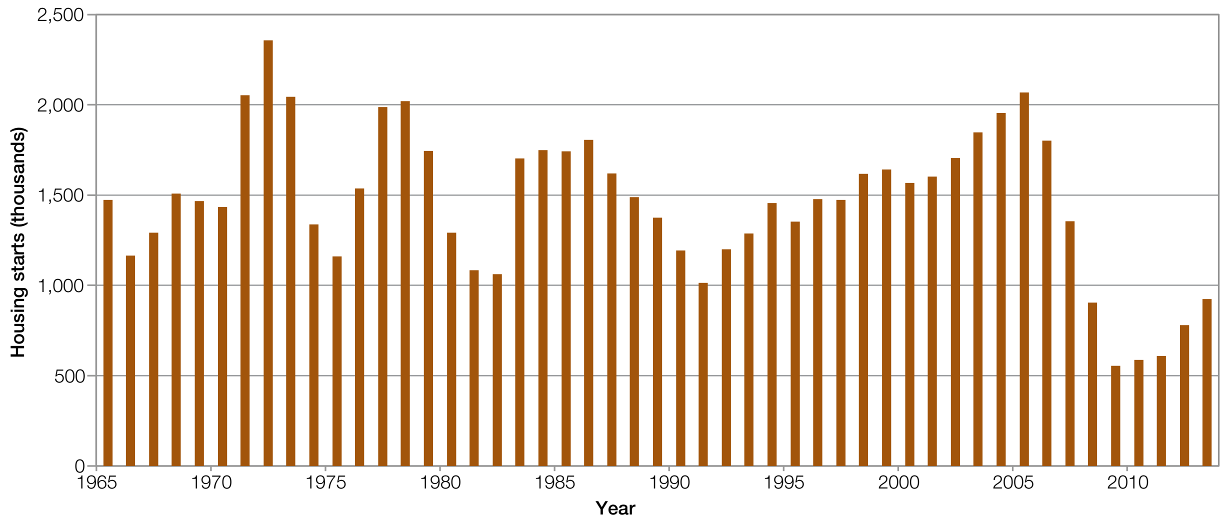
Production in the U.S. furniture industry, in retreat since 1999, was up 2.4 percent in August 2014 compared with production during the previous year. Although small increases in furniture production may persist, the long-term outlook for the domestic market share is for continued erosion due largely to low-cost furniture imports and also a sluggish global economy (Howard and McKeever 2014).

Housing Sector Outlook

- ❖ **Housing starts have continued to increase since the low in 2009 and may attain historical norms of less than 1.1 million in the next few years, but they are not likely to reach the high levels seen in 2004 and 2005 in the foreseeable future.**
- ❖ **The outlook for solidwood demand is uncertain because wood use per installed square meter has declined during the past 50 years, influenced by the diverging wood-use trends between multifamily and single-family units.**

The long-range U.S. housing construction outlook traditionally was supported by the theory of an "underlying" long-term housing demand driven by demographics of household needs. According to this demographic theory, average annual U.S. single-family housing starts should be upward of 1.4 to 1.5 million. Actual U.S. single-family housing starts, however, have averaged less than 1.1 million during the past 50 years and exceeded 1.5 million in just 2 of those years (2004 and 2005) as part of total housing starts (figure 6-2). In hindsight, those levels are now regarded as abnormally high (Ince and Nepal 2012).

Figure 6-2. Total U.S. housing starts, 1965 to 2013.

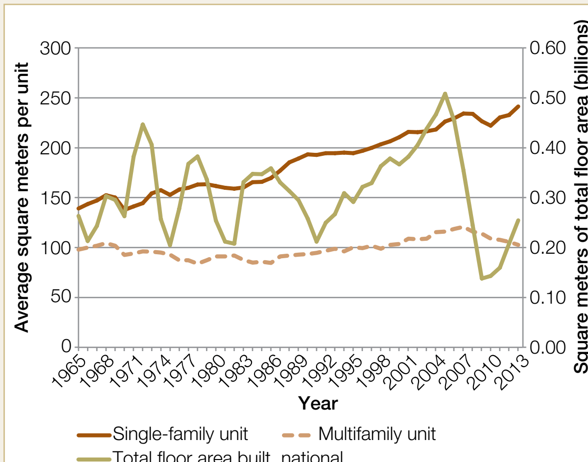


Source: U.S. Census Bureau (2014d).

Important indicators of structural change in the housing market include a correction in median wealth of U.S. households as home values declined along with homeownership rates. By 2012, the U.S. homeownership rate reported by the U.S. Census Bureau was retreating toward levels that were the norm from the late 1960s to mid-1990s, around 64 to 65 percent, which supports a view that housing demands are reverting toward historical norms (Ince and Nepal 2012). The housing recovery continues to maintain momentum. New housing construction totaled 925,000 units in 2013, up from 781,000 in 2012 (NAHB 2013). The seasonally adjusted annual rate for 2014 was slightly more than 1 million (U.S. Census Bureau 2015). In addition to housing's importance as a market for wood products, nonresidential construction is also an important market, accounting for approximately 25 to 35 percent of all construction value. In 2013, about 28 percent of all construction was for nonresidential buildings and nonbuilding-related construction (Howard and McKeever 2014).

Future solidwood demands depend strongly on the course of housing demand. The mix and composition of housing types influence total wood demands. Much of the most recent rise in housing starts occurred in the multifamily dwelling category (five or more families per dwelling), which has increased its share of the total number of housing starts since the peak of the previous cycle. This share averaged 18 percent between January 1998 and December 2006 and has averaged 32 percent since January 2012. Multifamily dwellings use less wood per person. According to the U.S. Census Bureau (2014e), multifamily dwellings completed in 2013 averaged 103 square meters in floor space, compared with 241 square meters for the average single-family house completed that year. New housing in the United States provides about 9 percent less floor area per family in the current recovery than in the previous cycle. Further, data (Skog et al. 2012) indicate that wood use per unit of installed square meter of floor area declined by about 10 percent during the past 50 years. Although the average floor area of multifamily units has been declining since 2007, the average floor area of single-family units in 2013 was the highest ever recorded, rising along a trend of an additional 2.13 square meters per year since 1965 (Howard and Westby 2013; U.S. Census Bureau 2014b, 2014d) (figure 6-3). It is not clear whether these divergent trends will continue into the future.

Figure 6-3. Average floor area per unit and total floor area built in residential units in the United States, 1965 to 2013.



Sources: Howard and Westby (2013); U.S. Census Bureau (2014b, 2014d).

Trends in Pulp and Paper

❖ **Trade patterns, a downturn in domestic spending, and the substitution of electronic media for paper media continue to put downward pressure on U.S. paper and paperboard production.**

Trade patterns continued to have a significant impact on paper and paperboard production and affected pulpwood use. The significant decline in U.S. paper and paperboard production and consumption, however, that occurred during the past decade was caused by the global recession, the decline in the paper-using manufacturing sector, and the substitution of electronic media for paper media. This decline mirrors the similarly timed experiences of many other member countries of the Organization for Economic Cooperation and Development (Hetemäki and Hurmekoski 2014). Exports of paper, paperboard, and converted products decreased between 2012 and 2013 by 1.9 percent, to 11.7 million metric tons, but imports of paper and paperboard increased by 4.9 percent, to 9.9 million metric tons. Paper and paperboard production decreased by 0.7 percent in that same period, falling to 72.9 million metric tons. The production of paper and paperboard in 2014 was forecast to be roughly the same as it was in 2013 (Howard and McKeever 2015).

Trends in Wood and Biomass Energy

❖ **The wood pellet sector is growing and dynamic.**

❖ **Use of wood to produce energy cannot be assumed to be carbon neutral.**

In the United States, industries, electric utilities, commercial entities, and residents use wood to produce energy. Industrial wood energy, produced by wood products and pulp and paper manufacturing, comprised 59 percent of all wood inputs to U.S. energy in 2014, the lowest percentage since comparable data collection was begun in 1990. Wood use for residential heat comprised 26 percent of wood inputs to energy, with smaller amounts used by commercial entities (3 percent) and electric utilities (11 percent, the highest since 1990) (U.S. DOE EIA 2016). Before 2011, exports of wood from the United States for energy production were limited, but a new market has developed in the European Union in response to renewable-energy policies (see chapter 7 for a special study on wood pellets).

The treatment of emissions from biomass has been a source of debate for several years. The U.S. Environmental Protection Agency (EPA) suggested the possibility that emissions from biomass might be treated on the same terms as emissions from fossil fuels. At the same time, EPA recognized the uncertainty about the carbon-offset benefits of wood and other biomass sources (U.S. EPA 2010). Biogenic carbon dioxide (CO_2) emissions being reviewed include diverse sources such as those derived from combustion of biological material, including all types of wood and wood coproducts, forest residues, and agricultural material (U.S. EPA 2011a). On January 12, 2011, EPA announced its plan to defer for 3 years the requirement for greenhouse gas permits for CO_2 emissions from biomass-fired and other biogenic sources (U.S. EPA 2011b).

EPA more recently provided a revision to its draft framework that provides guidelines for accounting for carbon emissions from stationary energy sources, such as electric power plants that could use a range of biogenic feedstocks, including forest biomass and wood residues, agricultural crops and residues, and municipal solid waste (U.S. EPA 2014a). The EPA indicates the draft framework is not written with specific policies in mind and seeks a framework that could guide applications for a range of policies. The revised framework acknowledges and responds to the review comments from the EPA Science Advisory Board regarding carbon neutrality from biomass energy, which cannot be assumed a priori.

The EPA framework includes draft guidance for estimating the net increased CO_2 in the atmosphere caused by increased biogenic feedstock use, by feedstock category and region, compared with a business-as-usual baseline with less or no biogenic feedstock use. The framework is under review and further decisions are needed to refine the guiding principles for estimation and specific methods for specific policy applications.

The U.S. Role in the International Forest Products Sector

❖ **The U.S. share of global wood products output peaked in the late 1990s, declined before the 2007-to-2009 recession, and has since fallen to an unprecedented low.**

❖ **Long-term trends in paper use, trade, and U.S. manufacturing activity indicate that the U.S. share of global paper output is unlikely to return in the foreseeable future to the peak levels observed in the late 1990s.**

The 2010 RPA included information about historical trends in the forest products trade but focused primarily on the projections of imports and exports for various products. In this section, we review the U.S. role in the international forest products sector, how it has changed over time, and the potential outlook, based on Prestemon et al. (2015).

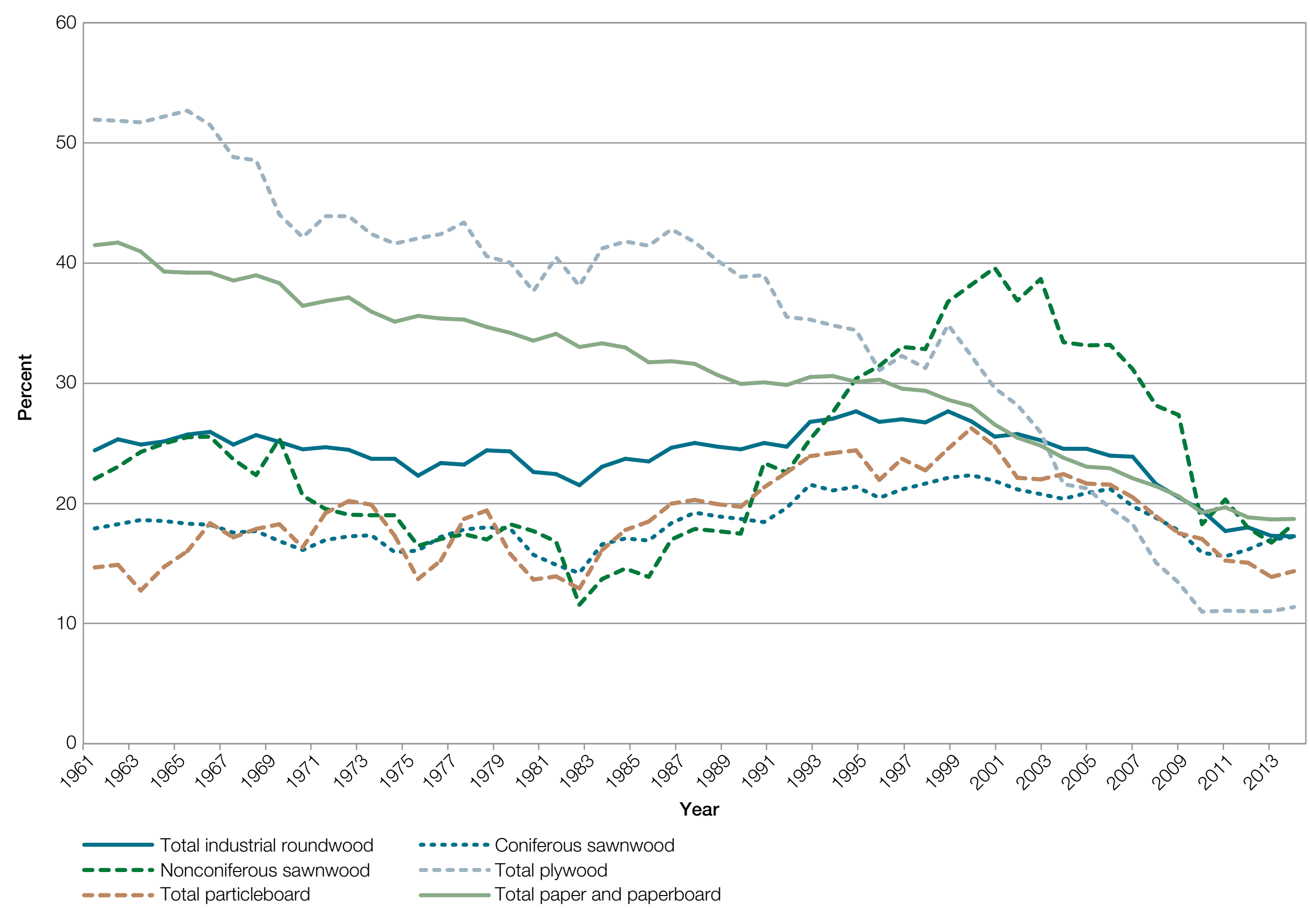
The United States led the world in industrial roundwood production from 1961 to 2013, although its share of global production declined from a peak of 28 percent in 1998 to less than 18 percent by 2013. Part of the decline is attributable to growth of roundwood production in Russia and New Zealand. The growth in some countries contrasts with shrinkage in others. For example, Japan's production has declined by 90 percent since 1973. Although economies throughout the world were affected by the global recession, the wood products sectors in the United States and Canada were affected to a greater extent than were major producing countries in the rest of the world. As well as having been the largest producer of roundwood, the United States has been the world's largest consumer of industrial roundwood throughout the same period of 1961 to 2013. The 2007-to-2009 recession had a disproportionate impact on U.S. wood consumption. After growing steadily from about 250 million cubic meters in 1961 up to 417 million cubic meters in 2005, U.S. consumption has receded to less than 280 million cubic meters since the housing market contraction. At the same time, the United States has also been a world leader in industrial roundwood exports and, since 1963, has had positive net exports. In 2013, the United States had net exports exceeding 15 million cubic meters.

Since 1961, U.S. production of total industrial roundwood and major categories of derivative timber products has declined as a share of global production (figure 6-4). The following sections address these trends in greater detail.

Coniferous Sawnwood Production Share

The United States has led the world in the production of coniferous sawnwood (lumber), even as it has long been a net importer of coniferous sawnwood, largely from Canada. The United States' dominance in production has narrowed since the late 1990s. The decline from the late 1990s, when global production share was more than 22 percent, can be attributed to declining domestic production and to increased production in Russia, China, and other countries with significant coniferous resources. The most recent recovery in U.S. share from the 2010 low of 15.6 percent to the 2013 share of about 17.2 percent is consistent with the partial construction market recovery; a continuing construction recovery is likely to bring this share closer to its 1961-to-2012 average of 18.5 percent. Countries with significant comparative advantage in coniferous sawnwood (Canada, Finland, Sweden, and now Russia),

Figure 6-4. U.S. production share of global production, by aggregate forest product category, 1961 to 2013.



Source: FAO (2014).

however, are exporting far more than they import. The United States, on the other hand, historically has depended on Canada to satisfy a large share of domestic demand for this product category. This dependence continues today, even after reduced imports from Canada since 2005 and increased exports from the United States to global markets. Expanded plantation resources in the Southern United States and the continued increase in the average floor area of single-family homes point to underlying long-run strength in U.S. production of coniferous sawnwood.

Nonconiferous Sawnwood Production Share

As it has been with coniferous sawnwood, the United States has been a world leader in the production of nonconiferous (hardwood) sawnwood since 1961. The U.S. share of global markets grew from less than 15 percent in the early 1980s to a peak of 39.6 percent in 2000. Its subsequent decline to about 18 percent reflects multiple factors: rapidly increasing production in China (currently the world leader in production), the offshoring of the U.S. furniture sector, and a decline in the U.S. share as the output of tropical hardwood sawnwood has expanded in Indonesia, Malaysia, and Brazil. Given these multiple overseas trends, the likelihood that the U.S. global share will return to its historical dominance is small, especially as long as China can obtain the imported wood needed to support its furniture sector and as long as other rapidly growing Asian economies and Brazil can produce and consume tropical hardwood to manufacture furniture and other hardwood products to satisfy burgeoning domestic consumption.

Plywood Production Share

The U.S. share of global production of plywood has been on a long-run decline since the early 1960s, falling from more than 52 percent in 1965 to approximately 11 percent by 2009, when it leveled off. The United States lost its lead in plywood production to China in 2003. Throughout nearly the entire 1961-to-2013 span of data, the United States has imported more plywood than it has exported. In the 1980s, total U.S. plywood exports grew to more than 1 million cubic meters, nearly equaling imports. By 1998, however, exports were again on the decline, but import quantity was increasing. The steep decline in the U.S. share of plywood output is linked to growth in Asia's economies over several decades. First Indonesia and then Malaysia became major net exporters. In the late 1990s and early 2000s, China emerged as a major net exporter of plywood after spending the previous two decades as a net importer. By 1990, China had already emerged as a one of the world's largest consumers of plywood, and China's consumption grew rapidly throughout the next two decades. In 2003, China became the world's largest consumer of plywood, and its production of plywood increased by 4 million cubic meters per year in the past decade, settling above 40 million cubic meters by 2009. Given that the U.S. market is shifting toward more production and consumption of OSB, it is highly unlikely that the U.S. global share of production of plywood will increase from its prerecession level of 20 percent. It is more likely that the U.S. level of plywood production and global share of plywood production will continue to shrink.

Particleboard Production Share

The U.S. share of global production of particleboard has ranged between 13 and 26 percent and has declined since the turn of the century. The U.S. share rose from about 15 percent in the early 1960s to a 1999 peak of 26.3 percent but dropped to 14.4 percent in 2013. The United States was the world's single largest producer of particleboard from 1961, until it was surpassed by China in 2013. Since the 1980s, the production of particleboard around the world has been rising steadily and at a rate faster than in the United States. This market remains dynamic, but it appears unlikely that the United States will realize substantial growth in market share for particleboard.

Wood Pulp Production Share

The United States has been a global leader in wood pulp production, averaging more than one-third of the world's output during the 1961-to-2000 period. Since then, however, its share has dropped slowly but steadily, to 28.3 percent in 2013. The decline in share is likely a long-run natural outgrowth of the United States' historical subordinate position to Canada, Finland, and Sweden in global markets and, lately, of the emergence of Brazil as a dominant competitor in global markets in the 2000s. The decline is apparently not due to recent changes in the rate of recovered paper consumption; the ratio of the tonnage of recovered paper consumed in the United States to the tonnage of wood pulp produced in the United States has deviated little from its average ratio of 0.57 during the entire span of 1996 to 2013. Brazil became the second largest net exporter of wood pulp in the 2000s, and Brazil's net export quantity of wood pulp reached a historical peak, at 9.4 million metric tons, in 2013. The decline in U.S. share is most consistent with the declining domestic use of paper by the manufacturing sector and the falling consumption of paper in print media. The United States has had a favorable balance of trade (positive net exports) in market pulp since 2007, and wood pulp exports have been increasing, even as domestic paper production in the United States has been receding.

Paper and Paperboard Share

❖ **Paper demands for writing, newsprint, and advertising have declined precipitously since 2000, because electronic media have supplanted these uses.**

The United States was a global leader in paper and paperboard production, but its global share of this production declined from more than 40 percent in the early 1960s to 18.3 percent in 2013. Multiple factors have contributed to this decline. First, Canada, Finland, and Sweden are among the most competitive countries globally in the paper sector, with paper exports exceeding imports for several decades. Second, China surpassed the United States in paper and paperboard production in 2008; its output grew from less than 10 million metric tons in 1984 to more than 100 million metric tons by the late 2000s, largely in response to growth in domestic demand. By the 1980s, China had become the world's third largest consumer of paper and paperboard, importing far more than it exported at the time. By 2008, China's consumption had risen to levels exceeding those of the United States, and, by 2010, China emerged as a net exporter of paper and paperboard. Third, the rising use of electronic media has put downward pressure—and is likely to put further downward pressure—on incentives to make printing paper, writing paper, and newsprint in the United States, undermining domestic demand for those products.

Discussion

❖ **Ongoing U.S. population and economic growth should raise demands for housing construction, and a return to long-run starts should eventually bring the U.S. share of global wood products markets close to prerecession levels.**

❖ **Although domestic economic activity dominates U.S. wood products production, trade has become increasingly important. Most notable in the area of trade is the growth in manufacturing output in China, which has shifted comparative advantage for paper and paperboard production toward Asia.**

The U.S. forest products sector has undergone changes that are both cyclical—tied to markets in sectors that use wood and that fluctuate with the domestic economy—and long term—linked to changes in multiple factors that are particular to output markets, evolution in tastes and preferences, changes in technology, and global economic growth. The overall trend in the U.S. share of global production has been negative in most categories, with some being evident since the 1960s and others emerging since the late 1990s.

Among the long-term trends is the advance of engineered wood products. Data indicate (Skog et al. 2012) that wood use per installed square footage of housing decreases slightly over time, and some of this decrease is attributable to engineered systems. This decrease, however, has been offset by the strong upward trend in the size of new single-family houses. Another strong trend is the decline in industrial roundwood use in the paper sector, a result of both recycling and the decline in the use of paper in the media. Finally, the apparent long-run decline occurring in the manufacturing sector in the United States has implications for the use of paperboard. These trends have been reflected in closures of U.S. pulp and paper facilities, reducing domestic demand for wood fiber and the labor required for processing it.

Technological change will continue to erode jobs in the paper and wood products industries, even while profits per unit of output might not decline or may even rise. China and other rapidly industrializing economies, such as Brazil and Russia, have growing forest products sectors and also have rapidly growing consumer demands for forest products, most of which will be produced within those countries. The wood furniture sector has moved to Asia, where a rapidly growing consumer base is located. Investments in paper manufacturing will continue to focus on the rapidly growing manufacturing sector in Asia. Restoring U.S. dominance in paper production appears highly unlikely, in spite of small recent increases in exports from the U.S. paper sector.

The cyclical housing sector has long been the dominant factor in the U.S. solidwood products markets. Recovery from a housing recession deeper than any experienced since World War II is slowly occurring, yet construction today is still below historical averages. Further recovery will drive U.S. production and likely push its global market share higher, but the composition of housing demands will influence the wood consumption associated with new housing construction. The more recent uptick in the share of multifamily housing units may not last. Overall, construction is increasing, and projections (e.g., Skog et al. 2012) indicate further recovery past the nearly 1 million housing starts (at an annualized rate) observed in the first half of 2014 (U.S. Census Bureau 2014d).

Among emerging trends in forest products output in the United States is the growing wood energy sector. This sector, however, depends on policies and programs that provide the financial incentives (e.g., in Europe, to meet its 2020 targets for renewable-energy provision). A detailed discussion and an analysis of the effects of the wood pellet trade are the focus of the next chapter.

Another trend (so far, not completely observed in the data) is the future potential decline or leveling off of populations in Europe, North America, and Japan. We are already seeing an accelerating decline in the importance of Japan in world forest product markets because of its population decline and economic stasis. Important destinations for forest product exports in Europe have leveling populations and today are experiencing sluggish economic growth. We might therefore expect receding foreign markets there. The United States has already experienced steep declines in production and consumption of paper used in media—trends that are likely to spread and accelerate in other countries as electronic media further penetrate those growing markets. The likely result is a waning global demand for the wood fiber that is needed in that sector. Increased rates of recycling are likely to dampen further growth in the use of virgin wood fiber per unit of paper output in the United States. The growth of paper output in China, enabled in part by rapid growth in exported U.S. recovered paper, however, may also mean a rising future market for U.S. exports of virgin fiber, in the form of market pulp.

Many uncertainties exist, and recent trends are not predictions of the future. Adjustments in forest product manufacturing capacity and timber supplies occur somewhat slowly, however, so some trends are indeed likely to continue. What is clear is that standing timber volumes in the United States are rising (Oswalt et al. 2014) and are likely to rise into the future, particularly as a legacy of the recent production downturn. This rise implies low pressure on timber prices in the United States. Heavy demand growth in countries such as China, however, is likely to bring higher global prices, particularly for inputs to the paper sector and furniture manufacturing. A likely result is expanded export opportunities to China and other emerging manufacturing economies, especially in Asia.

Although the United States has shown movement toward trade balance in several product categories, much of this shift is the result of declines in exports to the United States from Canada. It is not clear, at this point, how the loss of timber inventory to mountain pine beetle is affecting that country's ability to compete against domestic U.S. production. Canada's timber supply situation will continue to have important implications for U.S. production.

The role of wood substitutes is another source of uncertainty. Eastin et al. (2001) documented advances in the role of nonwood substitutes in construction. Wood is often a preferred building material for residential construction, and other materials' inroads in this sector are limited by wood's ease of use and the high cost of its available substitutes. Opportunities might advance in the multifamily and the nonresidential categories of building construction, however, in which steel and concrete are dominant building materials. Initiatives in the United States, Canada, and Europe to expand the use of wood in construction might also mean that wood production and export opportunities could rise even in the midst of other declines in wood consumption.

Finally, global advances in policies and programs demanding or requiring sustainability certification for forest products traded on global markets have the potential to affect foreign markets for U.S. forest products. Whether U.S. producers fully embrace certification, how certified producers conform to the sustainability requirements of destination of markets, and whether certification costs trend higher or lower will have implications for domestic U.S. timber growers and forest product manufacturers. In the longer run, we might expect that the strong resource endowment of the United States and its shift toward production from planted forests will continue to support a strong comparative advantage in wood products, especially if other countries reduce their timber inventories. Observed recent expansion in U.S. timber supply, while not the only requirement, is a step toward some recovery or a slowing of the loss in U.S. market share over the long run.

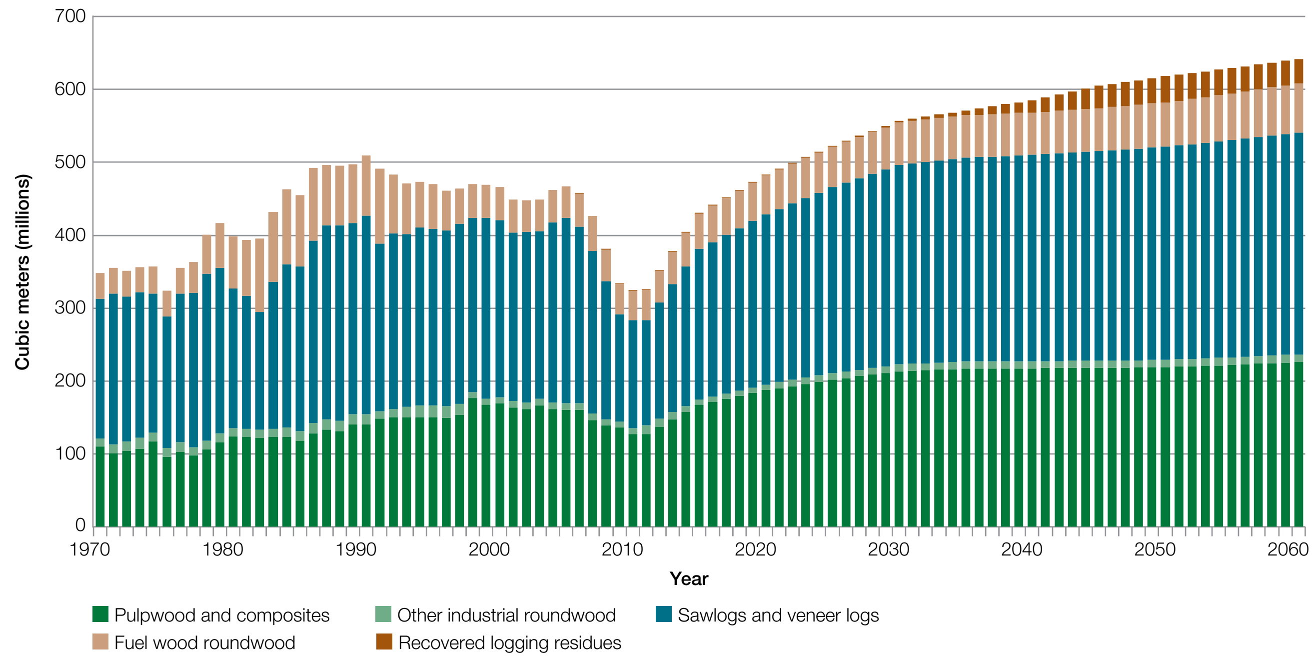
Outlook for Forest Products Production, Consumption, and Trade

The 2010 RPA projections for the forest products sector were based on economic assumptions and projections that did not include the effects of the 2007-to-2009 economic recession. As a result, economic growth in the first decade of the projection period and housing starts were overstated compared with actual levels of economic activity. Ince and Nepal (2012) revisited the 2010 RPA projections and developed a revised projection based on more current economic data.

The 2012 revised outlook accounted for the economic recession and decline in U.S. housing construction, structural changes in U.S. wood product demands, net trade responses to shifts in currency exchange rates, and shifts in U.S. timber stumpage markets. It included a rebound in housing construction by 2020. Long-run average single-family housing starts after 2020 are projected to follow the long-term historical trend line at around 1.1 million per year through 2060. U.S. timber harvest is projected to rebound from recent depressed levels. Timber harvest levels are projected to level off after 2030, largely because of declining wood pulp production. U.S. timber harvest in 2060 is projected to be about 30 percent higher than it was in 2005, not counting increased recovery of logging residuals for energy use (figure 6-5).

The projections foresee a doubling during the next 50 years in U.S. production of wood fuel feedstock, with some expansion in use of pulpwood and recovered logging residues. The analysis incorporates a trade-weighted exchange rate future, keeping the U.S. dollar cheap relative to the Canadian dollar (at less than 1 Canadian dollar per U.S. dollar) and other major currencies through the duration of the projection. This exchange-rate outlook, obtained from the 2012 USDA Baseline

Figure 6-5. U.S. historical annual timber harvest volumes, 1970 to 2011; revised projection of timber harvest and recovered logging residues, 2012 to 2060.



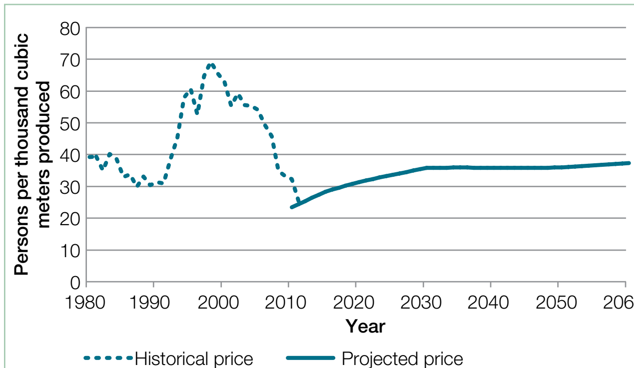
Source: Ince and Nepal (2012).

data projection of USDA ERS (2012) and extrapolated to 2060, served to favor greater and more positive net exports of U.S. industrial roundwood, lumber, and other paper and paperboard when compared with projections emerging from a version of United States Forest Products Module (USFPM) that kept U.S. dollar exchange rates closer to historical averages.

Projections of modest increases in U.S. timber harvests (figure 6-5), a modest rebound in real timber stumpage prices (figure 6-6), and continued expansion in U.S. timber growing-stock inventories have implications for forest management and policy. One implication is an expectation of a rebound in timber revenues, which could support public and private forestry activities. The rebound in timber revenues would be small, with only slight increases in real stumpage prices because of expanding timber inventories and modest growth in timber demand.

U.S. timber harvest is projected to exceed 2005 levels again in the decade after 2020 but then increase only gradually to 2060. The revised timber stumpage price outlook is closest to that of the RPA B2, with little increase in timber prices beyond 2030; projected harvest levels are also at the lower end of 2010 RPA projections. Lower harvests mean lower timber revenue and lower levels of induced investment in forest land that would intensify management or retain more land in forest. Thus, as indicated in the 2010 RPA scenarios with low timber price and harvest projections (USDA Forest Service 2012a), the Nation faces a challenge in enhancing the market value of wood resources. That challenge is shared by both forest landowners and forest managers, who seek to improve forest conditions and must cope with limited growth in timber revenues. The challenge is also experienced by forest product researchers and industry developers, who strive to design future technologies that will make forest enterprises economically sustainable.

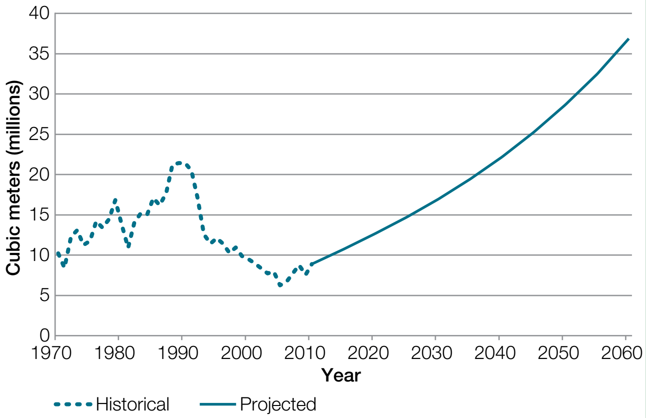
Figure 6-6. Average real historical stumpage prices for southern pine (softwood) sawtimber, 1980 to 2011, adjusted by producer price index and revised projection, 2012 to 2060.



Source: Ince and Nepal (2012).

The projected trend in U.S. net exports of industrial roundwood (figure 6-7) also reflects the growth in global demands for raw wood materials and cost competitiveness of foreign producers of wood products, as represented in the USFPM/Global Forest Products Model (GFPM). Projected expansion of roundwood

Figure 6-7. U.S. historical net exports of industrial roundwood, 1970 to 2011, and revised projection of annual net exports, 2012 to 2060.



Source: Ince and Nepal (2012).

exports suggests a dampening of U.S. employment opportunities that might otherwise exist if exports of industrial roundwood were instead converted by U.S. manufacturers to higher value products and then exported. Nevertheless, projected net exports from the present to 2060 represent an increase from a historical (1990 to 2013) average of 3 percent of U.S. industrial roundwood production to an amount representing approximately 10 percent of the historical average production.

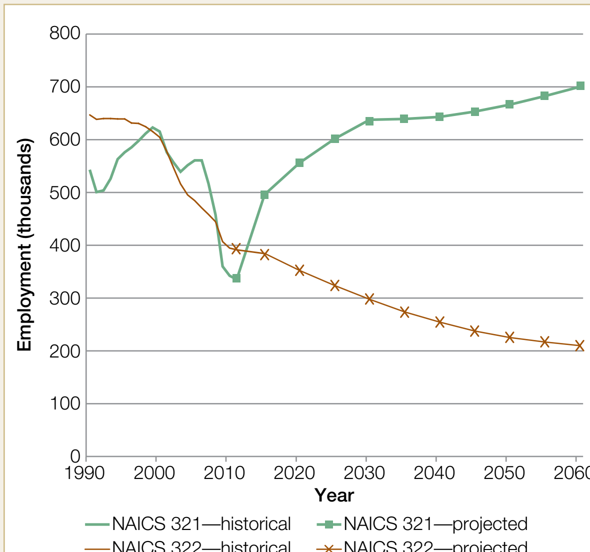
Finally, this revised analysis shows that sustaining future timber markets and timber revenues depends on sustaining the global competitiveness of the U.S. forest sector. Without the projected increases in net exports that occur partially because of an outlook of a weak U.S. dollar relative to the currencies of major trading partners and relative to the dollar's history, there would be no projected increase in U.S. output of pulp, paper, and paperboard and much smaller gains in output of lumber and wood panel products. As revealed in the previous section on the pulp and paper sector, paper manufacturing in the United States depends critically on activity in the rest of the manufacturing sector, which depends on paper for packaging and other processes and which has trended downward since the late 1990s. Together with declining consumption of paper for media in the United States, prospects for expanded paper sector output in the long run remains low. This outlook has implications for jobs in the forest sector (see the sidebar Forest Sector Employment).

Forest Sector Employment

The forest sector experienced significant job losses during the economic recession (Woodall et al. 2012). In addition to being affected by the collapse in U.S. housing construction, forest sector jobs also were negatively affected by structural changes, such as industry consolidation and labor-saving productivity gains.

Figure 6-8 shows U.S. employment trends in the primary wood products and paper manufacturing industries (North American Industry Classification System [NAICS] 321 and 322), along with projected employment derived from the revised projections of production volumes and historical trends in labor productivity. We used projections of U.S. sawnwood, wood panels, and veneer as the basis for employment projections in wood products (NAICS 321) and projections of U.S. paper and paperboard production as the basis for employment projections in paper manufacturing (NAICS 322). We adjusted employment projections in both cases for expected future productivity gains based on labor productivity trends from 1990 to 2011, which show labor productivity increasing more rapidly for paper manufacturing than for wood products manufacturing. Employment in the wood products industry is projected to rebound in the near term because of the projected rebound in housing and the gains in lumber and wood panel output and modest productivity. Paper industry employment is projected to decline because of larger productivity gains and only modest increases in industry output. By

Figure 6-8. U.S. historical employment in wood products and paper products, 1990 to 2011, with projections, 2012 to 2060.



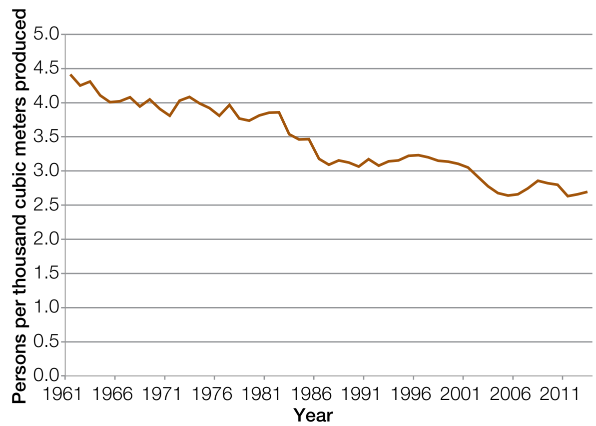
Note: Wood products employment is defined by North American Industry Classification System (NAICS) 321 and paper products employment is defined by NAICS 322.
Source: Ince and Nepal (2012).

2030, total employment in these primary industries is projected to peak and level out at around 0.9 million, which is nearly 25 percent more than depressed 2011 employment levels, but which is still about 25 percent less than peak employment levels of the late 1990s.

The analysis does not project employment in secondary wood products manufacturing, but declining historical employment trends have resulted from outsourcing of secondary manufacturing, such as outsourcing wood furniture production to countries with lower labor costs (Ince et al. 2007; Woodall et al. 2012).

Overall, technological advances in the entire forest products sector have favored capital over labor in the development of the sector (figure 6-9), resulting in a strong reduction in the labor used to produce forest products. New technology has allowed for progressively greater substitution of capital—in the form of machinery, computers, and other equipment—for labor in production. Even absent additional technological advances, with capital costs (interest rates) remaining low, we should expect this trend to continue (Prestemon et al. 2015).

Figure 6-9. Labor intensity in the forest products sector in the United States, 1961 to 2013.



Note: Labor intensity is measured as persons employed per thousand cubic meters of industrial roundwood produced.
Sources: FAO (2014); U.S. BLS (2014a, 2014b).

Future Work

The analysis of the forest products sector in the 2020 RPA will continue to rely on the GFPM as the driving engine for forests and forest products markets. With the embedded USFPM, the USFPM/GFPM system provides projections of markets and forest inventories based on historical data on forests and production and on consumption from the Food and Agriculture Organization of the United Nations (FAO) and the Forest Service, a description of forest product manufacture, peer-reviewed estimates of model parameters, and assumptions regarding how global economic conditions will evolve into the future. The model projects forests and markets for nearly all countries in the world.

We are currently extending GFPM to include planted forest projections by country and creating a capability to include the effects of climate change on forest productivity for all countries. The updated GFPM will be tested in analysis of the implications of the most recent recession on global forest product markets. Other updates address data discrepancies from FAO that involve wood input and wood output imbalances in some large countries (e.g., China).

Updates to USFPM include modifications that will allow for estimating how forest products markets affect both forest carbon removals and carbon storage in wood products. This update is part of an effort to project the role of the U.S. forest sector in meeting possible U.S. carbon emission-reduction goals.

Proposed future work could focus on adjusting GFPM parameters to better model the effects of changing markets for paper products in the United States and globally. Such adjustments, based on new empirical research, would be expected as a result of the growth in use of electronic media, in both wealthy and lower and middle-income countries.

Conclusions

The U.S. forest products sector has undergone both cyclical and long-run changes during the past decade. Cyclical changes are tied to markets in sectors that use wood and that fluctuate with the domestic economy. Long-run changes have been traced to multiple factors related to output markets, evolution in tastes and preferences, changes in technology, and global economic growth. The overall trend in the U.S. share of global production has been negative in most categories, with some being evident since the 1960s and others emerging since the late 1990s. The United States now produces less than 30 percent of the world's forest products in all major categories, and trends point toward further declines in these shares in all these aggregates, even while domestic production quantities increase in particular subcomponent products.

Long-term trends that will influence future U.S. forest products markets include the advance of engineered wood products, the decline in use of industrial roundwood in the paper sector, a long-run decline in the U.S. manufacturing sector, and rising production in other parts of the world. Advances in engineered wood products imply rising fortunes for OSB production, replacing plywood, and for other products that could comprise a greater share of inputs into both residential and nonresidential construction in the United States. Declines in newsprint, printing paper, and writing paper consumption as a result of electronic media substitution domestically could be partially offset by greater exports, but the long-run outlook promises falling consumption of these paper categories globally, implying limited export prospects for producers. On the other hand, although paperboard consumption is likely to further erode because it is tied to a declining domestic manufacturing sector, prospects for increasingly greater exports of this product category to countries where manufacturing is moving could be expected. Rising paper production in China to meet its manufacturing sector needs also depends on increasingly greater quantities of recovered paper, currently mainly derived from imports. Recovered paper fiber, however, needs to be supplemented with virgin wood fiber in paper manufacture, and some of this virgin wood fiber could come from U.S. forests.

The wood products sector in the United States has undergone, and will continue to experience, large fluctuations tied to the construction market. As construction activity in the U.S. market rises from its 2009 low, production of lumber and wood panels will rise to meet part of the growth. The high share of housing starts comprising multifamily structures (more than 32 percent currently), in which the square footage per unit has been declining in recent years, is constraining U.S. wood products demand growth at present. If lending rates recover significantly from their recession-era lows, however, this share should recede toward its prerecession average of 18 percent. Likewise, the continued and rather steady march upward in the square footage of new single-family homes implies expanding markets for wood products in the coming years. Finally, Canada has provided a large share of wood products for the sector, but uncertainty still exists regarding the degree to which it will respond to rising U.S. demand and thereby attenuate domestic U.S. production growth possibilities.

A growing bioenergy sector, particularly in the production of wood pellets, has an uncertain future. Data indicate that it has a small but increasing influence on the pulpwood market in parts of the Southeastern United States. In the near term, it is unlikely to significantly influence broader markets for timber products nationwide or lead to changes in the overall U.S. position on global markets. Uncertainty is linked to the nearly complete dependence of the sector on policies promoting its consumption in Europe and the United States.

Chapter 7. Wood Pellet Export Markets and the Effects on Forests in the U.S. South

The use of forests as feedstock for the production of wood pellets is not new, but the recent increase in pellet production due to international policies is changing markets for wood products in the United States, particularly in the South. This chapter summarizes information from a recent report (Abt et al. 2014) and provides more recent information when available. This chapter was included in the Resources Planning Act (RPA) Update because the pellet export market is new—mostly developing after 2011—and because the potential scale of this market could affect southern forests. This summary begins with a review of the current policy environment, provides trends in pellet production and demand in the U.S. South, and reports on a simulation of the potential effects of projected demand on forests of the U.S. coastal South.

Highlights

- The production of wood pellets for export is a new U.S. market, with most of the pellets shipping from the U.S. South to the European Union (EU) to be burned in utility-scale power generation to meet EU renewable-energy requirements.
- Forests of the U.S. South are expected to continue to provide the largest share of U.S. pellet production, and pellets account for a growing portion of Southern U.S. roundwood harvest.
- The ultimate influence of pellet production on southern forests will be a result of evolving regulations and subsidies in the EU, State and Federal policies and regulations that could affect domestic bioenergy production and consumption, and timber prices and production costs in the U.S. South.

International and Domestic Policy Environment

- The key driver of U.S. wood pellet production and export is the Renewable Energy Directive (RED) of the EU.
- Various Federal and State policies and regulations have the potential to affect domestic bioenergy production and consumption, which could compete with pellet production.

International policies are currently driving U.S. wood pellet production and export. These pellets are exported in bulk and are used in cofiring or direct firing in power plants to produce energy. Of perhaps most importance is the 2009 EU RED[4] and related guidance that seek to promote efficient, low greenhouse gas (GHG), renewable sources of energy in the EU. The primary impact of the EU RED is the requirement that each Member State increase the use of renewable energy and the subsidies granted by Member States to meet that requirement. As EU policy continues to evolve, the effect of new objectives on pellet markets is unclear and will likely remain so until the European Commission provides further clarification.

[4] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (known as the Renewable Energy Directive). OJ L 140/16. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN. [Date accessed: August 6, 2014].

EU bioenergy demand and supply are influenced by policies that seek to ensure that biomass use for energy results in real GHG emission reductions and that biomass use does not imperil the sustainability of bioenergy feedstock. These sustainability criteria are an area of uncertainty in pellet market development. The EU has established general guidelines by which individual Member States can develop their own policies on the use of biomass for electricity production and/or heating. Included in the guidelines are (1) requirements for GHG emission reductions relative to a fossil fuel alternative, (2) provisions to ensure the sustainability of the land use from which the biomass is derived, and (3) requirements for biomass chain of custody and sourcing (see footnote 4).

Three EU Member States have also developed their own sustainability policies: Germany, the Netherlands, and the United Kingdom (UK). Indications are that the EU might adopt sustainability requirements for solid biomass that could further influence the impact of RED on U.S. pellet production and, thus, on U.S. forests. Further action is expected to include the effects of biomass use on indirect land use change and alignment with the recently updated EU forest strategy (Bullein 2014). At this time, the sustainability policies are focused on GHG emission reductions and sustainable land use.

No current U.S. policies specifically encourage or discourage the domestic use of wood pellets, although many existing and potential future policies could influence both the domestic production and consumption of bioenergy. Current U.S. Federal laws that could indirectly influence pellet production and, thus, U.S. forests include the Energy Independence and Security Act (EISA) of 2007[5] and the Agriculture Act of 2014.[6] EISA governs the requirements for cellulosic biofuels and limits the type of wood feedstock that can be used when meeting these requirements. EISA requires that any woody biomass used to meet the renewable fuels standard should come from only non-Federal and nonecologically sensitive lands and from only (1) roundwood and mill residue from existing plantations, (2) slash and precommercial thinnings, or (3) wildfire hazard reduction materials. EISA will affect pellet production if (1) cellulosic biofuels become a commercially viable product and begin to affect timber harvests and/or (2) international policies or subsequent domestic policies use the EISA feedstock limits as a basis for their own sustainability criteria. These requirements would affect forests, because limiting the type and location of inventory available for pellet production could change the procurement costs for some wood feedstocks.

Perhaps the most notable current and proposed policies are taking the form of regulations promulgated by the U.S. Environmental Protection Agency (EPA). These policies include proposed new source performance standards,[7] proposed guidelines for regulating carbon emissions from fossil fuel power plants under section 111(d),[8] the adopted Boiler Maximum Achievable Control Technology rule[9] under the Clean Air Act of 1970,[10] and Non-Hazardous Secondary Material regulations[11] under the Resource Conservation and Recovery Act of 1976[12] (Probert 2012; Tarr and Adair 2014; U.S. DOE EIA 2013). The proposed new source performance standards and guidelines for regulating existing sources under section 111(d) of the Clean Air Act have the potential to increase the demand for bioenergy in the United States. The degree to which they influence domestic demand for bioenergy production depends, in part, on rules governing biogenic carbon accounting processes, which are still under development by EPA. If these accounting processes show biomass to be GHG-beneficial relative to other fuels, an increase could occur in the use of wood in electricity-generation facilities within the United States. The Clean Air Act, Boiler Maximum Achievable Control Technology rule, and Non-Hazardous Secondary Material regulations alternatively have the potential to increase the costs of biomass use, including wood pellet production, by requiring additional pollution abatement practices or technology. The precise impacts of both sets of drivers are currently unknown.

[5] Energy Independence and Security Act of 2007. Pub. L. 110-140. 121 Stat. 1492. http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/html/PLAW-110publ140.htm. [Date accessed: August 6, 2014].

[6] Agriculture Act of 2014. Pub. L. 113-79. 128 Stat. 649. http://www.gpo.gov/fdsys/pkg/PLAW-113publ79/html/PLAW-113publ79.htm. [Date accessed: August 6, 2014].

[7] EPA National Emission Standards for Hazardous Air Pollutants: Off-Site Waste and Recovery Operations—Proposed Rule. 79 Fed. Reg. 37850 (proposed July 2, 2014) (to be codified at 40 CFR pt. 63). http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2012-0360-0001. [Date accessed: August 6, 2014].

[8] EPA Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units—Proposed Rule. 79 Fed. Reg. 34830 (proposed June 18, 2014) (to be codified at 40 CFR pt. 60). http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2013-0602-0001. [Date accessed: August 6, 2014].

[9] EPA National Emissions Standards for Hazardous Air Pollutants for Area Sources: Industrial, Commercial, and Institutional Boilers—Final Rule. 78 Fed. Reg. 7487. 40 CFR pt. 63. https://federalregister.gov/a/2012-31645. [Date accessed: August 14, 2014].

[10] Clean Air Act of 1970. Pub. L. 159 (July 14, 1955) 69 Stat. 322, and the amendments made by subsequent enactments. 42 U.S.C. 7401–7626. http://www.epw.senate.gov/envlaws/cleanair.pdf. [Date accessed: August 6, 2014].

[11] EPA Commercial and Industrial Solid Waste Incineration Units: Non-Hazardous Secondary Materials That Are Solid Waste—Final Rule. 78 Fed. Reg. 9112 (February 7, 2013). 40 CFR pts. 60 and 241. http://www.regulations.gov/#!documentDetail;D=EPA-HQ-RCRA-2008-0329-1981. [Date accessed: August 6, 2014].

[12] Resource Conservation and Recovery Act of 1976. Pub. L. 94-580. 90 Stat. 2795. 42 U.S.C. 82 pt. 6901. http://www.gpo.gov/fdsys/pkg/STATUTE-90/pdf/STATUTE-90-Pg2795.pdf. [Date accessed: August 6, 2014].

Other Federal policies that could be enacted include possible extensions to the Federal biomass production tax credit or a Federal renewable portfolio/clean electricity standard, the latter of which has been introduced in Congress in recent years with little legislative traction. These standards would require a renewable component of national electricity production. No laws or policies are currently under consideration on these topics.

State-level renewable portfolio standards have the potential to influence wood consumption for energy production. Use of woody biomass for energy is still more expensive than other carbon-based energy feedstocks, and State-level policies do not provide subsidies for biomass use. Utilities will likely choose the least cost method of meeting State renewable portfolio standards requirements, which may not include burning biomass. A regional analysis of the RPA North suggests that renewable portfolio standards had little to do with the use of wood as a source of renewable energy in cofiring. After costs of procurement are included, it is likely that wood energy will contribute only a fraction to State-level renewable portfolios—unless subsidies increase and conversion efficiency improves substantially (Aguilar et al. 2012). In addition, the EPA's Tailoring Rule will affect how GHG emissions from burning biomass are counted, which may alter behavior and/or State requirements for biomass use for energy.

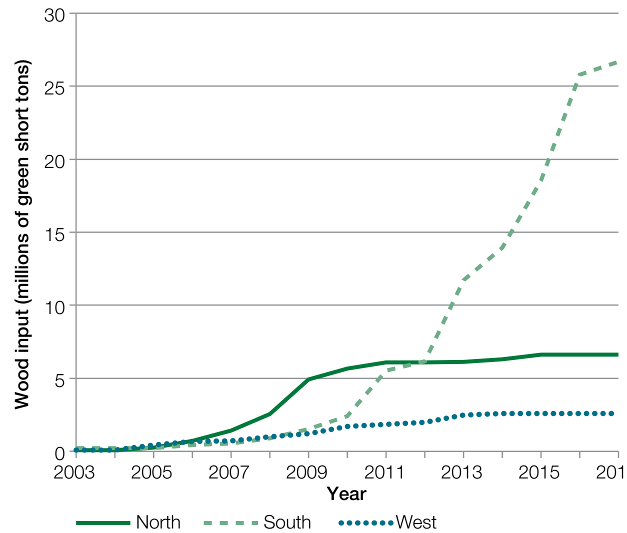
Trends in Wood Pellet Production in the United States

❖ The South dominates U.S. wood pellet production.

The wood pellet market in the United States historically has produced bagged pellets for use in residential wood pellet stoves, but the large-scale production of bulk pellets for export is a relatively new phenomenon. Influenced by EU policies, U.S. production and export of wood pellets have increased, with demand for pellet feedstock increasing from 3.8 million green short tons (mgt) in 2008 to 19.8 mgt in 2013. Increased pellet production is expected to come from the U.S. South, where 81 percent of all new pellet production capacity has been announced (Forisk Consulting 2014). Figure 7-1 shows the evolution of overall pellet production capacity by U.S. region during the past decade (Forisk Consulting 2014). The U.S. South currently contains more than 62 percent of total U.S. pellet production capacity, up from 12 percent in 2003.

Nearly all of the new capacity was developed to produce pellets for export to EU Member States (U.S. Department of Commerce 2015). From January 2012 to July 2015, 98 percent of U.S. exports were to the EU, dominated by the UK (65 percent), Belgium (17 percent), and the Netherlands (9 percent), with 3 percent going to each of Italy, Denmark, and the rest of the world. For 2015, the UK is even more dominant

Figure 7-1. Growth in wood pellet production capacity, by U.S. region, 2003 to 2014, and projected, 2015 to 2017.



Source: Forisk Consulting (2015).

(82 percent); Italy, Denmark, and the rest of the world received less than 1 percent of U.S exports through July of 2015. Future exports are expected to be dominated by exports to these same countries. During this time, nearly all U.S. pellet exports were from ports in the South. Some discussion in the literature addresses the potential for non-EU countries to become pellet importers (Roos and Brackley 2012; WRI 2014), particularly the Pacific Rim countries, but few U.S. exports are currently made to these countries.

Projected Wood Pellet Demand

❖ Absent major policy changes in the EU or United States, demand for U.S. wood pellets is expected to continue to grow.

❖ The U.S. South will continue to provide the largest share of U.S. pellet production for export.

Given the outsized role the EU is expected to play in future wood pellet markets, projections of global pellet demand tend to be EU focused. Woody biomass from the U.S. South is expected to be used to meet EU bioenergy targets during the next decade (Beurskens et al. 2011; Goh et al. 2013b; Joudrey et al. 2012).

Cocchi et al. (2011) summarized nine projections of EU pellet imports from worldwide supply regions. For 2020, the various projections range from 15 to 80 million dry metric tons. For the low estimate from Cocchi et al. (2011), the U.S. South and Canada are expected to supply about 36 and 28 percent, respectively, of the import estimate, with Australia, Brazil, Russia, and New Zealand supplying the remainder. Under the higher estimate from Cocchi et al. (2011), the volumes from the United States and Canada are not expected to increase, so the additional imports would come from increases in African, Russian, and South American production. Estimates provided by Goh et al. (2013b) also suggest that pellets from the U.S. South could provide more than one-third of total EU energy imports by 2020.

Potential competition for EU imports from other countries may be minimized by the historical pattern of biomass trade in this region, and/or through application of sustainability criteria, which would direct noneligible biomass to markets with less restrictive policies in place (Brackley 2013; Lamers et al. 2014; Roos and Brackley 2012). Market development in East Asia alternatively could divert Canadian exports away from the EU while also stimulating the expansion of existing pellet production capacity in Southeast Asia and Australia (Goh et al. 2013a). Wood Resources International (2014) discusses the possible exports from both Eastern Canada and British Columbia—two geographic areas that compete for the export of pellets to the UK—and also addresses how relative costs and relative anticipated GHG emissions reductions will affect the proportion of UK and EU pellets that are supplied from the U.S. South.

Projections by RISI, Inc. (2013) show a more than 250-percent increase in pellet production between 2011 and 2015 and a nearly 70-percent increase between 2015 and 2020. Forisk Consulting (2014), which instead projects changes in bioenergy production capacity based on operating and announced facilities, projects an increase of 450 percent in pellet production in the U.S. South between 2011 and 2015 and another 22 percent between 2015 and 2020. Recent projections by Forisk Consulting (2015) imply that not all of the announced capacity will be built in the next few years.

Current and Projected Biomass Production in the U.S. South

❖ Increases in wood pellet production could result in a net increase in timber removals.

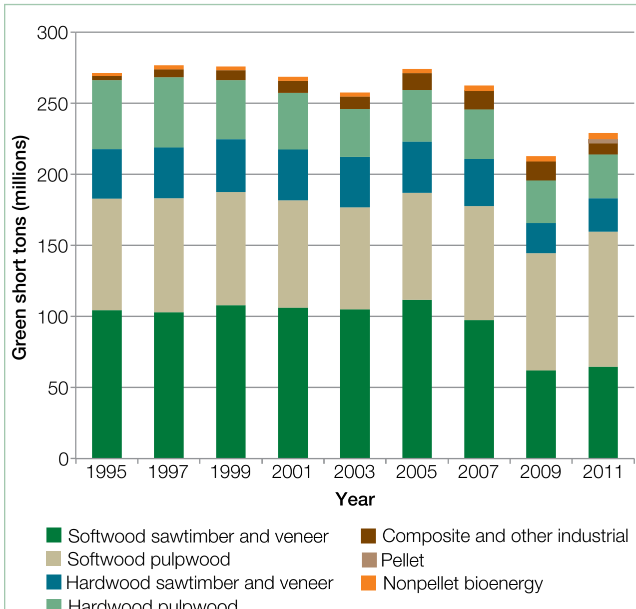
Domestic and foreign policies that promote or require renewable electricity production affect both the supply of and demand for wood feedstock. Changes in the supply and demand of wood feedstock will affect U.S. forests, forest management, forest landowners, and other users of forest products. Both the supply of and demand for timber is relatively unresponsive to price changes. Therefore, the market will be relatively slow to adjust to rapid increases in the demand for timber for renewable energy, and some type of leakage or displacement will likely be in the market in the short run. Demand will be affected by the level of renewable-energy goals and by the amount of subsidy supplied by individual governments. Supply will be affected by the specific requirements or restrictions of the policies, such as prohibitions on the use of roundwood or harvest exclusions in areas that are traditionally open to harvest in the United States.

Wood pellet mills are quick to construct, and production and startup can easily occur within 5 years, and possibly as soon as 12 to 18 months. Operating pellet capacity in the U.S. South is 2.5 times greater in 2013 than it was in 2011 (Forisk Consulting 2014), reflecting this quick startup time. This increase in pellet production is reflected in the most recent timber-production data.

Figure 7-2 shows timber removals from the U.S. South from 1995 through 2011, including removals for softwood and hardwood nonsawtimber and sawtimber and for industrial wood products. The effects of the 2007-to-2009 recession can be seen in the decline in softwood sawtimber removals from 2005 through 2009, before removals began to recover in 2011. Pine pulpwood removals do not show any recessionary effects and are level to rising from 2003 through 2011. Hardwood removals are less than one-half of softwood removals for this region, with hardwood nonsawtimber showing a long-term decline from 1995 through 2009 and a leveling off in 2011.

The use of wood inputs for pellet production accounted for about 1.4 percent of total southern timber production in 2011 (Abt et al. 2014) (figure 7-2). The impact of additional harvest, however, will depend on both the specific wood products compared and the geographic scale of the assessment. We did a more detailed comparison of historical and projected wood

Figure 7-2. Timber product output removals for the U.S. South (excluding Texas), 1995 to 2011.

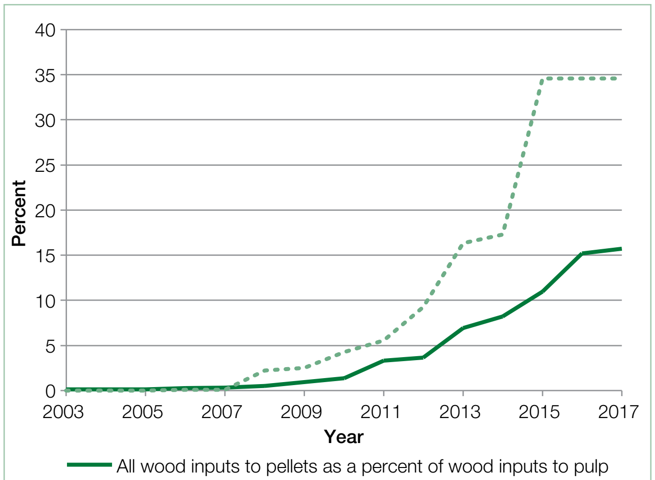


Sources: Abt et al. (2014); for nonpellet bioenergy and pellet, Forisk Consulting (2014); for all other output removals, Timber Product Output Database, USDA Forest Service (2014b).

inputs for pellet production as a proportion of wood inputs for southern pulp production. Figure 7-3 shows that pellets were about 4 percent of the total wood inputs for southern pulp production in 2012 but were 8 percent of softwood pulpwood inputs. Wood inputs to pulp production were fairly steady from 2003 to 2012. Comparing the projected pellet production with the 2003-to-2012 average wood inputs to softwood pulp production, the pellet wood use could be as high as 16 percent of pulp inputs by 2017, and softwood pellet wood use could be nearly 35 percent of softwood wood inputs to pulp. At smaller geographic scales, these percentages could be larger (if both pulp and pellet mills share the same procurement area) or smaller (if no pulp mills are in the pellet procurement area). Both the historical and projected wood input sources for pellets are derived from the announcing company and, thus, may include expectations about future prices and availability of all eligible feedstocks.

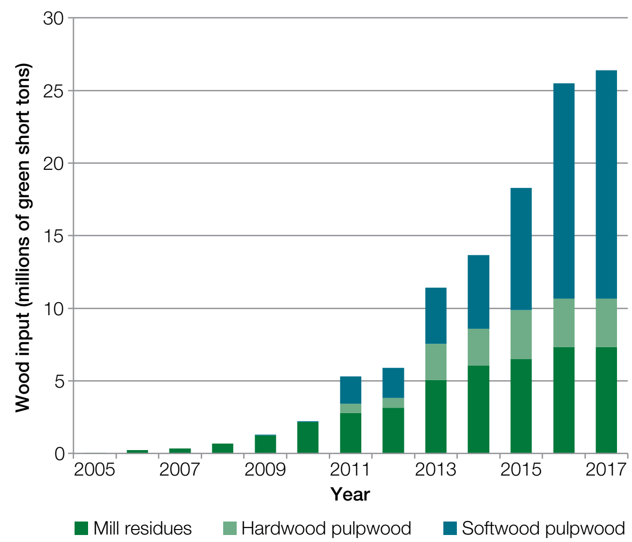
Primary sources for pellet production are mill residues and both softwood and hardwood nonsawtimber, all of which are classified as a "clean" feedstock, with little or no bark. Other types of bioenergy producers are more likely to use logging residues (Forisk Consulting 2014). Figure 7-4 shows that the proportion of projected pellet feedstock that is expected to come from mill residues declines through 2016, but the proportion from nonsawtimber increases. Note that the urban wood waste and logging residues never exceed 1 percent of announced feedstock use. These projections, made by the companies making the announcements, likely assume that the relative prices for feedstocks will not change. A rise in nonsawtimber prices could lead to changes in the feedstock mix, even at pellet plants.

Figure 7-3. Actual and announced wood inputs to pellets as a percent of actual and estimated wood inputs to pulp production, 2003 to 2017.



Sources: Bentley and Cooper (2015); Forisk Consulting (2015).

Figure 7-4. Actual and announced feedstock source for use in wood pellet production in the U.S. South, 2003 to 2017.[a]



[a] Urban wood waste and logging residues never exceed 1 percent of announced feedstock use and, therefore, are not displayed in this figure.

Source: Forisk Consulting (2015).

Effects of Wood Pellet Demand on Forests in the U.S. Coastal South

❖ **Increased wood pellet demand will lead to increased timber harvests and increased timber prices, providing short-run gains to forest landowners and short-run losses to other wood users.**

Changes in the demand for bioenergy, which are driving changes in wood pellet production in the U.S. South, have the potential to affect existing forests, forest management, and forest landowners. Using the most recent Forest Inventory and Analysis data for timber inventory and harvest in the U.S. coastal South (USDA Forest Service 2014a) and the most recent current and projected feedstock consumption by pellet mills and other bioenergy producers (Forisk Consulting 2014), simulations were developed to assess the impact of projected wood demand for traditional wood products and bioenergy on timber markets and forests in the U.S. South. For this analysis, the simulations do not model forest or life-cycle carbon outcomes nor do they impose any limitations on timber that can be used for supply.

The long-run impact of pellet demand on resources and markets depends on the current and projected composition of the inventory and on current and projected traditional demands. Short-run timber supply, on the other hand, reflects past management, including planting, which determines current species mix, age-class distributions, and current competitiveness with alternate land uses—mainly agriculture. This analysis focused on those counties and surrounding procurement areas where announced and existing pellet and other bioenergy facilities will be sourcing wood, referred to as the U.S. coastal South (figure 7-5).

Assumed demands for bioenergy, including both pellets and other domestic bioenergy feedstock capacity, are based on announced capacity (Forisk Consulting 2014). Assumed demands for pine sawtimber reflect a strong housing recovery, continued strength in pine nonsawtimber demand, and flat demand for hardwood products (figure 7-6). Figure 7-6 also shows the total adjusted[13] announced bioenergy capacity (Forisk Consulting 2014).

The Subregional Timber Supply model (Abt et al. 2009) was used to simulate a baseline scenario and a bioenergy scenario from 2010 to 2040. The baseline scenario has small variations

Figure 7-5. U.S. coastal South, showing counties and wood procurement regions for announced and operating pellet and bioenergy facilities.

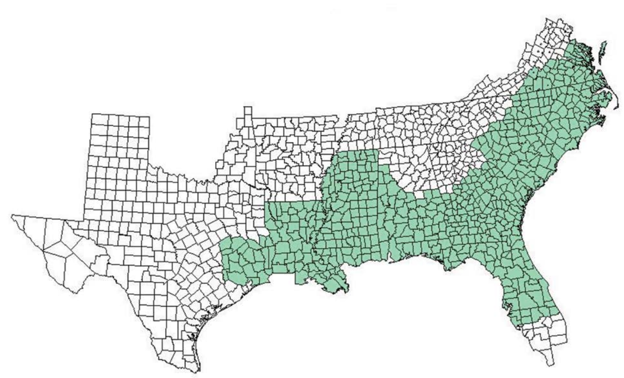
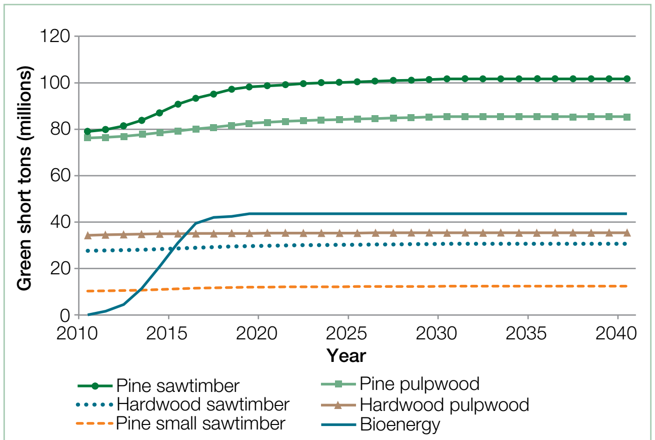


Figure 7-6. Timber and bioenergy demands for the U.S. coastal South, 2011 to 2040. The timber demands are used in both the baseline and bioenergy scenarios, but the bioenergy demands are used in only the bioenergy scenario.



Sources: Abt et al. (2014); for bioenergy demand, Forisk Consulting (2014).

in the prices, inventory, and removals for pine nonsawtimber, with prices falling toward the end of the projection period and with inventory and removals being higher at the end (figure 7-7a). Hardwood nonsawtimber in the baseline has prices falling, inventory rising, and removals being just slightly higher (figure 7-7c). By contrast, the bioenergy scenario shows pine nonsawtimber prices and removals increasing and inventory declining in the early years of the projection and shows all eventually returning to levels of about 20 percent above the initial year by the end of the projection (figure 7-7b). The hardwood nonsawtimber bioenergy scenario shows rapid increases in prices early, with prices, inventory, and removals eventually converging at 20 percent above initial year by the end of the projection (figure 7-7d).

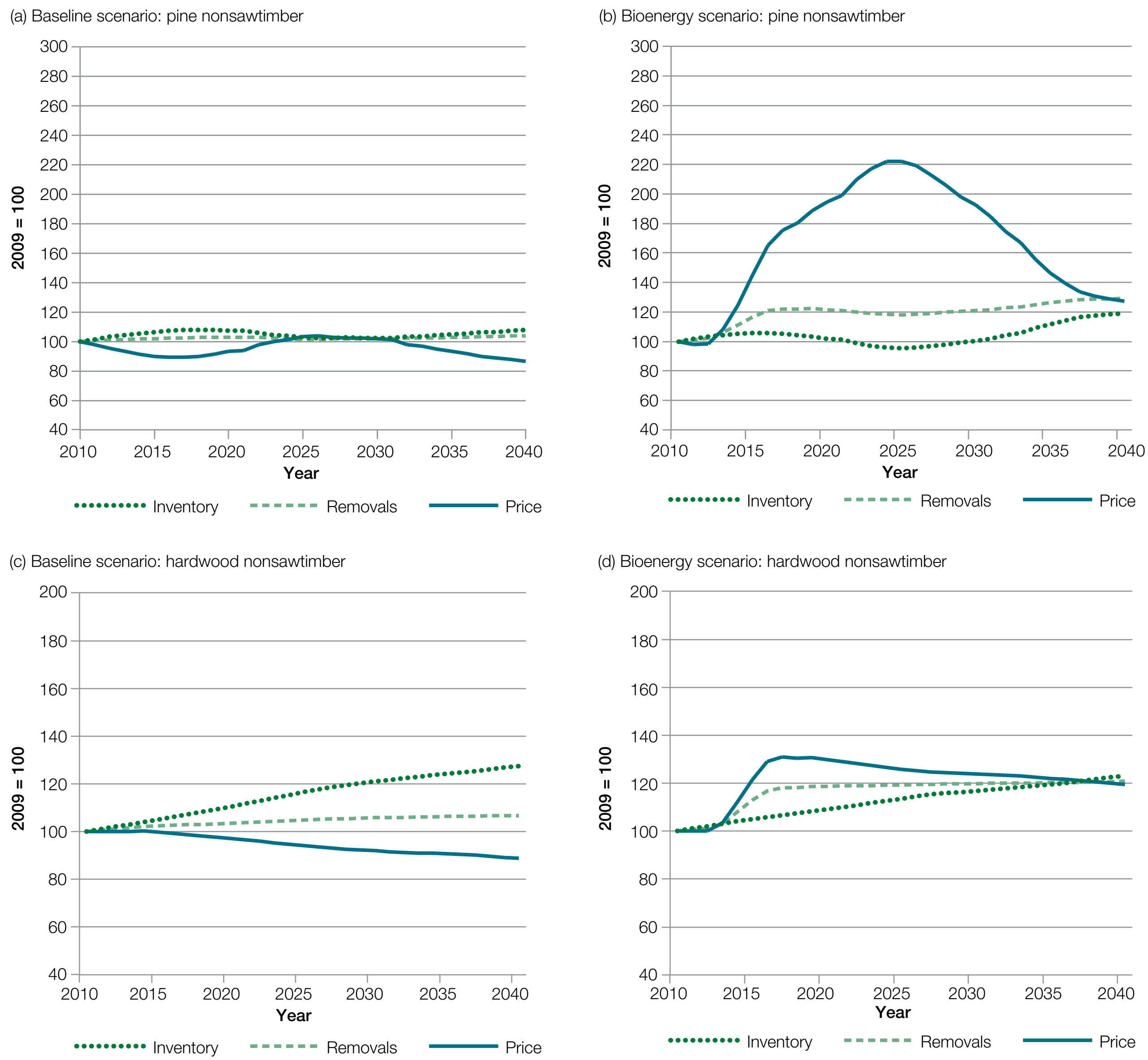
The results also show substantial potential leakage/displacement from the U.S. coastal South region, indicating that the potential for trade in timber may still exist between this region and the more interior regions that were not part of the analysis. As an alternative, increased international imports of either timber or residues could occur, allowing for the final processing to continue in the region, the closure or curtailment of existing wood-using mills, and/or increased imports of these final goods for consumption in the United States.

The land-area model captures the impact of timber rents relative to an assumed flat agriculture rent baseline (Hardie et al. 2000). Pine sawtimber prices recover as housing starts increase, but the prices do not recover to prerecession levels due to significant increases in inventory. After the initial increase, sawtimber prices are flat for the long run, which leads to a continued long-term loss of plantation and natural timberland in the baseline run. Increases in prices due to the increased demand for bioenergy are projected to lead to lower losses of timberland area in the bioenergy scenario.

The land-area model, however, does not inform how rents affect the composition of the forest. Assumptions made for these runs were that plantation acres were twice as sensitive to prices as natural pine, oak-pine, and upland hardwood stands and that lowland hardwood acres were one-half as price sensitive as other natural forest land. The spike in pine nonsawtimber prices in the 2015-to-2030 period significantly influences forest rents, so that plantation acres increase and loss of timberland to agriculture decreases relative to the baseline. Plantation acres expand at the expense of natural forest land and marginal agriculture, but this loss of natural forests to plantation acres is largely offset by the reduction in loss to agriculture. After the price bubble, the long-term decline continues, and, at the end of the projection, there is approximately a 3-percent increase in timberland area over the baseline, with plantations making up 34 percent of timberland in the bioenergy run and 31 percent

[13] Forisk Consulting adjusts the actual wood input projections for startup year by reducing the capacity estimate by one-half. We followed their convention in the modeling described in this section.

Figure 7-7. Total U.S. coastal South projection results showing inventory, removals, and price indices for nonsawtimber for both baseline and bioenergy scenarios and both pine and hardwood, 2010 to 2040. (a) = baseline scenario: pine nonsawtimber; (b) = bioenergy scenario: pine nonsawtimber; (c) = baseline scenario: hardwood nonsawtimber; (d) = bioenergy scenario: hardwood nonsawtimber.



Source: Abt et al. (2014).

in the baseline run. These simulations include only the Coastal Plain and Piedmont areas of the U.S. coastal South (figure 7-5), where marginal agriculture and pine plantations historically compete. An assumption of increasing agriculture rents would have dampened the land use dynamics and led to either more conversion of natural forest to plantations or a continuation of higher prices.

The results indicate that increased bioenergy demand could result in a significant increase in pine nonsawtimber prices. Without increased bioenergy demand, mill residues from the assumed strong housing recovery could be used to meet increasing demand for wood to make pulp and composite panels. The additional demand for feedstock from this predominately pine resource base, along with price inelastic supply, however, leads to sharp price increases and potential leakage and displacement. In the longer run, the price increase leads to expansion of the timberland area over the baseline, which increases inventory and restores price and inventory to near starting-point positions by 2040. By assumption, the increase in timberland area leads to an increase in pine plantation area, although some of this increase is at the expense of natural forest types. The potential for a significant shift in the use of pine from traditional products to bioenergy, however, could lead to structural changes, which are beyond the scope of this study.

For hardwoods, the demand increase leads to a price spike, but inventories continue to increase and dampen prices over time. Increased demand for hardwoods leads to an increase in harvest of both upland and bottomland hardwoods, but it does not exceed the underlying growth in hardwood inventories. The simulations did not include restrictions on land use due to sustainability criteria, which are expected to decrease inventory and increase equilibrium price. The simulations also included assumptions regarding the changes in land use that reflect historical management type changes (e.g., conversion of natural pine to pine plantations), which may not be indicative of future management type changes. The simulations also encompassed an empirical model of land use changes among urban, forest, and agricultural land uses that may not accurately reflect current or future land use changes. Finally, the simulations base harvest decisions to replicate historical harvest patterns by landowner, by species group, by age class, and by forest management type. These patterns may not be indicative of future harvest patterns.

If the demands before 2020 are lower than projected by Forisk Consulting (2014), then prices and timberland area would increase less. If the demands after 2020 are higher than projected, then prices and timberland area would be expected to increase more, or to stay at a higher level beyond 2020. The precise outcome would depend on assumed level of demand for each subregion or aggregate.

Sustainability Criteria and the Future of Wood Pellet Demand

- ❖ Limitations on GHG emissions, land use change, and certification requirements will affect future U.S. wood pellet production.
- ❖ Subsidies provided by EU Member States for the use of wood to produce energy will affect future U.S. wood pellet production.

The influence of sustainability criteria on the production of wood pellets in the United States and elsewhere remains uncertain. Sustainability criteria have to be considered in assessing the potential of woody biomass to reduce GHG emissions, in the treatment of land use change, in establishing chain of custody, in considering potential conflicts with trade policy, and in the willingness of EU Member States to continue to provide subsidies for the production of renewable energy using wood.

The first area of uncertainty derives from the GHG reduction potential of woody biomass, a subject of considerable debate in recent years (Colnes et al. 2012; Galik and Abt 2012; Latta et al. 2013; Miner et al. 2014; Walker 2010). Some experts suggest that the magnitude of biomass demand combined with increasing competition for other uses will make it difficult to meet sustainability criteria in North America (Hewitt 2011). Although the subject of little analysis thus far (except, see Schueler et al. 2013), EU sustainability criteria could limit the supply of southern U.S. biomass to European renewable-energy markets (Stephenson and MacKay 2014).

The ability of southern woody biomass to comply with EU GHG criteria will ultimately depend on the selected GHG accounting methods and actual domestic pellet production methods. Current EU GHG emissions accounting rules do not account for either indirect land use change or changes in land carbon stocks that could result from an increase in harvest to produce feedstock for pellets to produce renewable energy. These aspects of life-cycle accounting for GHG emissions could influence what feed-stocks, and from where, would meet EU renewable-energy needs. The possibility remains that the UK and/or EU regulators could incorporate these two additions to the GHG accounting.

A second area of uncertainty is the need to demonstrate compliance with land use restrictions and chain-of-custody provisions of the sustainability criteria. For many of the countries, including the UK, some of the sustainability requirements can be met through certification of the forest by independent third-party schemes, such as the Forest Stewardship Council, Sustainable Forestry Initiative, or Pan-European Forest Certification. Several overviews of these schemes, including a benchmarking of these schemes to the UK proposed regulations, have concluded that these schemes will require additional inputs to meet the land and chain-of-custody requirements of the EU guidelines and Member State regulations (see Kittler et al. 2012; Ladanai and Vinterbäck 2010; Scarlat and Dallemand 2011; United Kingdom Department of Energy and Climate Change 2014; van Dam et al. 2010; Vis et al. 2008;). U.S. State forestry best management practices (BMPs) may provide some information for compliance with sustainability criteria. The breadth and depth of BMPs vary from State to State, as do implementation rates (Ice et al. 2010). Within States, implementation rates also vary by both year and provision. BMPs may not, by themselves, satisfy EU sustainability requirements (Kittler et al. 2012).

Pellet production may also be affected by the adoption of State-level guidelines or restrictions that influence the volume and manner in which biomass may be harvested. Model guidelines drafted by the Forest Guild exist for the Northeast, Northwest, and Southeast United States. Guidelines have been adopted in several States, including Indiana, Kentucky, Maine, Maryland, Michigan, Minnesota, Missouri, Pennsylvania, South Carolina, and Wisconsin (Kittler et al. 2012). These guidelines supplement any State-level forestry BMPs. Although content varies among individual guidelines, most emphasize defining the allowable removal of down woody debris (Kittler et al. 2012), which will determine the amount of logging residue that can be removed from a harvested site. One exception is the harvesting rules adopted in Massachusetts, which apply only to biomass harvested to meet its renewable portfolio standards.[14] These rules require a GHG reduction and an efficiency level in the production of energy from biomass and place limits on qualifying biomass harvests.

The third unresolved question is whether sustainability criteria will be viewed as compatible with international treaties and trade agreements. For example, sustainability criteria may be vulnerable to challenge under World Trade Organization (WTO) agreements if they discriminate against products sourced from particular countries (Mitchell and Tran 2010). Trade modeling that includes EU biofuel tariffs suggests that patterns of trade may be altered by the EU biofuel policy (Burrell et al. 2012), raising the potential for a challenge. A challenge to the tariff-related sustainability criteria (e.g., on biofuels) by an accusing (injured) country potentially could be successful if the EU is shown to be applying a tariff on imports from the accusing country that is higher than the tariff applied to any other WTO-signatory country or countries (the bedrock "Most Favored Nation" principle codified in the WTO). Further, a challenge to nontariff aspects of sustainability criteria might be successful if an accusing country can prove that the standards applied to imports from the accusing country are more stringent than those required of domestic or EU producers of biofuel sources (the second bedrock principle of the WTO, "National Treatment") or that the criteria are deemed "arbitrary" barriers to foreign producers. For example, the requirement of fiber source certification before wood pellets receive credit under the EU's 2020 targets on energy from renewables may be deemed improperly favorable to domestic/EU producers. Swinbank (2009) expressed doubts that EU sustainability criteria will be found to be WTO-compatible, owing in part to the potentially arbitrary nature of GHG limits.

Other experts suggest that a General Exception may be available under Article XX of the General Agreement on Tariffs and Trade (GATT). This exception would allow for differential treatment across products and production techniques, especially as it pertains to the conservation of natural resources, as long as differentiating criteria are not deemed arbitrary and unjustifiable (Ackrill and Kay 2011; Mitchell and Tran 2010). Mitchell and Tran (2010) note that the environmental sustainability criteria for biofuels could be found inconsistent with GATT unless an Article XX exception can be defended. On the other hand, Ackrill and Kay (2011) suggest that EU biofuels sustainability criteria were developed to be compatible with the WTO.

Finally, willingness of EU Member States to continue to subsidize the use of wood for energy will affect both increases from the current level of demand and the long-term continuation of current demand. Both subsidies and tax relief have been used to promote wood use for electricity in the UK and other countries (USDA FAS 2013).

Conclusions

While we acknowledge the complex role of public policy in wood pellet market evolution, we expect global pellet markets are likely to experience strong growth in the coming years. Imports by the EU alone are expected to grow during the next decade in response to renewable energy and GHG emission-reduction targets. The extent to which pellets from the U.S. South are able to supply these markets depends on the magnitude of the energy targets themselves, the content of governing sustainability criteria, and the evolution of complementary and competing wood products industries.

At the current time, the major U.S. pellet-exporting region is the South, which is expected to continue to dominate this market. The UK and other EU countries are expected to continue to be major importers, within the constraints of both EU and national renewable and sustainable energy policies. Some uncertainty exists regarding whether the United States will continue to be the source of choice, depending on specific sustainability and GHG emission-reduction policies. If, however, renewable-energy policies in non-EU countries lead to an increased demand for pellets in the Pacific Rim, and if these pellets are supplied from western Canada, then this demand could put additional pressure on the U.S. South and also on the U.S. North, eastern Canada, and other countries to continue to supply pellets to the EU.

The major impact from these policies is the increased demand for wood, both timber and logging residues, from U.S. forests. This increase in demand will lead to increased timber harvests and increased timber prices, in addition to short-run gains to forest landowners and short-run losses to nonpellet producers (traditional wood-using industries and domestic bioenergy producers). Long-run impacts will depend on how each industry adapts to changing prices and to the specifics of changes in international and domestic policies.

The level of increase in nonsawtimber prices, combined with low sawtimber prices, is unprecedented in the U.S. South. Simulations and assumptions based on expert opinion and empirical relationship defined for traditional wood products were used to evaluate the effect of projected increases in demand on

[14] Massachusetts 225 CMR 14.00. http://www.mass.gov/eea/docs/doer/renewables/biomass/225-cmr-14-00-final-reg-doer-081712-clean-copy.pdf. [Date accessed: November 6, 2014].

markets. The results from simulations show that the increased policy-induced demand will lead to increased harvest of both pine and hardwood nonsawtimber and, thus, increased prices for both. The increased prices lead to an increase in land rents, which in turn leads to a projected increase in timberland area.

At present, the models being used to assess the impacts of both the requirement for renewable energy and the conditions under which it can be considered renewable are unable to address some of the more complicated aspects of the life-cycle analysis and market tradeoffs that are needed to fully understand the effects of these policies. One limiting factor is that these markets are new, and little empirical research has been done on them, so the models use assumptions based on research for other product types. A second limiting factor is that policies are continuing to evolve, both domestically and internationally, and thus we have no stable policy world on which to base our projections. Uncertainty in policies will likely raise the cost of doing business as a pellet-for-export manufacturer in the United States. Whether any of these policies will have a deterrent effect on U.S. pellet export demand is unknown, however, and will depend on the scale of subsidies and incentives and also on penalties and certification requirements.

Chapter 8. Forest Carbon

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) reviewed historical forest carbon stocks and flows and projected future carbon stocks and flows from forests and HWPs. The sequestration of carbon in forests has contributed to reducing net carbon emissions in the United States during the past two decades, but results from the 2010 RPA raised questions about future accumulation (USDA Forest Service 2012a; Wear et al. 2013). In the most recent National Greenhouse Gas Inventory (NGHGI) (U.S. EPA 2015), current annual forest carbon sequestration (including HWPs) was reported at 211.5 Tg of carbon, offsetting 11.6 percent of U.S. greenhouse gas (GHG) emissions in 2013. Forest carbon therefore represents an important "credit" in the national ledger of carbon emission accounts and could influence targets for other sectors of the economy in any scheme to reduce overall emissions. The size of the credit that forests provide in the future affects the overall cost of achieving policy goals through GHG emission reductions.

Highlights

- U.S. forests continue to sequester significant amounts of atmospheric carbon and provide an important offset to the Nation's carbon emissions.
- Isolating carbon sequestration in the forest sector requires a careful accounting of carbon transfers among dynamic land uses and to harvested wood products (HWPs).
- The forest sector sequestered 144 teragrams (Tg) of carbon in 2010, after accounting for land use changes, forest growth, and storage in HWPs.
- Rates of forest carbon sequestration vary strongly across regions: the Eastern United States accounts for 80 percent of historical sequestration and as much as 90 percent of projected sequestration.
- Total forest sector carbon sequestration—the sum of forest sequestration and changes in HWP carbon storage—increases from 2005 to 2020 and then declines very gradually.

In this RPA Update, we use the preliminary forest carbon inventory for the 2016 NGHGI as the basis for the forest carbon projections. The preliminary 2016 NGHGI forest carbon inventory is based on the U.S. Forest Carbon Accounting Framework (FCAF), a comprehensive approach to using the annual Forest Inventory and Analysis (FIA) data to improve historical forest carbon data and to seamlessly model future forest carbon (Woodall et al. 2015). Projections complement the 2010 RPA scenarios (see chapter 2) by providing projections based on recent measured changes in forest inventory, new estimates of forest soil organic carbon, and projections of land use changes consistent with USDA scenarios described in this chapter. We report on advances in separating changes in forest carbon associated with change in the total area of forests from changes associated with forest growth.

U.S. Forest Carbon Accounting Framework

FCAF replaces the older carbon accounting system that was designed more than a decade ago when FIA's annual inventory system was first being implemented and could provide limited insights into many questions regarding sink dynamics. The new framework directly addresses questions regarding disturbance and land use effects, using all available inventory information. These changes improve the consistency of historical estimates and respond to the latest international scientific guidelines for carbon accounting and projections (UNFCCC 2013). We focus on the accumulation or depletion of carbon within forests in this chapter. In accordance with that focus, all positive values indicate growth in the forest carbon pool, and negative values indicate losses.[15]

The annual inventory system measures disturbances and carbon stocks on all forest plots while identifying land use and change on all plots, regardless of presence of forest, and serves as the foundation of the accounting system. Older, periodic inventories with their inconsistent field protocols and sample designs have been removed from the accounting system per recommendation from the United Nations Framework Convention on Climate Change (UNFCCC) expert review team (Woodall 2012). A modeling approach now moves the annual inventory system from the start of the annual system in the early 2000s back to 1990 and forward through time to provide carbon estimates and projections that satisfy UNFCCC requirements and future commitments.

The FCAF system comprises a forest dynamics module and a land use dynamics module. The land use dynamics module assesses carbon stock transfers associated with afforestation and deforestation. The forest dynamics module estimates changes in carbon density within forests in response to aging, growth, harvesting, and natural disturbances. Forward and backward projections are conducted at fine scales (plot level in the Eastern States and State or sub-State level in the Western States) and aggregated to report on regional and national carbon stock dynamics (see Wear and Coulson 2015). Projections reflect the assumptions of scenarios constructed by USDA and informed by land use projections from the 2010 RPA.

Land Transfer Effects on Forest Carbon Change

❖ **Accounting for land transitions among different land uses improves understanding of carbon stocks and fluxes on forest land.**

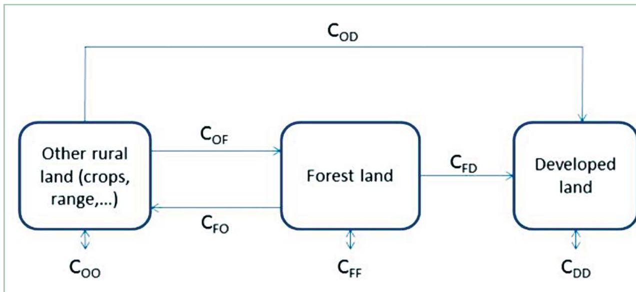
❖ **Estimating forest sequestration of atmospheric carbon dioxide (CO_2) requires separating land use transfers from net forest growth.**

Forest carbon represents one component of terrestrial carbon stocks. The forest use component of the land sector is one element of the NGHGI that involves transfers between forests and all other land uses. An area that has changed from a nonforest use to a forest use increases the forest carbon pool, and an area that has changed from forest use to nonforest use decreases the carbon pool. Carbon gains and losses derived from forest use changes indicate both transfer of carbon from one terrestrial pool to another and atmospheric fluxes. In addition, some harvested forest carbon may be transferred to durable forest product carbon pools. These transfers need to be accounted for in determining forests' net sequestration of atmospheric CO_2.

Figure 8-1 shows a simple description of carbon transfers associated with land use changes among forests, developed land, and all other rural land. The NGHGI defines change in forest carbon as C_{FF}+C_{OF}-C_{FO}-C_{FD}, where C_{FF} is carbon accumulating within persisting forests, C_{FD} is carbon transferred from forest (F) to developed (D) uses, and so on. Stock-change is simply the change in forest carbon inventories between measurements. To isolate the carbon sequestered from the atmosphere by forests (C_{FF} alone) requires accounting for the land use transfers.

When evaluating forest carbon changes, we isolated the land transfer component from the forest growth component—a proxy for the net impacts on carbon exchange between forests and the atmosphere. For the Eastern United States, we tracked land transfer carbon directly based on remeasured plots. For the Western United States, we assumed that the soil organic carbon component of forest land is the amount of carbon that is transferred between land uses. Forest products carbon was addressed

Figure 8-1. Carbon change within and between land uses.



C_{FF} = carbon accumulation in forests remaining forests.
C_{FO} = carbon transferred with land use change from forest to other land uses.
C_{FD} = carbon transferred with land use change from forest to developed land.
C_{OO} = carbon accumulation in other land uses remaining in other land uses.
C_{OF} = carbon transferred with land use change from other land uses to forest.
C_{OD} = carbon transferred with land use change from other land uses to developed land.
C_{DD} = carbon accumulation in developed land remaining developed land.

[15] Note that this convention is different from accounting systems that are focused on changes in the atmospheric stock of carbon dioxide (i.e., the signs of change would be opposite in this case).

separately. Some portion of forest vegetation may be retained with land use change to the "Settlements" component of the NGHGI. We assumed the portion of vegetation transferred to developed uses to be small relative to the transfer of soil pools and did not include it in our transfer estimates (this represents an area for future refinement).

Forest Carbon, 1990 to 2015

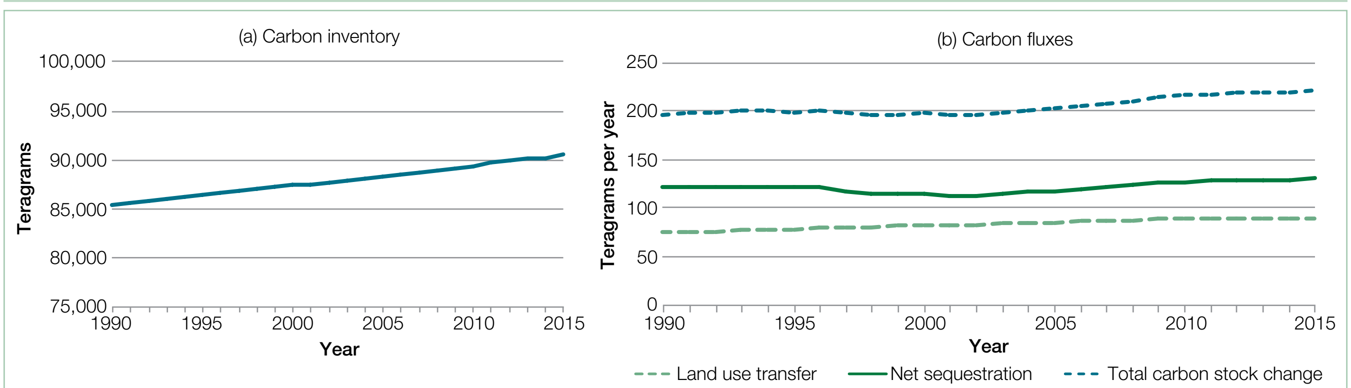
- ❖ Net forest sequestration ranged from 112 to 133 Tg per year between 1990 and 2015 and averaged 122 Tg per year.
- ❖ Forest area increase accounted for about 41 percent of the total forest carbon stock change.
- ❖ Forests in the Eastern United States accounted for more than 60 percent of U.S. forest carbon stocks and 80 percent of net forest carbon sequestration.

The results discussed in the remainder of this chapter are based on the updated forest carbon baseline using FCAF (Woodall et al. 2015) and therefore do not match numbers reported in the 2015 NGHGI[16] (U.S. EPA 2015). In the United States, forest carbon increased from 86,064 Tg of carbon in 1990 to 91,262 Tg of carbon in 2015 (figure 8-2a). The rate of change in recent years was about 0.23 percent of the stock and was estimated at 222 Tg of carbon per year between 2010 and 2015 (figure 8-2b). This rate of change reflects both the annual accumulation of forest area averaging +1.03 million acres per year (+417,000 hectare [ha] per year) between 1990 and 2015 and forest growth (i.e., forests remaining forests in UNFCCC terminology). Land use transfers of carbon resulting from forest area expansion accounted for about 90 Tg of carbon per year between 2010 and 2015, or about 41 percent of total forest carbon sequestration in the NGHGI (figure 8-2b). Forest growth therefore yielded a net sequestration from the atmosphere of 132 Tg of carbon per year during this period. Recent increases in carbon accumulation rates for forests correspond with harvest reductions from the economic contraction of 2007.

Forest carbon stocks were highest in the two RPA regions in the Eastern United States in 2015, when the South and North[17] Regions constituted 31 and 30 percent of carbon stocks, respectively. The Rocky Mountain and Pacific Coast Regions in the Western United States constituted 20 and 18 percent, respectively. Annual change in carbon stocks was also greatest in the eastern regions (+84 Tg of carbon per year and +68 Tg of carbon per year for the North and South Regions, respectively) when compared with the Rocky Mountain Region (+46 Tg of carbon per year) and Pacific Coast Region (+23 Tg of carbon per year). Eastern regions accounted for an even greater proportion of net forest carbon sequestration from the atmosphere, roughly 80 percent, with 33 and 47 percent attributable to the North and South Regions, respectively.

Temporal patterns of forest carbon dynamics also differed by region (figure 8-3). In the North, South, and Pacific Coast Regions, net sequestration trended up between 1990 and 2015, with largest gains in the last half of the period for the South Region. In the Rocky Mountain Region, sequestration declined, likely reflecting the effects of forest aging and disturbances, including wildfire. Transfers of carbon associated with land use were high in the North Region (roughly equivalent to the rate of sequestration) and in the Rocky Mountain Region (nearly twice as high as the rate of sequestration) but were low relative to sequestration in the South and Pacific Coast Regions. See the sidebar Forest Growth and Disturbance Effects on Carbon Stocks for more details about patterns of disturbance in the Eastern United States.

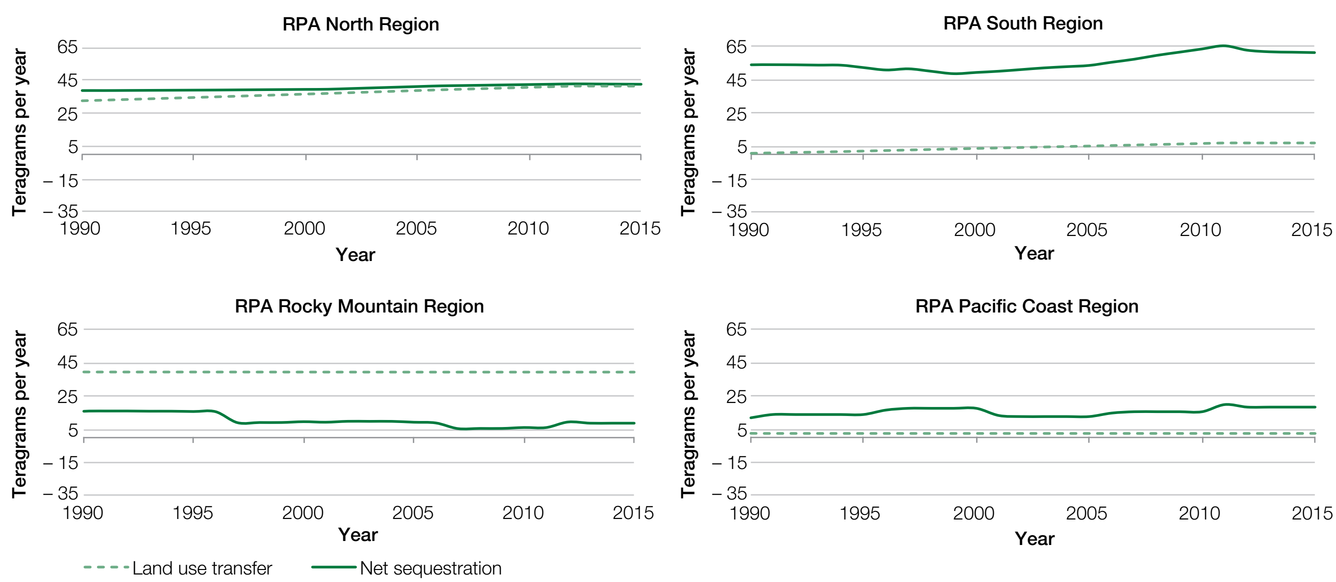
Figure 8-2. (a) U.S. forest carbon inventory and (b) forest carbon fluxes decomposed into land use transfer and net carbon sequestration components, 1990 to 2015.



[16] The forest carbon inventory in the NGHGI includes forest land of the conterminous United States, Hawaii, and coastal Alaska. Analyses in this chapter that decompose forest carbon transfers for historical data and projections include forests in the conterminous United States and coastal Alaska only.

[17] The eastern Great Plains States of Kansas, Nebraska, North Dakota, and South Dakota are included in the North Region in these analyses.

Figure 8-3. Change in U.S. forest carbon by RPA region, decomposed into net transfers into the forest carbon pool through land use change and the change attributable to overall forest sequestration (including disturbance-related mortality and growth), 1990 to 2015.



RPA = Resources Planning Act.

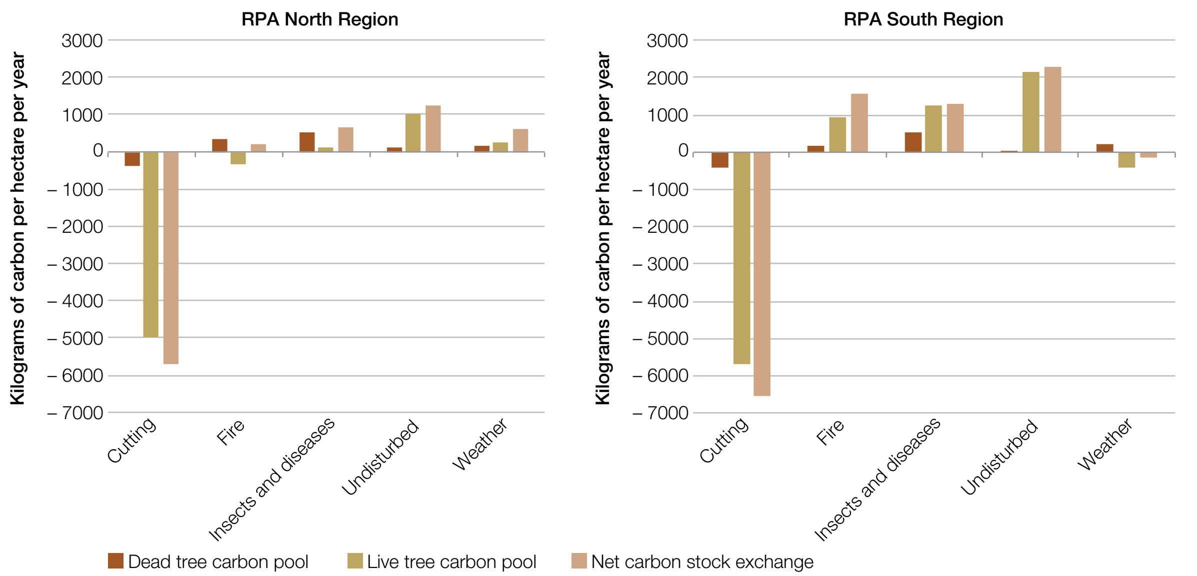
Forest Growth and Disturbance Effects on Carbon Stocks

The change in carbon density is influenced by a number of factors summarized by growth, mortality, and removals. Forest growth is determined by biological and physical factors but within a region can be coarsely summarized as a relationship between age and growth rates. Stand-level growth rates generally follow a characteristic biological yield function: growth rates rise with age to a maximum and then eventually decline to zero as the forest approaches a maximum capacity. Mortality is influenced by a number of factors, including forest age, but is often altered by natural disturbances, including fire, insects and disease, and weather events. Removals are associated with utilization of forest products.

Disturbance-related forest dynamics are an important part of forest carbon change. Based on data from the most recent inventory periods for each State (circa 2012), 34 million acres of forest had insect and disease disturbance, 22 million acres had fire disturbance, and 16 million acres had weather disturbance. Natural disturbances are pervasive in forested ecosystems, with their effects depending on disturbance type and severity. For example, some forest types, including longleaf pine ecosystems in the RPA South Region, are more productive when burned frequently. Fully remeasured forest inventories enabled us to evaluate changes in carbon for various types of disturbance and harvests in the Eastern United States, an analysis that will eventually be possible nationwide (figure 8-4).

Figure 8-4 shows the carbon accumulation rates for the live tree and dead tree pools and also net accumulation (across all pools) under four disturbance regimes and for undisturbed forests. When areas are disturbed in the Eastern United States, the typical pattern observed is reduced accumulation in the live tree pool and increased accumulation in the dead tree pool (which is essentially a carbon transfer). For example, in the RPA South Region, areas disturbed by insects and diseases had a live tree carbon accumulation rate of 1,232 kilograms (kg) per hectare (ha) per year and a dead tree accumulation rate of 550 kg per ha per year. When compared with rates in undisturbed forest, this rate is approximately a 16-fold increase in the dead tree carbon pool and a 43-percent decrease in the live tree carbon pool. While the forest recovers with additions to the live biomass pool, dead tree carbon decomposes with respiration to the atmosphere or transfers to the forest floor pool, essentially buffering the emissions from the disturbance over time. Note that in all cases, except weather disturbances in the South Region, the net carbon accumulation is positive. Also note that the influence of these disturbances is substantially different from forest cutting, in which decreased carbon accumulation is seen in the live tree pool, the dead tree pool, and net carbon accumulation. Although forest cutting results in emissions, a portion of these emissions are captured in wood products and are accounted for in the NGHGI account for HWPs. Note as well that only a small portion of plots experience some sort of disturbance/cutting, and a strong majority are undisturbed, resulting in the strong net sequestration of forest carbon observed for both the North and the South Regions in the 1990-to-2015 inventory. Coulston et al. (2015) provide more details regarding disturbance dynamics in the South Region.

Figure 8-4. Carbon accumulation rates (kilogram per hectare per year) resulting from disturbances in the Eastern United States, based on the most recent remeasured Forest Inventory and Analysis data (about a 6-year time step).



Forest Carbon Projections

- A regionally specific modeling approach accounts for differences in aging and disturbance dynamics.
- Projections of forest carbon link biological forest dynamics with socioeconomic dynamics, affecting land use and timber harvesting.

Projections of forest carbon enable us to evaluate the potential for the forest sector to continue offsetting atmospheric emissions of carbon from other sectors of the economy. Separating net sequestration and land use transfers of carbon as highlighted in FCAF allows for isolating the offset provided by forests. Future forest carbon dynamics depend especially on how land use changes and timber harvesting will evolve over time. For the 2010 RPA, we developed long-run forest product market and land use change projections linked to the 2010 RPA scenarios based on economic and population growth trajectories. For this RPA Update, we adopted three scenarios developed by USDA to project GHG emission paths in forestry and agricultural sectors and applied them using the FCAF projection methods. These scenarios accounted for the economic downturn of the mid 2000s (which was concurrent with the analysis phase of the 2010 RPA) and subsequent recovery, and they better linked forest projections to projected trends in other economic sectors. A Reference scenario was linked to the 2015 Annual Energy Outlook projections of economic growth (U.S. DOE EIA 2015) and U.S. Census Bureau projections of population growth (U.S. Census Bureau 2014f) and was bracketed by scenarios that allow for higher (High scenario) and lower (Low scenario) rates of growth to provide a range of possible forest carbon outcomes. These projections were used as input to the U.S. Biennial Report specified by obligations under UNFCCC.

We projected forest carbon changes using a forest carbon dynamics model for the 2015-to-2060 period (Wear and Coulston 2015). This model replaces 2010 RPA projections of forest carbon to account for the explicit USDA scenarios and to be consistent with the new forest inventory, especially the substantially revised estimates of forest soil organic carbon. Projections of carbon stored in wood products are based on harvests projected by the U.S. Forest Products Module (Ince et al. 2010) coupled with the HWP carbon inventory model used for the 2010 RPA (USDA Forest Service 2012a), but they reflect projections of population, economic growth, and housing starts consistent with the USDA scenarios. None of these projections include the potential effects of productivity enhancement from accumulation of atmospheric CO_2 or nitrogen deposition or of productivity implications of changing climate conditions, nor do they include new policy initiatives.

We explored potential futures for forest carbon stocks and forest sequestration of atmospheric CO_2 in the United States to address questions regarding the likelihood of future sequestration at various levels (Coulston et al. 2015). Projections account for the socioeconomic, biological, and physical factors that influence forest development and incorporate detailed forest inventory data to address forest age and also other site and productivity variables, including disturbances. Biological agents (insects and diseases) and physical agents (fire and wind events) set off sequences of mortality and growth and associated carbon emissions and accumulations. Human activities (harvesting and other management treatments) similarly affect carbon losses and gains but also involve transfers from some carbon in standing forests to storage in long-lived forest products. Land use changes can result in losses or gains in forest carbon (Coulston et al. 2014).

Forest carbon dynamics vary over space and forest conditions. For example, the maximum carbon content of a forest on the western slope of the Cascade Mountain Range in Oregon is much higher than observed for a forest in the Southeastern United States, but the annual rate of accumulation may be higher in the Southeast. Projecting forest carbon changes in the United States requires detailed inventory data and a regionally differentiated approach to account for these types of productivity differences and for aging and disturbance dynamics. (The

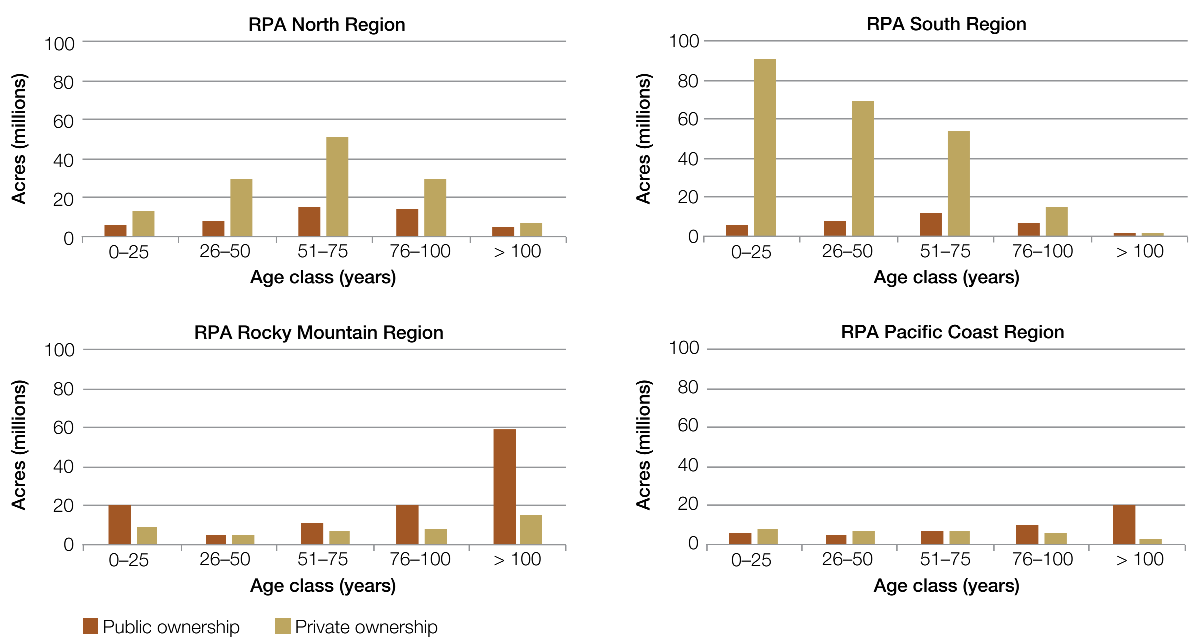
Regional Forest Ownership and Forest Age Class

The Eastern United States has the largest share of forest resources in the conterminous United States. The South Region has 267 million acres of forest land, and the North Region has 177 million acres. In both regions, the forests are primarily privately owned: 87 percent in the South Region and 74 percent in the North Region. By contrast, forest land in the Western United States is primarily publicly owned. The Rocky Mountain Region has 160 million acres of forest land, of which 73 percent are publicly owned. The 79 million acres of forest land in the Pacific Coast Region are 62 percent publicly owned.

The ownership pattern also influences age structure on each region's forest land. In the South Region, the dominant age class on public lands is 51 to 75 years, and the dominant age on private lands is 0 to 25 years. On public land, 25 percent of the forest is 76 years old or older as compared with 8 percent on private lands (figure 8-5). In the North Region, the dominant age class on both public and private lands is 51 to 75 years. Forests on public lands, however, tend to be older than those on private lands. For example, on public land, 40 percent of the forest is 76 years old or older as compared with 28 percent on private lands (figure 8-5).

In the Rocky Mountain Region, the dominant age class on both public and private lands is more than 100 years. As in the North Region, however, forests on public lands tend to be older than those on private lands. For example, on public land, 51 percent of the forest is 101 years old or older as compared with 35 percent on private lands (figure 8-5). Age class diverges on public and private land in the Pacific Coast Region. The dominant age class on public lands is more than 100 years, while private forests are evenly distributed across age classes. On public land, 42 percent of the forest is 101 years old or older as compared with 9 percent on private lands (figure 8-5).

Figure 8-5. Forest ownership, by age class and RPA region, 2012.



RPA = Resources Planning Act.

sidebar Regional Forest Ownership and Forest Age Class describes the distinctive forest regions of the United States.) Whether forest carbon densities could also vary temporally through fertilization by increased atmospheric CO_2 levels is debated in the literature.

We constructed projection models to be consistent with the format of the NGHGI system and used the same datasets in each region of the United States. Differences between sampling rates (number of plots per year) and the availability of repeated observations in the eastern and western regions led to different modeling approaches. In the East, where the inventory cycle is approximately 5 years, remeasured plots supported explicit transition measurements (aging, disturbance, harvesting) for individual inventory plots based on observed changes during the most recent past and allowed for direct extrapolation. In the West, where the inventory cycle is at least 10 years, forest transitions were modeled using inventory aggregates along with aging and disturbance rates applied to carbon density distributions drawn from the most recent inventories. Projections were developed at the subregional scale in the East and at the State or sub-State level in the West (Wear and Coulston 2015).

Projection Assumptions

- Projections were driven by socioeconomic scenarios designed by a USDA team for coordinated analysis of economic activity affecting all lands.
- For the Reference scenario, observed forest area was assumed to continue growing for the next decade, level off, and then begin to fall after 2030.

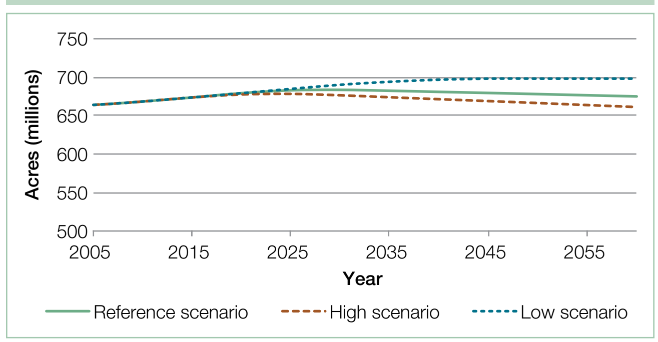
The forest carbon projections are based on a set of assumptions about land use changes, economic growth, and population growth. Recent forest area trends indicate an ongoing increase in forest area of about 1 million acres per year in the United States, but projections developed for the 2010 RPA (USDA Forest Service 2012a) indicated a decrease in forested area during the next five decades in response to other land use demands, ranging from 115,000 and 217,000 acres per year between 2010 and 2060 (46,540 and 87,820 ha per year) (an overall forest decline of between 2 and 4 percent over 50 years). Forest losses in the 2010 RPA reflected the effects of an anticipated continuation of development driven by population and economic growth and a halt to the transition of agricultural to forest land uses. Current rates of forest accumulation indicate that agricultural land continues to make the transition toward forests in the United States.

The USDA Reference scenario essentially assumed that recent history is a good guide for projecting the near term (especially given the protracted slowing of development associated with the recent housing-led recession) but that the longer term is informed by the projections of population, income, and housing starts consistent with the 2010 RPA projections. As a result, the USDA Reference scenario assumed that forest area will continue to grow at current rates for the next decade (2012 to 2022), then dampen to 50 percent of the historical trend in the second decade (2022 to 2032), and level off in the year 2030. In subsequent decades, we assumed that forest area will begin to fall (at 227,000 acres per year [92,000 ha per year]) in response to projected development pressures and roughly consistent with the 2010 RPA scenarios (figure 8-6). Two additional scenarios bracket the Reference scenario. The Low (development) scenario assumed that forest area will continue to accumulate at its current rate through 2030, at one-half the historical rate through 2040 and then level off. The High (development) scenario assumed that forest area will continue to accumulate at current levels until 2020, increase at a decreasing rate until reaching zero change in 2025, and then begin to decline at about 0.5 million acres per year (200,000 ha per year) to 2060.

Our projection models essentially assume that forest productivity remains a constant across the projection period, but warming temperatures and increasing atmospheric CO_2 levels could result in enhanced photosynthesis and carbon accumulation in forests within the timeframe of our projections. The overall implications for productivity are unclear, however, given the compounding influence of nitrogen deposition, drought, storm events, and phenology leading to differences in response across regions and forest types (Ryan et al. 2012).

Because expanding storage of forest carbon could decrease pressures to reduce carbon emissions from other sectors, especially in the short run, policies have been proposed to enhance terrestrial carbon sinks. Carbon taxes and cap-and-trade policies are most often raised as instruments for reducing carbon emissions and enhancing stocks. Our modeling does not incorporate effects of these or other types of policies. Wear and Coulston (2015) provide a first approximation of some productivity adjustments and policy approaches using this framework.

Figure 8-6. Area of U.S. forest land use from the U.S. National Greenhouse Gas Inventory, 2005 to 2015, and projections for the Reference, High, and Low scenarios, 2016 to 2060.



Forest Carbon, 2015 to 2060

- Forests are projected to remain an important sink of atmospheric carbon throughout the projection period.
- The total forest carbon inventory increases at historic rates between 2015 and 2025 and then gradually approaches zero as land use transfers offset sequestration.
- After accounting for land use transfers, the amount of forest sequestration of atmospheric carbon declines very gradually during the projection period.

Projections of forest carbon dynamics show the relative effects of land use changes with associated carbon transfers into and out of forest and net sequestration by forests (figure 8-7 and table 8-1). Through 2020, carbon stock change, net sequestration, and transfers are relatively stable at 2015 levels across the three scenarios; land use transfers account for about 40 percent of the increase in forest carbon stocks. As forest area gains decline to zero, so does the associated land use carbon transfer (figure 8-7). A shift to declining forest area in the Reference and High scenarios leads to a strong transfer of soil carbon out of the forest pool and into other land use carbon pools. In accordance with that shift, the rate of change in the forest carbon pool declines from 222 Tg of carbon per year in 2015 to about 5 Tg of carbon per year in 2060, when the transfer out of forests is just slightly less than the carbon sequestered by forests. Under the High scenario, with a higher rate of forest loss in the later decades, stock change is strongly negative by 2060 (-29 Tg of carbon per year).

Although much discussion emphasizes the stock change of forest carbon that, by definition, includes change in land use, this variable does not approximate the exchange of carbon between forests and the atmosphere; it overstates the contribution of forests when forest area is expanding and overstates losses when forest area is declining. To define net sequestration of carbon from the atmosphere by forests requires subtracting the land use carbon transfers from forest carbon stock change—defining the net sequestration line in figure 8-7. Actual sequestration of carbon by forests is much less variable than forest carbon stock change across scenarios, and it declines gradually over time. Under the Reference scenario, net sequestration declines from about 131 Tg of carbon per year in 2015 to 99 Tg of carbon per year in 2030 and to 79 Tg of carbon per year in 2060, reflecting the influence of forest aging and disturbance (table 8-2). The 2060 values range between 71 Tg of carbon per year for the High scenario and 95 Tg of carbon per year for the Low scenario (tables 8-3 and 8-4).

Figure 8-7. Projections of U.S. carbon stock changes, including transfers associated with land use change and the net carbon sequestered by U.S. forests, for the Reference, High, and Low scenarios, 2005 to 2060.

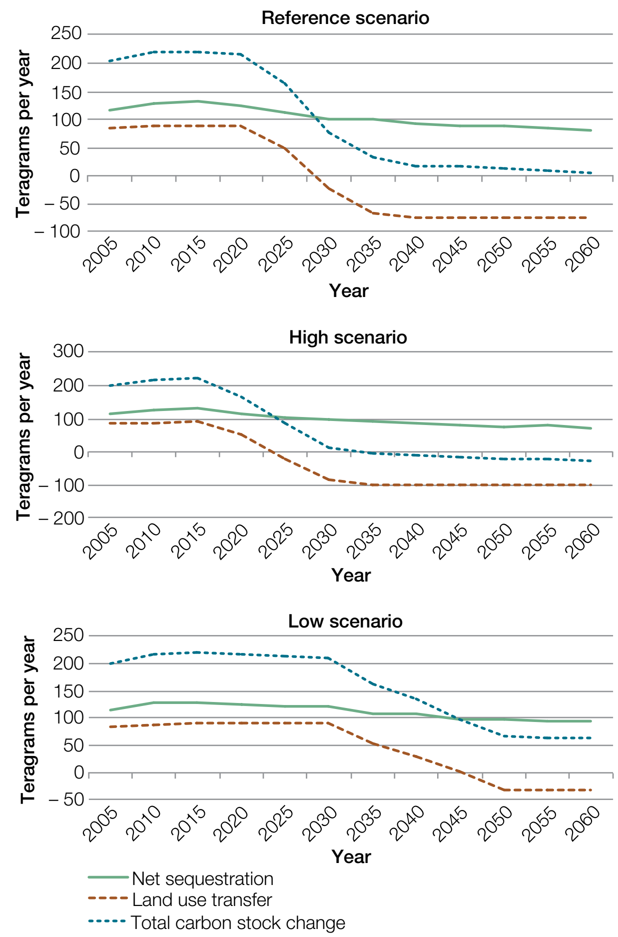


Table 8-1. Projections of change in forest carbon, carbon sequestration, and land use carbon transfers, based on the Forest Transition Model, 2005 to 2060.

Projection year (report year)	Forest area	Change in forest carbon	Carbon sequestered	Land use carbon transfer
	acres (thousands)	*teragrams per year*		
2010	668,325	216.4	127.2	89.2
2020	679,179	214.9	124.6	90.3
2030	683,555	75.7	99.3	– 23.5
2040	680,924	16.8	91.3	– 74.6
2050	678,034	12.8	87.4	– 74.6
2060	675,014	4.5	79.1	– 74.6

Table 8-2. Historical and projected average annual change in carbon sequestered by forests and carbon sequestered by the forest sector, Reference scenario, 2005 to 2060.

	2005	2010	2020	2025	2030	2040	2050	2060
	teragrams of carbon per year							
Average annual carbon sequestered by forests								
Change in forest carbon[a]	199	216	215	164	76	17	13	5
Land use carbon transfer	86	89	90	50	– 24	– 75	– 75	– 75
Forest carbon sequestration[b]	114	127	125	114	99	91	87	79
Average annual carbon sequestered by the forest sector								
Forest carbon sequestration	114	127	125	114	99	91	87	79
Wood products carbon	28	17	35	38	38	39	40	43
Forest sector carbon sequestered	142	144	159	152	137	130	128	122

[a] Change in forest carbon as defined by the National Greenhouse Gas Inventory = carbon sequestered in forests remaining forests + carbon associated with land transfers to and from the forest sector.

[b] Forest carbon sequestration = change in forest carbon – land use carbon transfer.

Note: Totals may not sum due to independent rounding.

Table 8-3. Historical and projected average annual change in carbon sequestered by forests and carbon sequestered by the forest sector, High scenario, 2005 to 2060.

	2005	2010	2020	2025	2030	2040	2050	2060
	teragrams of carbon per year							
Average annual carbon sequestered by forests								
Change in forest carbon[a]	199	216	168	85	14	– 13	– 23	– 29
Land use carbon transfer	86	89	51	– 21	– 83	– 100	– 100	– 100
Forest carbon sequestration[b]	114	127	116	106	97	87	77	71
Average annual carbon sequestered by the forest sector								
Forest carbon sequestration	114	127	116	106	97	87	77	71
Wood products carbon	28	17	35	38	38	39	40	43
Forest sector carbon sequestered	142	144	151	144	135	125	117	114

[a] Change in forest carbon as defined by the National Greenhouse Gas Inventory = carbon sequestered in forests remaining forests + carbon associated with land transfers to and from the forest sector.

[b] Forest carbon sequestration = change in forest carbon – land use carbon transfer.

Note: Totals may not sum due to independent rounding.

Table 8-4. Historical and projected average annual change in carbon sequestered by forests and carbon sequestered by the forest sector, Low scenario, 2005 to 2060.

	2005	2010	2020	2025	2030	2040	2050	2060
	teragrams of carbon per year							
Average annual carbon sequestered by forests								
Change in forest carbon[a]	199	216	216	214	211	137	69	62
Land use carbon transfer	86	89	90	90	90	29	– 30	– 32
Forest carbon sequestration[b]	114	127	126	123	121	108	99	95
Average annual carbon sequestered by the forest sector								
Forest carbon sequestration	114	127	126	123	121	108	99	95
Wood products carbon	28	17	35	38	38	39	40	43
Forest sector carbon sequestered	142	144	160	161	159	147	140	137

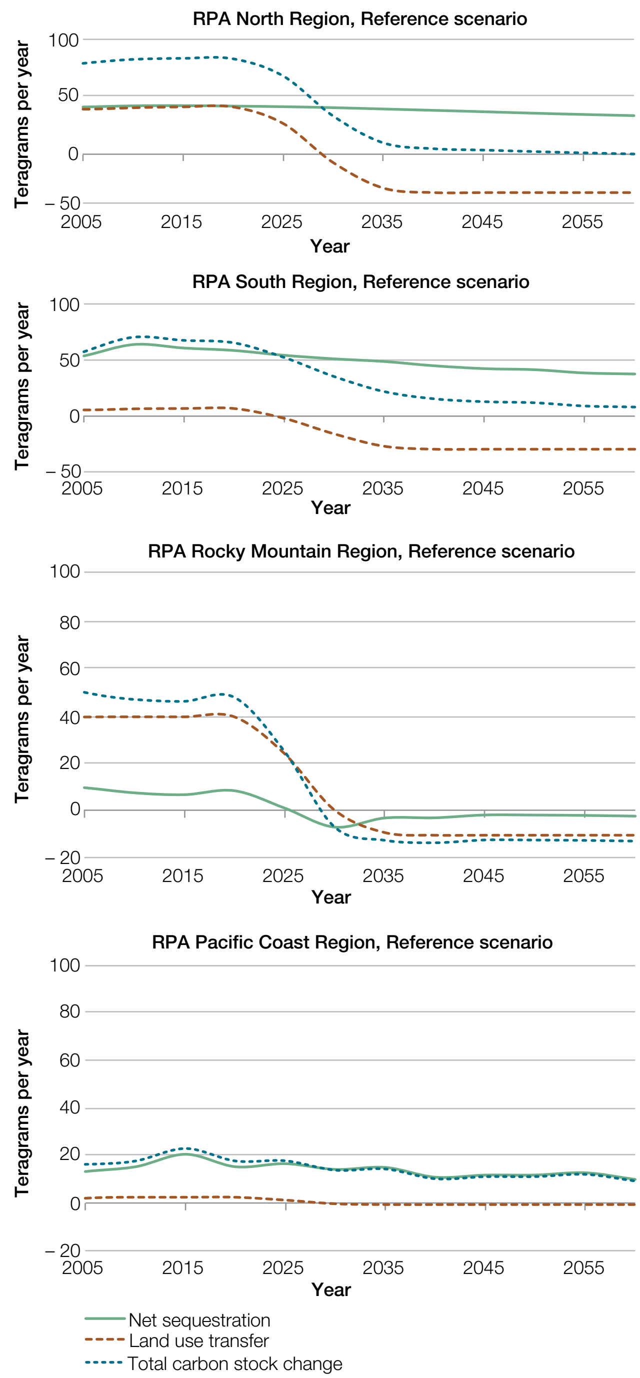
[a] Change in forest carbon as defined by the National Greenhouse Gas Inventory = carbon sequestered in forests remaining forests + carbon associated with land transfers to and from the forest sector.

[b] Forest carbon sequestration = change in forest carbon – land use carbon transfer.

Note: Totals may not sum due to independent rounding.

Forest carbon dynamics differ substantially among regions of the United States. In the recent past, all four RPA regions showed some increases in forest area, with associated positive land use transfers of soil carbon into the forest pool (figure 8-8). In the Rocky Mountain Region, these transfers accounted for nearly all of the forest carbon stock change in 2015. In the North Region, land use transfers were roughly equivalent to forest sequestration and, in the South and Pacific Coast Regions, land use transfers were much lower than actual sequestration. Under the Reference scenario (figure 8-8), land use transfers decline and switch from positive to negative at about 2030, consistent with the assumptions of the scenario. Still, actual sequestration remains strongly positive in the North Region (+34 Tg of carbon per year) and South Region (+38 Tg of carbon per year)—the share of U.S. sequestration in eastern forests shifts from 80 percent in 2015 to 90 percent in 2060.

Figure 8-8. Projections of U.S. forest carbon stock changes, including transfers associated with land use change and the net carbon sequestered by U.S. forests, for the Reference scenario by RPA region, 2005 to 2060.



RPA = Resources Planning Act.

Net sequestration in the Rocky Mountain Region is slightly negative in 2060 (-3 Tg of carbon per year), and sequestration in the Pacific Coast Region declines from 20 to 10 Tg of carbon per year between 2015 and 2060.

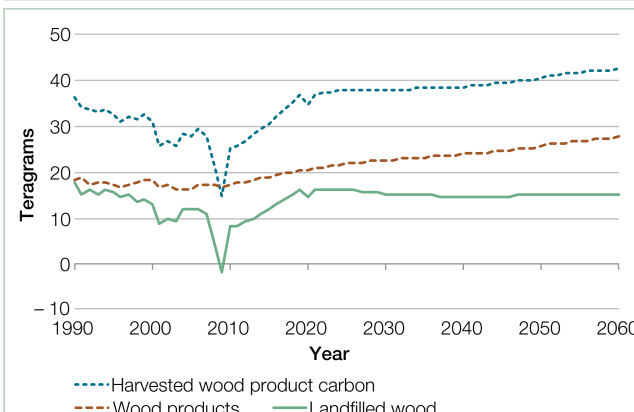
Harvested Wood Products Carbon

- The amount of wood products carbon declined to historic lows during the recent economic downturn.
- Wood products carbon storage rates have recovered and are expected to increase to historic averages in future decades.

To complete a full accounting of carbon dynamics in the U.S. forest sector requires a final adjustment to account for carbon transfers from forests to durable wood products. The stock-adjustment approach to evaluating change in forest carbon implicitly treats removals due to harvesting as an atmospheric emission. We need to account for how HWPs store and emit this carbon over time. These harvested materials accrue at a rate determined by conversion to end products and also the decay of products over time according to product class. The HWP pool therefore represents a separate and complex inventory with a variety of factors influencing accumulation in the pool and depreciation of the pool (eventual emissions to the atmosphere). An important element of the HWP is the transfer of wood products in use to landfills. We account for storage in these two separate major categories—wood products in use and landfilled wood.

Projections of carbon stored in HWPs are based on estimates of timber harvests from the U.S. Forest Products Module developed for the 2010 RPA (Ince et al. 2010; USDA Forest Service 2012a) using models developed by Skog (2008). These linked models were run using the assumptions of the USDA scenarios with outputs being especially sensitive to projections of population, income, and associated estimates of housing starts. Wood products carbon varies across the projection period, as figure 8-9 illustrates.

Figure 8-9. Estimates of U.S. historical and projected carbon stored in wood decomposed into components for wood products in use (wood products) and wood products stored in landfills (landfilled wood), Reference scenario, 1990 to 2060.



Harvested wood products carbon declined somewhat between 1990 and 2000, fell to historically low levels in 2005, and recovered to 1990s levels in 2015. These dynamics are explained by changes in the wood-products-in-use category and reflect the historic nadir of housing construction observed in the mid-2000s. By contrast, storage in landfilled wood remained fairly constant throughout the historic period. Projections reflect a recovery of the housing market with growth and then stabilization of wood products carbon combined with a steady increase in landfilled wood products carbon through the projection period. Total HWP carbon is projected to accumulate at a rate of 43 Tg per year in 2060, 19 percent higher than the rate of 36 Tg per year observed in 1990.

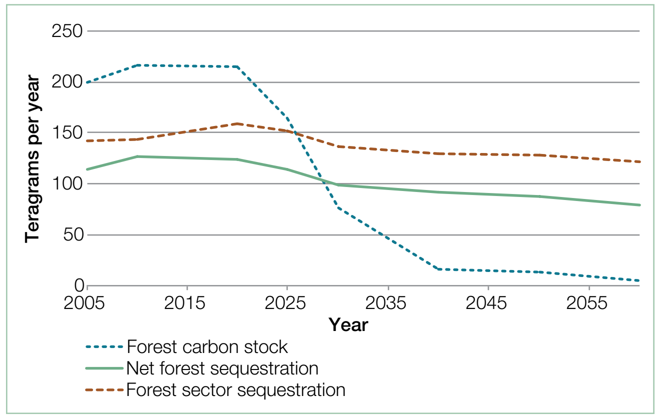
Forest Sector Carbon

❖ **Total forest sector carbon sequestration—the sum of forest sequestration and changes in HWP carbon storage—increases from 2005 to 2020 and then declines very gradually.**

Estimates of changes in total forest carbon, combined with estimates of carbon transfers into and out of the forest carbon pool from land use change and HWP, enable us to estimate the total contribution of the forest sector to sequestering and storing atmospheric carbon. Table 8-2 shows total annual change in forest carbon stocks (row 1) and the transfer into and out of the forest pool from and to other land uses (row 2). Subtracting land use transfers from the total carbon stock change defines our estimate of total carbon sequestered by forests (row 3). The sum of carbon sequestered by forests and changes in HWP carbon (row 5) defines the total sequestration by the sector for the 2005-to-2060 period. Forest sector sequestration increases from 2005 through 2020, because sequestration in standing forests slows but storage in HWPs increases with economic recovery. Forest sector sequestration then begins to decline at a gradual rate (2025 rates are about 4 percent higher than 2005 rates). The rate of sequestration in 2060 is about 14 percent lower than rates estimated for 2005. Forest carbon sequestration projections under the High and Low scenarios are shown in tables 8-3 and 8-4.

Figure 8-10 highlights the differences among these measures of change in carbon. The changes in total standing forest stocks show the dramatic shift from strong accumulation through 2020 to near zero accumulation in 2060, reflecting the inclusion of land use transfers first into and then out of forests. Change in the total forest carbon stock is not an estimate of sequestration of atmospheric carbon. The net sequestration trend removes the land use transfers to define the accumulation of carbon net of land use transfers. The strength of the forest sink also declines, but only gradually, between 2020 and 2060. Total forest sector carbon adds changes in HWP inventories to forest sequestration to define our best estimate of the total impact of the sector on sequestering atmospheric carbon. Under the Reference scenario, the strength of the sink increases from 2005 to 2020 and then declines gradually through 2060.

Figure 8-10. Estimates of changes in U.S. forest carbon stocks, net forest carbon sequestration, and forest sector sequestration of carbon, Reference scenario, 2005 to 2060.



Future Work

Ongoing work for the 2020 RPA Assessment focuses on enhancing projection methods for forest conditions in general and total forest carbon in particular. Long-term forest carbon projections require better insight into the implications of climate change for forest conditions (including species distributions and all forest disturbances) but also for overall forest productivity. The combination of changes in temperature, precipitation, disturbance events, and CO_2 enrichment implies changes in overall productivity that will likely vary across space. Ongoing research also focuses on enhanced modeling of the separate pools of carbon within forests, from soils to tree biomass, and will enhance the precision of carbon sequestration estimates. Our application of these modeling approaches to backcasting forest carbon inventories corrected for historical data inconsistencies. Future projections will also benefit from more information regarding carbon transfers among land uses, notably the transfer of forest vegetation in addition to soil carbon.

Conclusions

Our findings indicate a persistent but declining rate of forest carbon sequestration at the national level, with varying projections by region. During the 25-year projection period, forest carbon sequestration in the United States declines from 129 to 79 Tg of carbon per year (averaging 103 Tg of carbon per year). The decline in sequestration rates generally supports others' findings (e.g., Hurtt et al. 2002; Turner et al. 1995), but with substantial regional variation and variation in the magnitude of change in sequestration. The largest projected change is the rapid loss of sequestration in the Rocky Mountain Region, declining from +10 to -3 Tg of carbon per year, where timber harvesting and growth rates are the lowest (by total and proportion) and aging and disturbance govern forest change. Sequestration in the Pacific Coast Region declines only slightly (from ~13 Tg to 10 Tg of carbon per year). In the Eastern United States, sequestration declines very gradually and represents an increasing share of the national total from 80 percent in 2015 to about 90 percent in 2060. The regions with the most timber harvesting (the South Region followed by the North Region) have a larger portion of young forests and therefore provide the most stable future sequestration.

Multiple factors influence the accumulation of carbon in forests from aging to forest disturbance to land use changes. Among these, land use has the strongest and most immediate effect on future forest carbon sequestration. Timber harvesting also has an important influence on forest carbon dynamics, but findings reflect that forest carbon recovers quickly following harvest (especially in the South Region, where most harvesting occurs and growth rates peak at early ages). In addition, timber harvesting also yields additional carbon storage in HWPs. The combination of timber growth dynamics and ongoing utilization of wood products defines U.S. forests as an important sink for atmospheric carbon for the foreseeable future. This sink is declining gradually over time, however, suggesting a careful look at policies that might enhance future rates of sequestration.

Chapter 9. Rangeland Resources

In the 2010 Resources Planning Act (RPA) Assessment (2010 RPA), the extent of U.S. rangelands was estimated at about 662 million acres (268 million hectare [ha]) in the conterminous United States, recognizing that differences in definition can lead to variation in estimates of rangeland area (Reeves and Mitchell 2011). Most rangelands are privately owned (Joyce 1989). Although the area of rangeland has remained relatively constant since 2000, a slow decline in rangeland area is expected in response to development pressures (Reeves and Mitchell 2012).

The stable rangeland base has produced a steady flow of goods and services. Livestock numbers were determined to be quite sustainable, given the relationship between forage demand and production on rangelands circa 2009. Rangeland productivity was also relatively constant between 2000 and 2009. The 2010 RPA findings suggested that, nationwide, U.S. rangelands have the potential to support more grazing from wild and domestic herbivores; only a small proportion of rangelands appeared to be chronically overstocked (Reeves and Baggett 2014).

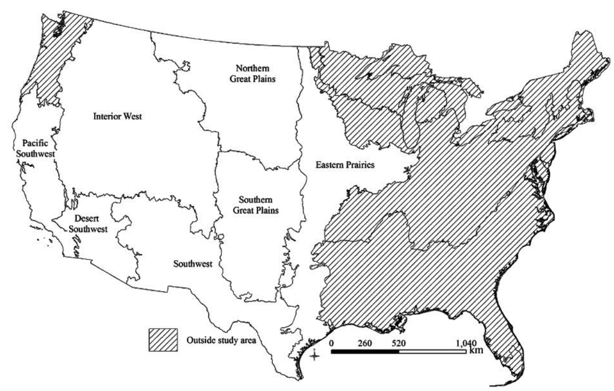
Highlights

- Changing climate effects on rangeland net primary productivity (NPP) indicate that moisture limitations to vegetation growth are likely to intensify over time.
- Northern grasslands, where increased temperatures improve the growing season but are not sufficient to deteriorate the water balance, are likely to prosper.
- The Southwest and Desert Southwest rangeland ecoregions are expected to be the most vulnerable as present patterns of drought continue and possibly intensify in the future.
- The vulnerability of cattle operations to climate change is also projected to be higher in the Southwestern United States, while the northern portion of the Great Plains rangeland ecoregion exhibits less vulnerability.
- Diversifying livestock operations and maintaining flexibility in herd sizes and stocking rates will be important strategies in adapting to climate change.

In this RPA Update, we continue to focus on the sustainability of rangelands, but we also add a series of impact studies on the effects of climate change on rangeland resources. First, we revisit rangeland productivity by examining the potential effects of climate change on NPP of rangelands in the future. Second, given the strong linkages between NPP and soil organic carbon (SOC), we characterize the flux from and storage on rangelands in the conterminous United States and estimate future storage capability expressed against the backdrop of a changing climate. Third, we quantify the vulnerability of U.S. livestock that depend on rangeland forage for all or part of their life cycle to projected future changes in climate and vegetation. Fourth, in recognition of the connection among land management, SOC, and NPP, we quantify the status and trends of degradation on U.S. rangelands across the United States. Finally, we examine the present and ongoing drought situation to understand conditions that have led to relatively low U.S. cattle inventories.

All analyses in this chapter are summarized across a variety of regions, depending on the section. Regions derived from ecological subsections (Bailey and Hogg 1986) that are dominated by rangeland vegetation are hereafter referred to as "rangeland ecoregions" (figure 9-1), and other analyses are summarized according to RPA regions and subregions (figure 2-1 in chapter 2).

Figure 9-1. Rangeland ecoregions derived by aggregating ecological subsections.



Source: Bailey and Hogg (1986).

Climate Change Effects on Productivity of U.S. Rangelands

- ❖ Moisture limitations to vegetation growth appear to intensify over time.
- ❖ Temperature increase is likely to favor growth in northern latitudes of the region but may also alter species composition.
- ❖ The signal is often mixed—the exception appears to be northern grasslands, where increased temperatures improve the growing season but are not sufficient to deteriorate the water balance.
- ❖ The Southwest and Desert Southwest rangeland ecoregions seem to be the most vulnerable of all in terms of NPP reductions.

Reeves et al. (2014) conducted an analysis of the effects of climate change on NPP on rangelands of the United States. NPP, or the rate of assimilation of carbon dioxide (CO_2) through photosynthesis, is a fundamental link between the atmosphere and the biosphere. In rangelands, productivity is mainly determined by the distribution of precipitation and resultant effects on soil water availability (Campbell et al. 1997; Izaurralde et al. 2011; Knapp et al. 2001). Precipitation variability alone has been shown to reduce NPP while, by contrast, semiarid regions may experience the largest gains in NPP because of the influence of elevated CO_2 on water-use efficiency (Fay et al. 2003; Izaurralde et al. 2011). Furthermore, plant species vary in their response to these factors, and alteration of NPP can be expected in the future as species respond to climate change through range shifts or local population dynamics (Morgan et al. 2007; Polley et al. 2012).

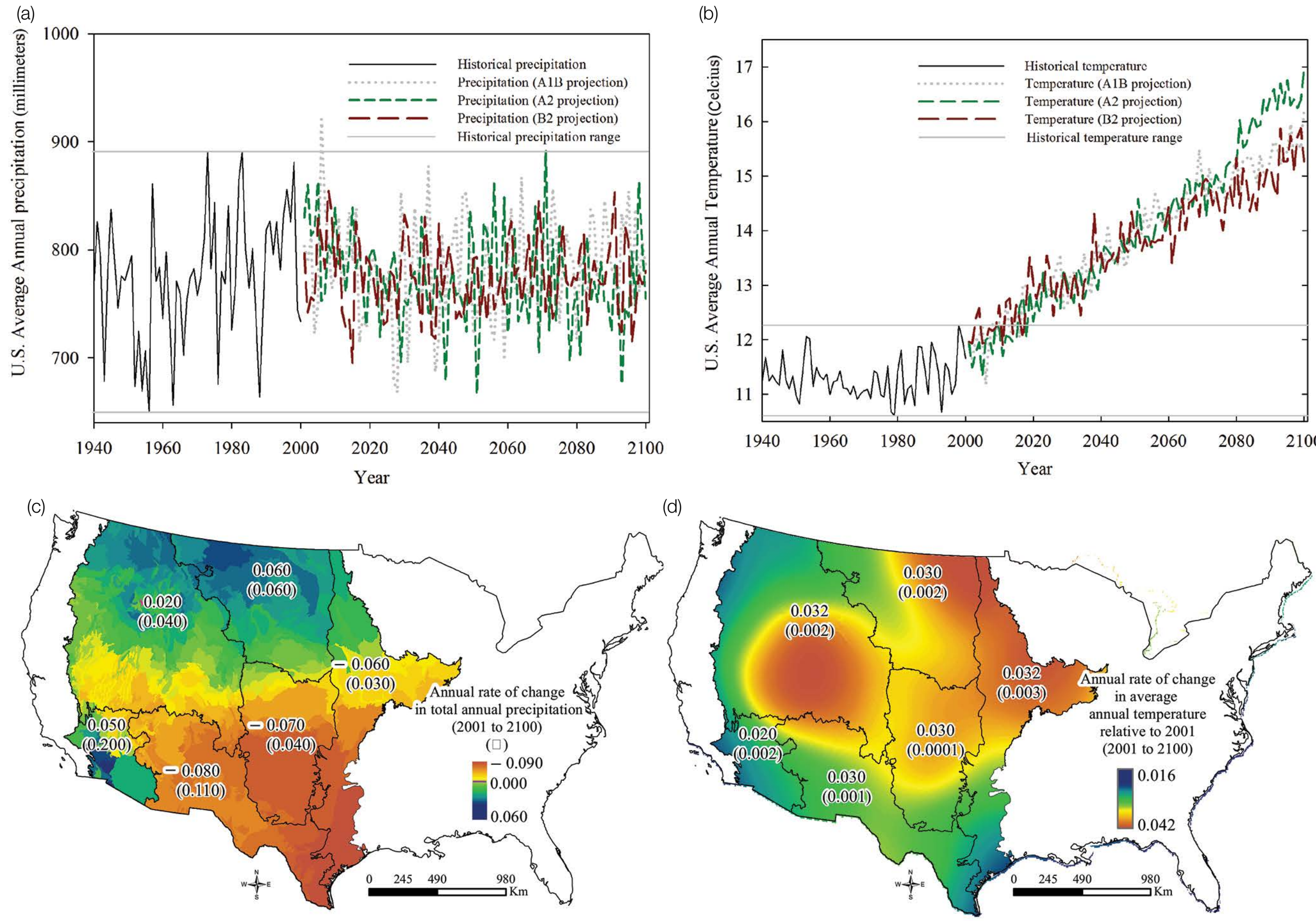
We projected NPP to the year 2100 for rangelands of the conterminous United States (Reeves et al. 2014) using the ecosystem process model Biome-BGC (Running and Hunt 1993) across broad regions dominated by rangeland vegetation (figure 9-1). Current species composition, coupled with Biome-BGC, and climate projections from four general circulation models (GCMs) associated with three Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) scenarios were used to model NPP at a spatial resolution of 8 square kilometers (km^2). In addition, climate and dominant drivers of NPP were characterized, temporally and spatially, across U.S. rangelands for each GCM and scenario. Finally, spatial and temporal patterns of change in NPP from a contemporary baseline were quantified. The IPCC AR4 scenarios were the same as the basis for the three 2010 RPA scenarios: A1B, A2, and B2 (IPCC 2014). We used downscaled climate data associated with the 2010 RPA scenarios as described in Coulson et al. (2010a, 2010b).

The spatial extent of rangelands in the conterminous United States was identified from Reeves and Mitchell (2011). The proportion of plant functional types was estimated by using the Landscape Fire and Resource Management Planning Tools Project Reference Database (Rollins 2009). Estimates of annual NPP on U.S. rangelands were produced by simulating ecosystem dynamics through application of Biome-BGC across the entire projection period for every scenario-climate combination. The contemporary distribution of growth forms and photosynthetic pathways were held constant throughout the projection period. Therefore, results reflect changes only in CO_2 concentration, nitrogen deposition, and climate variables.

Projected Climatic Trends

The average annual temperature increases (figure 9-2(b)) in each of the three scenarios but varies considerably by rangeland ecoregion (figure 9-2(d)). Near 2017, the average annual temperature is projected to surpass the upper limit of historic variation measured since 1940 and continues to rise steadily throughout the projection period. The Interior West and Eastern Prairie rangeland ecoregions exhibit the greatest amount of warming. Some ecological subsections (Bailey and Hogg 1986) in the Interior West, at the upper altitude limits of the conterminous United States, experience significant increases in temperature, often exceeding 4 °C by the end of the projection

Figure 9-2. (a) Historical and projected precipitation, 1940 to 2100; (b) historical and projected temperature, 1940 to 2100; (c) spatial patterns of change in precipitation, 2001 to 2100; and (d) spatial patterns of rates of change in temperature, 2001 to 2100 on U.S. rangelands for A1B, A2, and B2 scenarios.[a]



[a] Spatial patterns of rates of change are measured as the slope of linear regression from 2001 to 2100. Mean rate of change across all emissions scenarios in a region is represented by numbers in white outline; the standard deviations for the regional means are shown in parentheses.
Source: Reeves et al. (2014).

period. The Northern Great Plains, Southern Great Plains, and Southwest ecoregions all warm at about the same rate, and the Desert Southwest ecoregion warms at the slowest rate.

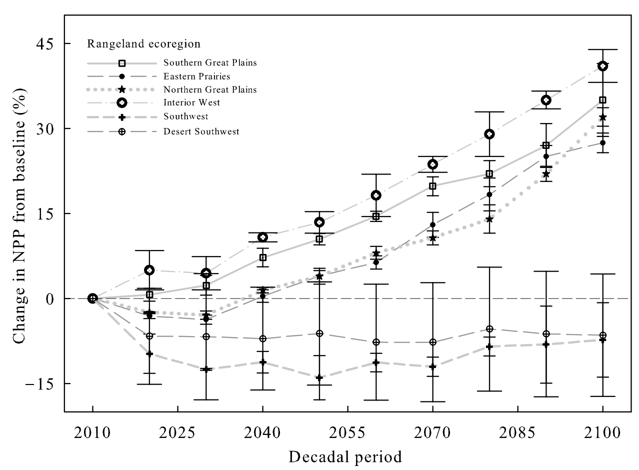
In contrast with changes in temperature, projected changes in precipitation are not as dramatic, but they are more variable in terms of model disagreement and scenario differences. From a national perspective, precipitation remains close to or within the historic range of variability of precipitation for all three scenarios across the entire projection period (figure 9-2(a)). Overall, the mean precipitation difference from 2001 to 2100 across all three scenarios is -1.5 percent, with a standard deviation (SD) of 5.2 percent. This SD represents the variability inherent among precipitation projections associated with the three scenarios. Among the rangeland ecoregions, the Northern Great Plains had the greatest rate of precipitation increase (figure 9-2(c)) but was also highly variable. Annual precipitation in the Eastern Prairies and Southern Great Plains ecoregions exhibits less variability than in the Northern Great Plains. The Southwest ecoregion exhibits the greatest decrease in annual precipitation, albeit with high variability. The mean precipitation response is positive in the Desert Southwest, but the ecoregion exhibits extreme variability.

Vegetation Productivity

The overall NPP trends suggest increases of 16, 19, and 15 percent for the A1B, A2, and B2 scenarios, respectively, for all conterminous U.S. rangelands by 2100. Although the trend for the entire projection period is strongly positive, with an average annual increase of 0.26 percent, NPP does not begin moving in a positive direction until approximately 2030. These general trends, however, belie the varying patterns across the extent of rangelands in the Western United States (figure 9-3).

Productivity in the Southern Great Plains, Northern Great Plains, and Eastern Prairies rangeland ecoregions increases at roughly the same rate of 3.6-percent increase per decade, but

Figure 9-3. Percent change in net primary productivity (NPP) for U.S. rangelands from baseline (2001 to 2010) across the A1B, A2, and B2 scenarios by rangeland ecoregion, 2001 to 2100. Error bars represent standard deviation about the mean for averaged scenarios.



Source: Reeves et al. (2014).

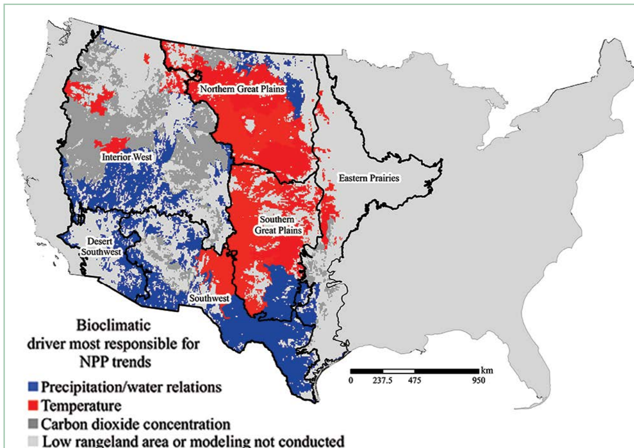
in the Interior West, it increases the most, at 4.5 percent per decade. NPP in the Desert Southwest and Southwest rangeland ecoregions decreases slightly during the projection period, at -0.67 and -1.05 percent per decade, respectively. Significant variation in terms of the NPP response exists within each rangeland ecoregion. For example, declines in productivity for southern and southwestern Texas and central Arizona often exceed 11 percent during the projection period.

Evaluation of the deviation or disagreement among the scenarios in terms of NPP response is informative. In many instances, parts of the Desert Southwest and Southwest ecoregions experience significant declines in NPP yet exhibit high disagreement among scenarios, suggesting that the ultimate fate of NPP of these rangeland ecoregions is more uncertain. By contrast, the variation in NPP response across the Northern and Southern Great Plains among the three scenarios is quite low, potentially indicating less uncertainty for future outcomes.

Relations between bioclimatic drivers and projected NPP trends are shown in figure 9-4. The Northern Great Plains, Southern Great Plains, and Eastern Prairies rangeland ecoregions are characterized as grass-dominated expanses comprising mixtures of C4 (warm season) species and C3 (cool season) species. NPP of these grass-dominated regions tends to be most influenced by temperature. By contrast, the Interior West ecoregion, dominated by C3 grasses or shrubs, tends to be most highly correlated with CO_2 in terms of NPP through time. As expected, NPP trends of the more southern rangelands are most highly correlated with precipitation and water relations.

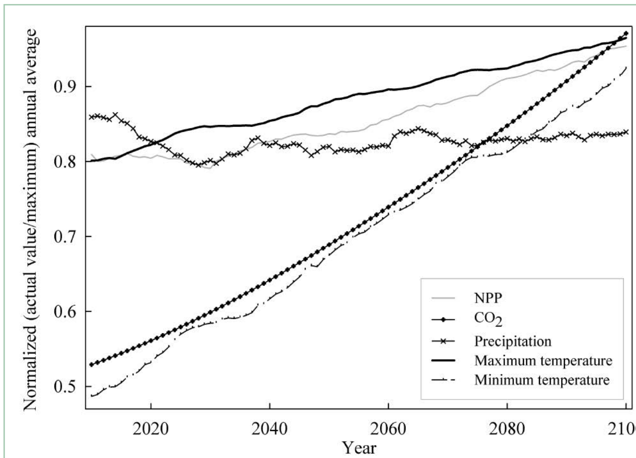
Although some gains in NPP were expected, the extent of rangelands experiencing increases and the magnitude of the increases were surprising. The earlier stages of the projection period suggest decreasing NPP from the present day to the 2030s while tracking the trend in precipitation (figure 9-5). After this initial lag, NPP begins to increase steadily and diverge from the trend in precipitation (figure 9-5). The divergence of the NPP response from precipitation is related to CO_2 fertilization and ever-increasing temperatures (figure 9-5). A lengthened growing season increases the opportunity for CO_2 fixation if moisture is sufficiently abundant (Christensen et al. 2004). Thus, losses resulting from moisture limitations in the southern extent of the study area begin to be offset and surpassed by increases in NPP due to increased growing season length in northern latitudes beginning in the 2030s. The amount of disagreement among scenarios was highest in the last decade of the simulation period (figure 9-3), suggesting that the ability of GCMs to predict climate patterns, and therefore the ability

Figure 9-4. Bioclimatic driver with the highest correlation to estimated net primary productivity (NPP) trends for six U.S. rangeland ecoregions.



Source: Reeves et al. (2014).

Figure 9-5. Normalized (actual value/maximum) 10-year moving average of trends in annualized net primary productivity (NPP), carbon dioxide (CO_2), precipitation, maximum temperature, and minimum temperature across the A1B, A2, and B2 scenarios, 2020 to 2100.



Source: Reeves et al. (2014).

to model NPP, decreases with increasing time from the present day. The amount of uncertainty or disagreement among models is also reflective of the sensitivity to various radiative forcings and underlying assumptions inherent within the GCMs used in this study. Model disagreement is more pronounced in more arid regions and is, in part, due to differences in model sensitivity to CO_2 for estimating temperature. The GCMs used in this study exhibit climate sensitivities very near those examined by Randall et al. (2007), indicating that the climate data used for this study are within the range of those used for other purposes globally. NPP data derived using these GCMs, however, must be evaluated against other sources of information.

Uncertainty in climate projections, species assemblages, disturbance regimes, and changing land use will undoubtedly affect future NPP. Disagreement among and assumptions within the climate projections from the GCMs used here associated with the A1B, A2, and B2 scenarios offer potential for skepticism, particularly toward the end of the century. Data for the projected temperatures exhibit far less variability among scenarios and GCMs than do data for the projected precipitation. Therefore, projections from rangeland ecoregions where temperature, rather than precipitation, is a dominant driver may be more reliable. Changing climatic regimes will undoubtedly influence phenology in unusual ways. For example, in tallgrass prairie, a 4 °C increase in ambient temperature caused earlier flowering among spring-blooming species and later flowering in fall-blooming species (Sherry et al. 2007), implying that climatic change will influence vegetation in complex, unexpected ways (Suttle et al. 2007; Walther 2010).

Uncertainty in future climates suggests that the generalization of increased NPP across rangelands is an oversimplification of the ecological consequences of climate change. Although estimates of climate change appear to enhance NPP overall, the present study does not address likely changes in species composition (Morgan et al. 2007) and other factors related to land health. Prolonged drought combined with higher temperatures could ultimately lead to less residual cover and greater overland flow, resulting in permanent soil loss and reduced vigor by perennial grasses. Reduced vigor by perennial grasses may, in turn, promote the recruitment of shrubs (Tietjen et al. 2010). In a similar way, biotic integrity will decrease if invasive species become notably more prevalent as expected in many cases (Archer and Predick 2008).

Some rangeland ecoregions could exhibit sharp reductions in NPP, which could lead to negative ecological changes and losses of critical goods and services. Even increases in NPP cannot be assumed to translate to increased economic gain without flexibility and adaptation. Adaptation strategies clearly need to take a regional or local approach, but they may prove difficult to develop, because the timing and length of growing seasons may produce unforeseen growth patterns requiring novel management techniques. Integrating flexibility into operations and conducting risk analyses, however, can help address changing conditions (Joyce et al. 2013). The need to ensure livelihood of global populations and the uncertainties associated with projections indicate a strong need for better forecasting tools and coordinated monitoring (Luo et al. 2011) combined with more robust modeling capabilities. The patterns of NPP influence the availability of rangeland goods and services, such as sequestered carbon. The next section examines the future carbon storage and present-day carbon flux on and from rangelands of the conterminous United States.

Carbon on U.S. Rangelands

- ❖ High variability in rangeland SOC flux suggests oscillations between sequestration and emissions are common, especially in the RPA Rocky Mountain Region.
- ❖ No statistically significant trends in SOC on rangelands were observed in any region.
- ❖ Increasing SOC amounts are projected for U.S. rangelands.

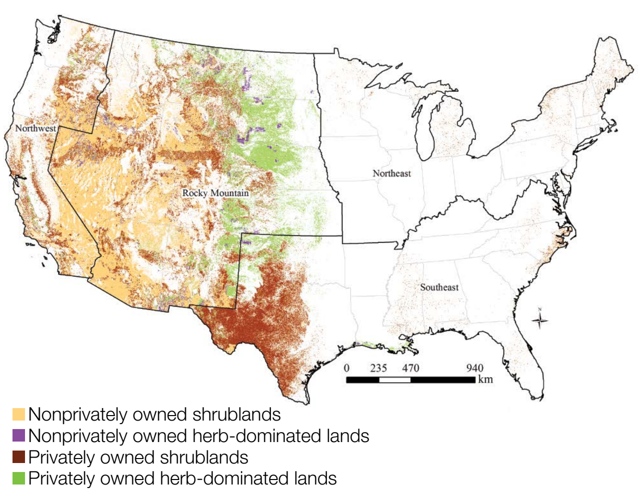
Compared with forests, rangelands receive relatively little attention regarding evaluations of carbon stocks because, in part, compared with forests, rates of carbon sequestration and carbon flux are relatively small. This disparate attention also stems from the lack of a nationally consistent rangeland inventory approach, such as the inventory employed by the Forest Inventory and Analysis (FIA) program. As a result, limited data are available from which carbon stocks can be estimated.

Despite limited inventory data, we were able to draw on two analyses of SOC available for describing the present and future carbon situation on U.S. rangelands. The first source is the SOC estimates available in the annual National Greenhouse Gas Inventory (NGHGI) report (U.S. EPA 2014b). These estimates are the authoritative and "official" estimates for the vegetation and ownerships they represent because they are from the most statistically rigorous process describing the SOC situation on rangelands. The second data source is the SOC estimates from the LandCarbon Project (http://www.usgs.gov/climate_landuse/land_carbon/), which provides estimates of SOC from 2000 to 2050 for the A1B and A2 scenarios (Zhu 2010).

When estimating rangeland carbon quantities, it is important to avoid double counting on any parcel of land that may be classified as forest in some inventory systems but as rangeland in others. To ensure that SOC estimates from "rangelands" were not coincident with SOC estimates from "forested lands," the extent of rangelands from Reeves and Mitchell (2011) was intersected with the spatially explicit estimates of forest carbon stocks developed by the FIA program (Wilson et al. 2013). Any pixels used in the assessment of "forest carbon stocks" were subsequently removed from the rangeland extent database. After removing pixels where carbon accounting for forests has been previously conducted, the remaining pixels were assigned ownership using the Protected Areas Database of the United States (http://consbio.org/products/projects/pad-us-cbi-edition). In addition, each pixel was assigned vegetation lifeform dominance (herb or shrub dominance) so that carbon trends from each life form could be evaluated (figure 9-6). Using this resulting analysis mask, temporal trends from 2000 to 2050 for A1B and A2 scenarios were evaluated for—

1. Shrublands and herb-dominated systems.
2. RPA regions and subregions.
3. Privately owned and nonprivately owned rangelands.

Figure 9-6. The intersection of lifeform estimates (shrublands or herb-dominated lands) with the ownership of rangelands, circa 2011.



Sources: Shrub and herb-dominated extent from Reeves and Mitchell (2011); rangeland ownership from PAD-US (Foster 2012); forest extent from Wilson et al. (2013).

Soil Organic Carbon Estimates for NGHGI Reporting

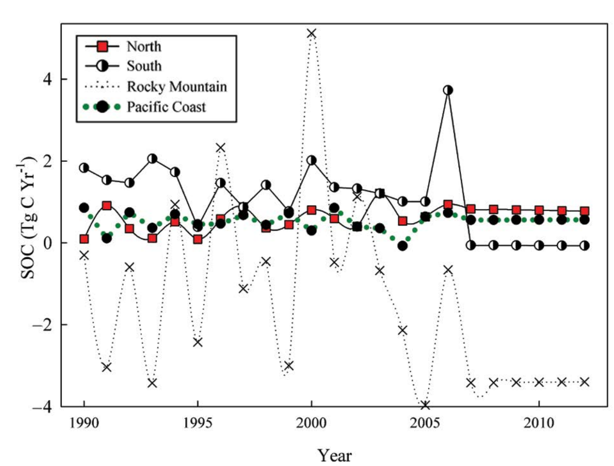
The United States reports SOC on grasslands as part of our national commitment for annual greenhouse gas (GHG) reporting. Methods used to calculate SOC on grasslands follow IPCC protocols, with documentation in Ogle et al. (2003), Parton et al. (1998), and U.S. EPA (2014b). Mineral and organic soils are calculated separately. The estimates currently are limited to SOC on private lands, based primarily on vegetation inventory data from the National Resources Inventory.

In the NGHGI reporting, interannual fluxes of SOC are given, not SOC stocks. The data are available at the State level and are divided among six IPCC-defined categories, including (1) grasslands remaining grasslands (GRG), (2) croplands converted to grasslands, (3) forests converted to grasslands, (4) other lands converted to grasslands, (5) settlements converted to grasslands, and (6) wetlands converted to grasslands. The last five of these categories collectively represent "lands converted to grassland (LCG)." Data are further subdivided between mineral soil and organic soil estimates. For this analysis, carbon flux estimates from both organic and mineral soils at the State-level data were subsequently aggregated to the four RPA regions.

Trends in SOC from LCG and GRG were derived using the State-level estimates in U.S. EPA (2014b) and are shown in figure 9-7. Figure 9-7 depicts estimated SOC fluxes by RPA region from 1990 to 2012 consisting of the GRG and the LCG categories. It is important to note that none of these trends are statistically significant because wide uncertainty (estimates of confidence intervals at the 95-percent level) exists. These levels of uncertainty are often larger than the actual flux estimates, although the uncertainty surrounding the SOC flux estimates from LCG is smaller. The amount of interannual variability (computed as the SD of annual SOC flux) for each RPA region is shown in table 9-1. The RPA Rocky Mountain Region exhibits the highest interannual variability, which is approximately two times the average annual flux in the region. In figure 9-7, values less than zero represent estimates of lost SOC.

Several caveats need to be stated for proper interpretation of the data. First, precise State-level estimates of SOC should be obtained from the official GHG estimates (U.S. EPA 2014b) and Ogle et al. (2012). Second, simulation uncertainties (95-percent confidence intervals reported in Ogle et al. [2012]) are not scaled to the RPA regions in this analysis, even though the SOC fluxes are, so the error about the predictions developed here is unknown. Third, the estimates provided here and in U.S. EPA (2014b) characterize only a portion of the overall SOC flux from rangelands, because the flux estimates available from

Figure 9-7. Total average annual flux in soil organic carbon (SOC) (teragrams of carbon per year [Tg C yr^{-1}]) for lands converted to grasslands and grasslands remaining grasslands by RPA region, 1990 to 2010.



RPA = Resources Planning Act.

Table 9-1. Average annual flux, standard deviation, and coefficient of variation for soil organic carbon from lands converted to grasslands and grasslands remaining grasslands by RPA region, 1990 to 2012.

	GRG				LCG				Total SOC			
	RM	N	S	PC	RM	N	S	PC	RM	N	S	PC
	teragrams of carbon per year											
Average	– 1.443	0.621	1.078	0.526	0.328	0.360	0.748	0.056	– 1.115	0.981	1.825	0.582
SD	2.283	0.293	0.930	0.223	0.113	0.087	0.111	0.022	2.293	0.361	0.926	0.226
CV	1.582	0.471	0.863	0.423	0.345	0.242	0.148	0.397	2.056	0.368	0.507	0.388

CV = coefficient of variant. GRG = grasslands remaining grasslands. LCG = lands converted to grasslands. N = RPA North Region. PC = RPA Pacific Coast Region. RM = RPA Rocky Mountain Region. RPA = Resources Planning Act. S = RPA South Region. SD = standard deviation. SOC = soil organic carbon.

U.S. EPA (2014b) apply only to privately owned grasslands. Therefore, most shrub-dominated systems or any nonprivately owned rangelands are not sampled.

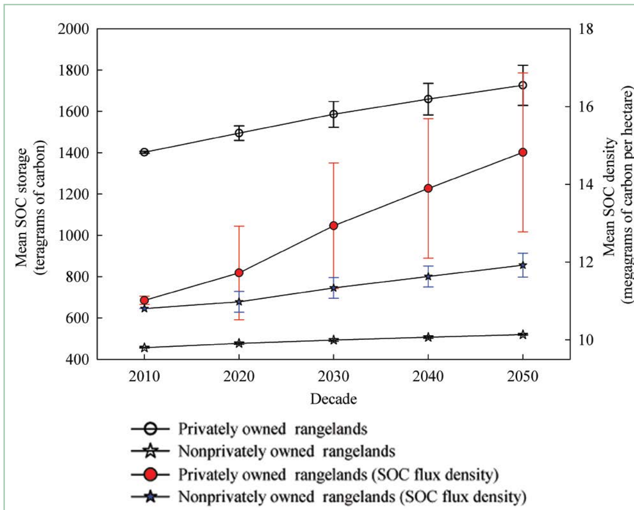
Soil Organic Carbon Estimates From the LandCarbon Project

The LandCarbon project is a national assessment focused on improved understanding of carbon sequestration and GHG fluxes in and out of ecosystems related to changes in land use (http://www.usgs.gov/climate_landuse/land_carbon/). The LandCarbon project develops spatially explicit estimates of sequestered SOC annually from 2000 to 2050 for the A1B, A2, and B1 scenarios from the AR4 (Liu et al. 2014a). Only the A1B and A2 scenarios were analyzed here. From these data, both carbon stores and fluxes can be calculated for rangelands of the conterminous United States. These data are produced at a spatial resolution of 2 km^2 but cover all ownerships and vegetation types.

Total carbon storage on rangelands, as estimated with the LandCarbon data, which were spatially subset to the mask depicted in figure 9-6, is approximately 1,860 teragrams (Tg) of carbon. Wilson et al. (2013) estimate that forests contain approximately 17,700 Tg of carbon SOC, about 10 times the SOC estimated on rangelands currently. The estimated SOC on rangelands by 2050, however, is greater than present-day estimates across both the A1B and A2 scenarios, representing an increase of about 17 percent compared with the same spatial extent at the present time. Reeves et al. (2014) estimated the overall impact of the A1B and A2 scenarios on NPP as positive because of factors such as increased growing season length and improved water-use efficiency via CO_2 enrichment. These same factors presumably affect the LandCarbon-modeled estimates of SOC as well.

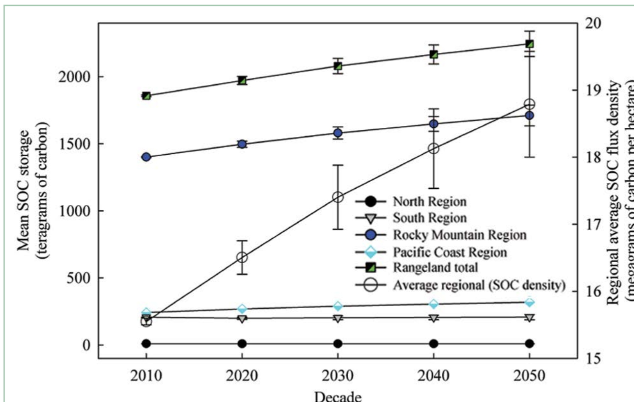
From a national perspective, the LandCarbon data suggest steadily increasing rangeland SOC in both A1B and A2 scenarios, regardless of ownership, vegetation dominance, or RPA region (figures 9-8, 9-9, and 9-10). In each of these figures, the data represent mean SOC stocks between the A1B and A2 scenarios. Likewise, the error bars at each data point are the SD about the mean. In this manner, the larger error bars indicate greater disagreement between SOC estimates derived from

Figure 9-8. Mean soil organic carbon (SOC) storage (primary y-axis) and mean SOC flux density (secondary y-axis) for rangelands of the conterminous United States, by ownership, 2010 to 2050. Means represent the average of the A1B and A2 scenarios. Error bars represent the standard deviation (or scenario disagreement) between SOC estimates.



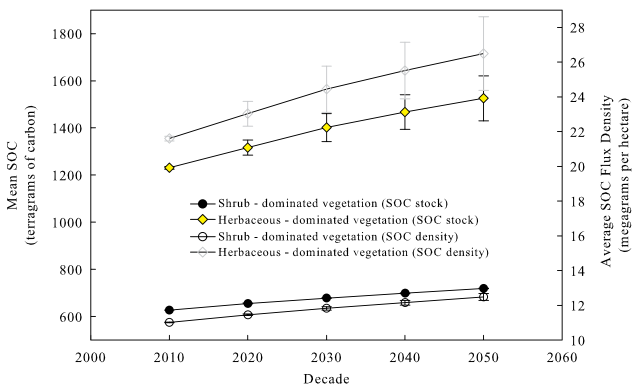
Source: Estimates derived from the LandCarbon SOC data (Liu et al. 2014a).

Figure 9-9. Mean soil organic carbon (SOC) storage (primary y-axis), by RPA region, and mean SOC flux density (secondary y-axis) for conterminous U.S. rangelands, 2010 to 2050. Means represent the average of the A1B and A2 scenarios. Error bars represent the standard deviation (or scenario disagreement) between SOC estimates.



RPA = Resources Planning Act.
Source: Estimates derived from the LandCarbon SOC data (Liu et al. 2014a).

Figure 9-10. Mean soil organic carbon (SOC) storage (primary y-axis) and SOC flux density (secondary y-axis) for dominant rangeland life forms across the conterminous United States, 2010 to 2050. Means represent the average of the A1B and A2 scenarios. Error bars represent the standard deviation (or scenario disagreement) between SOC estimates.

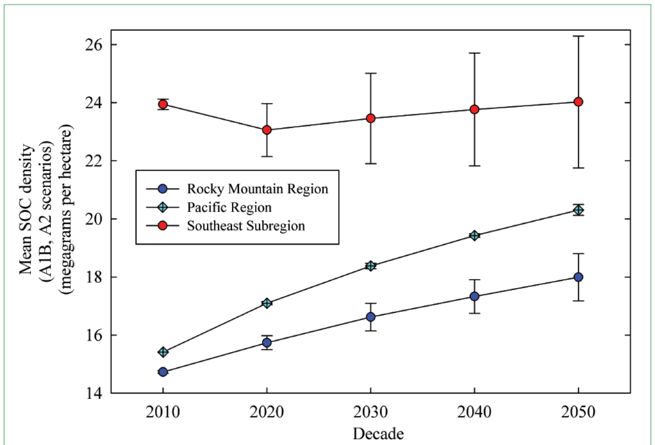


Source: Estimates derived from LandCarbon SOC data (Liu et al. 2014a).

the GCMs run for the A1B and A2 scenarios. This method of displaying data is used consistently throughout the results, and interpretation should be commensurately consistent. This generalization applies to both rates of sequestration (milligram per ha [mg ha^{-1}]), indicated by secondary Y-axes in figures 9-8 through 9-10 and total sequestration (Tg of carbon).

Rates of sequestration for the RPA Rocky Mountain and Pacific Coast Regions and the Southeastern Subregion in the RPA South Region are shown in figure 9-11. The Southeastern Subregion consistently shows the highest SOC accumulation rate but also exhibits the highest disagreement among scenarios. The high rate of sequestration in the Southeastern Subregion

Figure 9-11. Mean soil organic carbon (SOC) flux density for two RPA regions and one RPA subregion, 2010 to 2050. Means represent the average of the A1B and A2 scenarios. Error bars represent the standard deviation (or scenario disagreement) between SOC estimates.



RPA = Resources Planning Act.
Source: Estimates derived from LandCarbon SOC data (Liu et al. 2014a).

(figure 9-11) occurs because the region is characterized by humid and warm conditions and longer growing seasons compared with the relatively more arid Rocky Mountain Region. Average rates of SOC accumulation are nearly double for herb-dominated vegetation and are consistently higher for privately owned rangelands. Many of the rangelands in the public domain are dominated by relatively xeric, shrub-dominated landscapes that tend to be less productive. The RPA North Region is omitted from figure 9-11 because SOC densities in that region are much greater than in other regions, which offsets the scale, and because the sample size is very small (< 0.001 percent of the rangeland area analyzed) (figure 9-6). A final feature of the future SOC estimates derived using the A1B and A2 scenarios is that the Rocky Mountain Region exhibits the greatest increasing rate of change from the present day to 2050. This finding is consistent with NPP estimates derived by Reeves et al. (2014) and corroborated by experimental research from Morgan et al. (2011).

Summary

Because of model uncertainty, no statistically significant trends exist in SOC fluxes present in the EPA data (U.S. EPA 2014b). High variability in rangeland SOC flux, especially in the RPA Rocky Mountain Region since 1990, suggests oscillations between sequestration and emissions may be expected in the future. The future outlook for SOC conditions, however, appears relatively positive from a national perspective, according to data derived from the LandCarbon project. Reeves et al. (2014) suggest a similarly positive national outlook for NPP (linked to, but different from, SOC flux), especially in more northern latitudes. The increased growing season length owed to increasing temperatures and improved water-use efficiency resulting from CO_2 enrichment is potentially a positive factor for both NPP and SOC accumulation, but much uncertainty remains (Reeves et al. 2014).

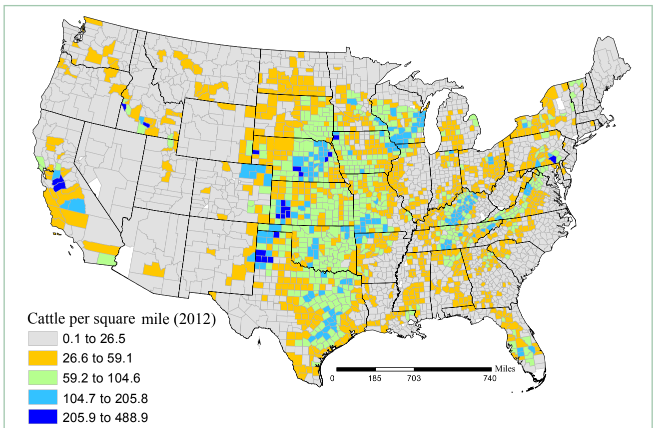
Vulnerability of Cattle Production to Climate Change

- In general, the northern portion of the Great Plains exhibits less vulnerability than the Southern or Southwestern United States, especially Texas.
- Most interpretations suggest increasing vulnerability in the Southwest even before taking in account effects on surface water.
- These findings emphasize the importance of diversifying livestock operations and maintaining flexibility in herd sizes and stocking rates.

In this section, we present a spatial analysis of future cattle production vulnerability on U.S. rangelands using four key ecological elements sensitive to climate change: (1) forage quantity, (2) vegetation type trajectory, (3) heat stress, and (4) forage dependability (Bagne and Reeves 2016). Vulnerability of cattle production is important because the United States is the world's largest producer of beef, and beef production is an important good derived from rangelands. U.S. cattle production has been relatively constant to slowly declining during the past decade, with approximately 97 million cattle on rangelands, as opposed to pastures, concentrated throughout the Northern and Southern Great Plains rangeland ecoregions, Interior West rangeland ecoregion, and Pacific West rangeland ecoregion (figure 9-12) (Reeves and Mitchell 2012).

We viewed future cattle production as production potential from an ecological perspective, ignoring the complex of social, economic, and other factors involved in setting actual stocking rates. Rather than model weight gain for individual cattle as in Baker et al. (1993), we examined key climate-sensitive variables, which approximated sensitivity and adaptive capacity and projected the magnitude and direction of change (i.e., exposure) using GCMs associated with four AR4 scenarios to 2100 (A1B, A2, B1, B2) for each (table 9-2). Our metric of vulnerability was departure from current conditions (2001 to 2010) because of its relevance to sustainability, local knowledge, and ease of interpretation.

Figure 9-12. Density of beef cattle per square mile by county in the conterminous United States, by rangeland ecoregion, 2012.



Source: National Agricultural Statistics Survey (2014).

Climate change is expected to have a wide range of effects that will potentially alter rangeland ecosystems (Polley et al. 2013). It is important to know that climate change can exacerbate current threats to rangeland health, such as expanding ranges of invasive species, increasing duration and severity of droughts or floods, and declining aquifers. Considering the multiple drivers and factors regulating response, alteration of goods and services from U.S. rangelands will not be uniform, spatially or temporally, and adaptation measures cannot be universally applied.

Elements of Vulnerability and Composite Vulnerability Index

For this analysis, vulnerability is described spatially as departure from current conditions for the four key elements: forage quantity, vegetation type trajectory, heat stress, and forage dependability in response to estimated patterns of climate change. Vulnerability is considered to be the degree to which a system is exposed to negative impacts (Mitchell et al. 1989). Thus, vulnerability can encompass a large range of complex intrinsic and extrinsic processes.

We measured vulnerability of U.S. livestock operations as future departure or difference from a baseline of current or recent values in a specific location. This approach is particularly useful for an element such as cattle production because current management of livestock operations can be presumed to be adapted to and reasonably sustainable under the range of recent conditions experienced. In addition, much is known about the U.S. cattle market, given its size and economic importance.

The ultimate goal of this study was to examine the regional vulnerability of local cattle production to climate change relative to the present day in the conterminous United States. With many pathways by which climate change can alter cattle production, we chose to simultaneously examine multiple ecological elements considered important in determining production using a composite score, or vulnerability index,

Table 9-2. Source of data for elements and variables used to calculate climate change vulnerability of U.S. cattle production on rangelands. Output units are for each rangeland pixel (2.5 arc minute or ~8 km^2).

Element	Variable used	Units	Data source	Source
Forage quantity	Total annual NPP	kg C ha^{-1} · yr^{-1}	Biome-BGC	Reeves et al. (2014)
Vegetation type trajectory	Pixels projected as grass or forb types each year	Percent per decade	MC2	Bachelet et al. (2001)
Heat stress	THI	Days · yr^{-1} THI > stress threshold	IPCC TAR and AR4	Coulson et al. (2010a, 2010b)
Forage dependability	NPP interannual variability	Decadal SD of annual NPP (kg C ha^{-1} yr^{-1})	Biome-BGC	Reeves et al. (2014)

AR4 = Fourth Assessment Report. C = carbon. ha = hectare. IPCC = Intergovernmental Panel on Climate Change. kg = kilogram. NPP = net primary productivity. SD = standard deviation. TAR = Third Assessment Report. THI = temperature-humidity index. yr = year.

Notes: Biome-BGC is an ecosystem process model. MC2 is a global vegetation model.

Source: Bagne and Reeves (2016).

which is helpful in the absence of a deterministic mathematical model, because it integrates multiple vulnerability elements into one quantitative metric that can be used to make regional comparisons temporally and spatially.

To create a composite index, all elements that affect the targeted outcome can be set to a consistent unit, such as percent change or a categorical index score, to allow for multiple elements to be summed or averaged (Hurd et al. 1999; Joyce et al. 2008). In the simplest form, elements can be combined based on predicted direction of change, regardless of magnitude, and can balance a set of increasing and decreasing impacts (Bagne et al. 2011; Baker et al. 1993; Batima 2006; O'Brien et al. 2004b). In the following subsections, we describe the four key ecological elements of livestock production subject to alteration by climate change and highlight those elements we included in our model.

Forage availability is essential to setting stocking rates and is the combination of primary production and the proportion of that production that is useable by cattle (Holechek 1988). Although elevated CO_2 can stimulate plant growth, NPP fluctuates with climate variables, particularly soil water availability, and ultimately drives the number of cattle that can be raised. Change in NPP is accordingly expected to vary spatially and temporally (Reeves et al. 2014). We examined forage availability as two variables: (1) total annual NPP as a measure of forage quantity, regardless of vegetation type, and (2) the trajectory of potential vegetation type toward or away from woody-dominated types.

Forage Quantity

Forage quantity was estimated through evaluation of changes in NPP from the biogeochemical model Biome-BGC (Running and Hunt 1993). Total annual NPP in each year for each pixel was subtracted from the 10-year average baseline NPP (2000 to 2010). Greater vulnerability was assumed from greater reduction from baseline and similarly greater resilience or potential benefit from greater increase. NPP estimates for U.S. rangelands were taken from Reeves et al. (2014).

Vegetation Type

Vegetation type trajectory is a simple metric related to available forage that indicates if vegetation is projected to become grassier or woodier compared with present-day vegetation. Cattle preferentially use forbs and grasses rather than shrubs or other woody plants, thus trajectories toward greater herbaceous dominance would be beneficial to cattle and toward more woody vegetation would indicate greater vulnerability from this perspective. Future potential vegetation was simulated using output from the dynamic global vegetation model, MC2 (Bachelet et al. 2001; Peterman et al. 2014).

Heat Stress

The impact of heat on livestock production is of growing concern as global temperatures rise (Baker et al. 1993; Howden et al. 2008). High temperatures and humidity can induce heat stress in livestock, which increases water demands and reduces weight gain as rumination ceases and energy is expended to reduce body temperature (Bonsma et al. 1940; Finch 1986; Howden et al. 2008). Heat stress in cattle is related to a temperature-humidity index (THI), a simple index correlated to physiological heat response that has been shown to closely track more extensive models of heat transfer (Howden and Turnpenny 1998).

Projected daily values for average daily temperature and relative humidity were used to calculate the THI following Hahn (1997) and Brown-Brandl et al. (2005). Our heat stress index (HSI) vulnerability for cattle production was calculated from the total number of days per year where THI > 74. HSI was calculated for each pixel as the percent change in number of days above threshold from the baseline decade. This THI threshold of negative impact is based on a thermal neutral zone for beef cattle below THI = 72 and is the initial threshold of heat stress for the livestock weather safety index (Hahn et al. 2009).

Forage Dependability

The predictability of forage or forage dependability is one of the most critical aspects of livestock production, determining the viability of livestock operations in a region (Ash et al. 2012; Eakin and Conley 2002). Variation in NPP can alter availability of forage and also the long-term sustainability of livestock operations. Interannual variation in NPP is a contributing factor to vulnerability, regardless of total production, because variation creates unpredictable conditions and requires increasing flexibility in cattle operations, including stocking rates, herd size, herd movement, and use of supplemental feed (Ash et al. 2012; McKeon et al. 2009).

Dependability of forage supply was attributed to variability in forage quantity and measured as the decadal interannual variation in NPP as previously described under forage quantity. Interannual variability was measured by change in the decadal moving average of SD of annual NPP from the 10-year baseline average SD. For example, the first moving average value represents the years 2000 through 2010 and the second represents 2001 through 2011.

Other critical factors known to affect cattle production were not dealt with in this analysis. We lacked relevant datasets for additional factors that would likely affect future cattle production, including forage quality, water, pests, disease, and biodiversity (Thornton 2010). As more data and analyses become available, we aim to expand the present vulnerability assessment to include the likelihood and magnitude of impacts from water shortages and increased pests, such as lice, ticks, horn flies, and cattle grubs.

Overall Vulnerability

We categorized vulnerability for each of the four elements, using the same proportional magnitude of departure from the baseline period. These four measures of vulnerability were then summed to create an index of overall vulnerability for each pixel in each projected year (table 9-3). Thus, all elements were considered to be independent and equally important to the vulnerability of cattle production. By setting all thresholds equal, a 20-percent change in forage quality has the same relative impact to vulnerability as forage variability, although a 20-percent change in forage quantity may not translate to the same change in the number of cattle that can be produced.

We calculated the SD of scores comprising overall vulnerability for each pixel, which measured the range of scores and indicated the relative amount of agreement among the four elements of vulnerability. Less deviation would indicate general agreement among the elements regarding the relative vulnerability of a pixel or region. Larger deviations indicate disagreement. We also calculated the average deviation for each rangeland ecoregion.

Table 9-3. Classification of vulnerability scores. Change is relative to baseline conditions, 2001 to 2010.

Relative change in vulnerability element	Vulnerability score
(percent)	*(unitless)*
value < – 20	– 2
– 20 ≤ value < – 10	– 1
– 10 ≤ value ≤ 10	0
10 < value ≤ 20	1
value > 20	2

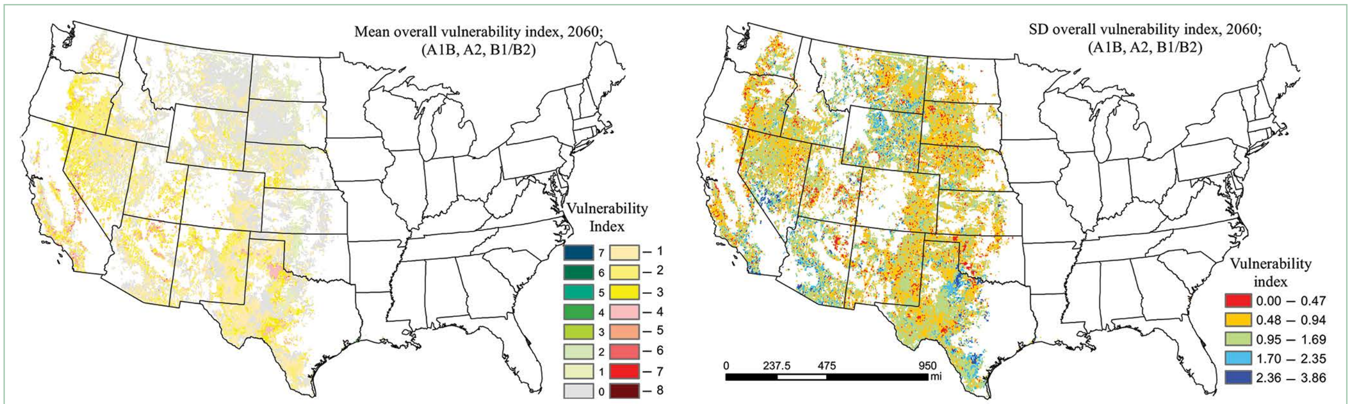
Source: Bagne and Reeves (2016).

Results

Relative percent change from the baseline was translated into vulnerability with respect to improving or declining cattle production (table 9-3; figure 9-13). These simple vulnerability index scores for the four elements were then summed for an overall index of vulnerability. The four individual elements examined, each with a possible range of -2 to +2, were then summed for a possible range of -8 to +8. Levels of the index are not directly related to cattle production values, but they give an indication of the expected overall direction of change as driven by the four key elements related to cattle production. Results indicate greater vulnerability of cattle production for much of the rangeland extent in the United States (figure 9-13). Relatively more arid rangeland ecoregions have the strongest trends toward greater vulnerability, and most elements agree on the direction of change (figure 9-14). The Eastern Prairies, Northern Great Plains, and Southern Great Plains rangeland ecoregions were expected to change the least and show some areas of potential resilience or improving conditions for production by the latter half of the century (figure 9-14). It is important to know that this relative lack of overall vulnerability for the plains and prairies is due to opposing trends across elements rather than a consistent lack of climate effects (figures 9-13 and 9-15).

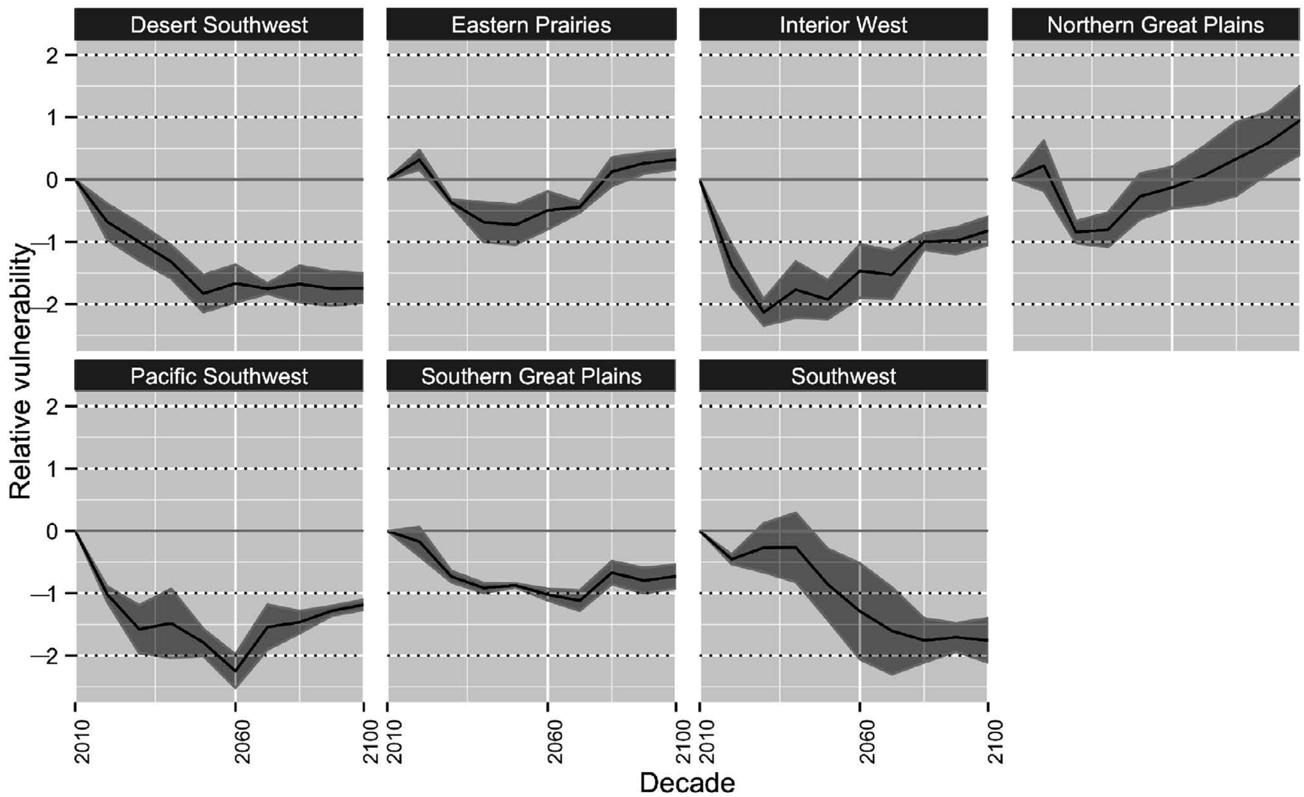
The SD of index scores increases over time for all regions; thus, scores become more opposing rather than converging. Scores differ the most among elements in the Northern Great Plains rangeland ecoregion and some parts of the Southwest rangeland ecoregion, particularly Texas. The western extent of rangelands also tends to have lower score deviation. We classified deviation and overall vulnerability to create a spatially explicit representation of this concept. Overall scores were

Figure 9-13. Mean overall vulnerability index (sum) (top) and standard deviation (SD) from overall vulnerability index (bottom) in 2060 under averaged scenarios for U.S. rangelands. Negative numbers indicate greater vulnerability and positive numbers indicate less vulnerability compared with present-day numbers. The B1/B2 scenario nomenclature is used because all elements in the vulnerability assessment, with the exception of MC2 output, were available for the A1B, A2, and B2 scenarios, but the MC2 output was available only for A1B, A2, and B1. Therefore, the B1/B2 represents a combination of the two scenarios.



Source: Bagne and Reeves (2016).

Figure 9-14. Trend in average overall vulnerability index for U.S. rangeland ecoregions, averaged across scenarios, 2010 to 2100. Standard error is shown in the shaded region. Negative numbers indicate greater vulnerability and positive numbers indicate less vulnerability compared with present-day numbers.



Source: Bagne and Reeves (2016).

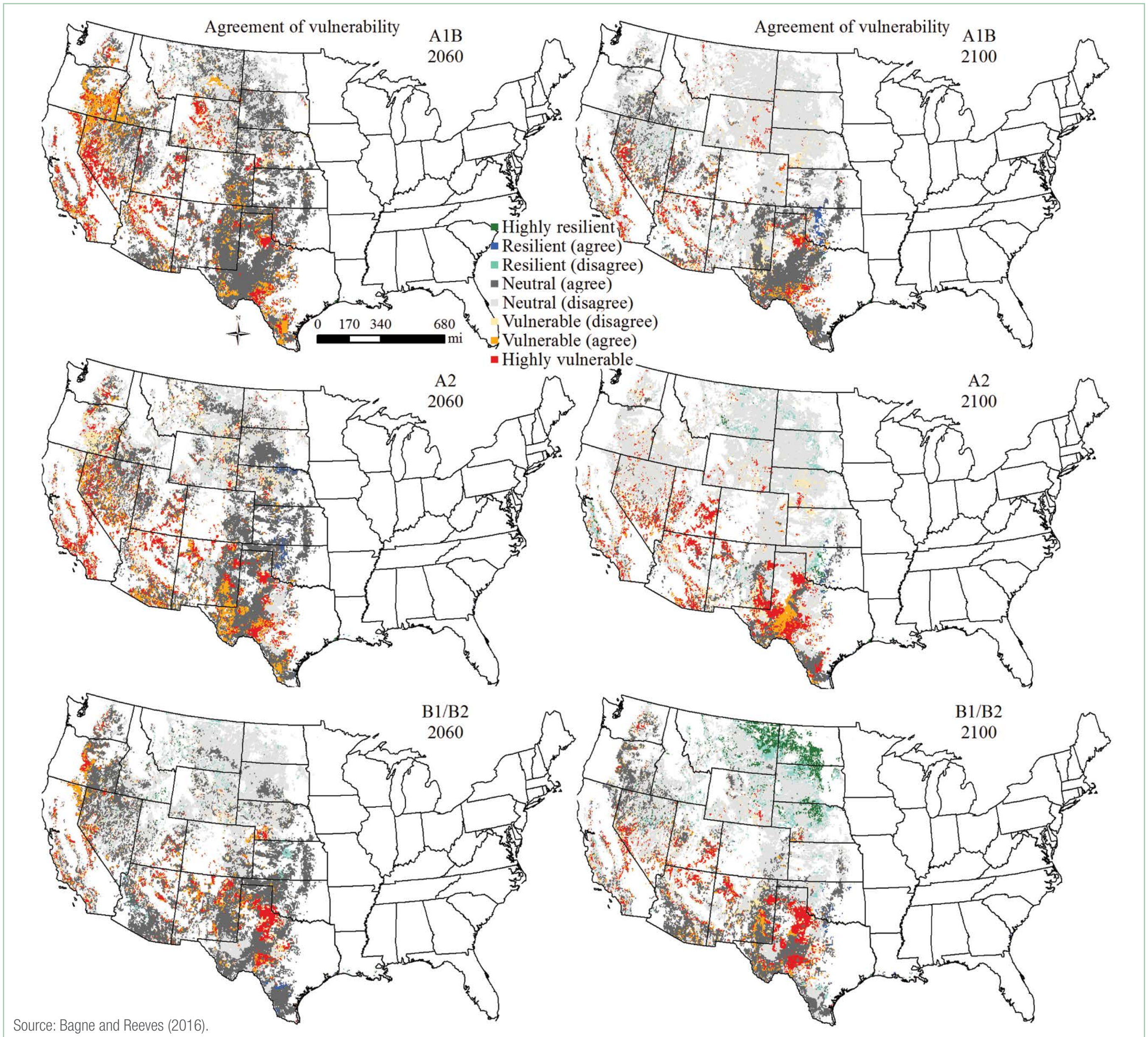
classified as highly resilient (≥4), resilient (>2), neutral (≤2 and ≥-2), vulnerable (<-2), or highly vulnerable (≤-4). Scores were considered as agreeing if SD < 1.15 and as disagreeing if SD ≥ 1.15. With deviation overlaid on vulnerability, we can identify robust change and regions with opposing predictions, where the interplay of elements will be critical to future production (figure 9-15). Strong evidence exists across elements and scenarios for increasing vulnerability in the Southwest and Desert Southwest ecoregions, particularly in California, the Texas Panhandle, and northern Arizona (figure 9-15). Resilience is indicated in the Northern Great Plains ecoregion, Kansas, and small areas of coastal California, but considerable variation exists among emissions scenarios. The Northern and Southern Great Plains ecoregions are often neutral, but they are in disagreement among vulnerability elements (figure 9-15).

Results should be interpreted as a broad prediction of the expected relative change in potential cattle production due to these four elements. Relative to the current baseline (2001 to 2010), we found—

- NPP increases in a number of regions, potentially benefiting cattle production.
- Vegetation types move toward more grass overall but vary considerably across the rangeland extent and within regions.
- The number of days when cattle may be heat stressed increases rapidly across all regions with the largest departure from baseline in the Interior West and Pacific West rangeland ecoregions.
- Regional trends do not indicate a steady progression of impact over time, except for heat stress, but rather nonlinear fluctuations and presence of thresholds.
- Expected impacts are consistently negative across multiple elements in the Southwest and Desert Southwest rangeland ecoregions.
- Benefits of increased NPP or inertia toward grassier vegetation types in more northerly latitudes are mostly tempered by increasing heat stress and variability in production.

These results must be viewed with caution because of the uncertainty inherent in these kinds of analyses of possible future conditions. Uncertainty stems from multiple processes during vulnerability assessment: from modeling and downscaling climate to integrating multiple and interacting sources of impacts

Figure 9-15. Summary of the direction of predicted change based on overall vulnerability index and agreement among modeled elements under A1B, A2, and B1/B2 scenarios for U.S. rangelands, 2060 and 2100. The B1/B2 scenario nomenclature is used because all elements in the vulnerability assessment, with the exception of MC2 output, were available for the A1B, A2, and B2 scenarios, but the MC2 output was available only for A1B, A2, and B1. Therefore, the B1/B2 represents a combination of the two scenarios.



Source: Bagne and Reeves (2016).

(Izaurralde et al. 2011; Kerr 2011). In most cases, the direction of change for an element is well supported by all GCM results, but timing of change is more uncertain because it depends on numerous factors affecting atmospheric GHG levels. Although differences among GCM results are not great, variation among models tends to be larger in relatively more arid regions and for estimates of forage variability.

Implications

This assessment of the future of U.S. cattle production on rangelands sets the stage for initiating more detailed studies and designing adaptation solutions for sustainable goods and services applicable across regional extents. Rangelands, in particular, are amenable to adaptation measures because of the close connection with goods and services, history of cooperation between rangeland scientists and managers, and the diversity of available solutions (Joyce et al. 2013). We chose cattle production because of its economic importance, but we recognize that rangelands provide a wide range of goods and services that will not necessarily respond to climate change similarly.

Adaptation, in the context of vulnerability, is an action taken by individuals, groups, or governments to prepare for or respond to change. Effectiveness of adaptation will depend on goals as applied to chosen spatial and temporal scales, but, because outcomes of actions and response to future climate are uncertain, actions should have robust benefits and be flexible to changing conditions (Adger et al. 2005). Many options are available, and the magnitude of predicted change can be viewed as akin to a range of adaptive management choices from resistance or maintenance of the resource in its current condition to transition to a new condition accompanied by a new set of goods and services (table 9-4) (Millar et al. 2007; Peterson et al. 2011).

Table 9-4. Adaptation options for affected U.S. rangeland ecoregions and States as suggested by average predicted climate change effects to 2100.

Element	Rangeland ecoregions and States likely affected	Adaptation options
Forage quantity (decreasing)	Southwest, Desert Southwest	Supplemental feed, conservative stocking, fire and weed management
Forage quantity (increasing)	Intermountain West, Northern Great Plains	Flexible stocking and rotation, forage harvest
Vegetation type = grassier	Eastern Prairies, California	Flexible stocking and rotation
Vegetation type = woodier	Texas panhandle, eastern Wyoming, western Nevada	Woody plant removal, change livestock species
Heat stress (increasing)	All	Change livestock breeds or species, select for lighter coats, add shade and water, alter rotation schedule
Forage dependability (decreasing)	Intermountain West, Pacific Southwest	Increase flexibility or reduce stocking rates, carryover of yearlings, utilize forecasting
Forage dependability (increasing)	Northern Great Plains	Increase stocking rates, increase utilization rates

Source: Bagne and Reeves (2016).

Degradation of Rangelands

- ❖ About 7 percent of U.S. rangelands exhibit significant decreases in productive potential.
- ❖ Relatively small areas have statistically significant decreasing trends in productivity.
- ❖ Relationships between productive capacity and annual precipitation are much stronger in the Northern Great Plains rangeland ecoregion than in the Southern Great Plains ecoregion.

Rangelands are extensive arid and semiarid regions that are characterized by relatively low productivity and a high proportion of bare ground; therefore, they account for less than 15 percent of terrestrial NPP (Ellis and Ramankutty 2008). Rangelands are relatively fragile ecosystems because of environmental factors, including aridity, thin soils, and low productivity. As a result of these factors, sustained NPP can be relatively easy to compromise. Most research on degradation has been global or international, often focused on sub-Saharan Africa, but much is still unknown about the extent and magnitude of rangeland degradation. Remote-sensing system applications have been limited by three principal factors: (1) availability of reliable ground-truth data; (2) high variability in precipitation that can mask land degradation; and (3) a lack of appropriate reference conditions that, by comparison, represent lands not degraded.

A study by Reeves and Baggett (2014) focused on degradation of rangelands using a process for detecting lands with statistically significant reductions in productive capacity estimated with the Normalized Difference Vegetation Index (NDVI) compared with similar sites in close proximity. NDVI is a commonly used remote-sensing metric using red and near-infrared wavelengths to estimate biomass, greenness, vegetation health, and other phenomena. The process enabled the researchers to analyze statistical differences from 2000 to 2012 between the trend and mean response (status) of NDVI from rangelands compared with reference conditions (see the sidebar Evaluating Status and Trends in Rangeland Degradation). Analysis of the status or mean response was necessary because many sites were degraded before 2000.

The process was first tested on the Northern and Southern Great Plains rangeland ecoregions of the conterminous United States. The Northern and Southern Great Plains were chosen because of the diversity of land ownership and unique history. Legislative action beginning in 1862 encouraged expansion of settlement to the Western United States, resulting in a sixfold increase in cattle production by 1890 (Poling 1991) and a twentyfold increase in sheep production in the same period (Stoddart and Smith 1943). Past management from more than 100 years ago does not necessarily drive present landscape patterns, but past management is assumed to influence the productive capacity of a site.

The Northern and Southern Great Plains ecoregions occupy a total of 328 million acres (135 million ha) and are broad, relatively flat regions in which natural vegetation is composed primarily of mixed- and short-grass prairie (figure 9-17). Of the land area, 96 percent is in non-Federal ownership, so many different land management regimes are present. Annual precipitation generally increases from west to east, and average NPP from 2000 to 2012 tends to follow a similar pattern (figure 9-17).

Evaluating Status and Trends in Rangeland Degradation

For this study of rangeland degradation, reference conditions were defined as the temporal Normalized Difference Vegetation Index response of like-kind sites within a given region. For example, all the sites represented as Intermountain basin big sagebrush communities in an ecological subsection were aggregated to represent the reference conditions for that type of site in the region (figure 9-16). To identify degradation, each pixel that belongs to a given site (e.g., Intermountain basin big sagebrush) is iteratively withheld from the formulation of reference conditions and subsequently compared with the reference condition for both the trend and status comparisons. Degradation trend is measured by a t-test and p-value that represent the t-test and associated p-values between the slopes of each pixel and reference conditions. Degradation status is the t-test and associated p-values between the mean responses of each pixel and reference conditions.

The resulting data can be evaluated using differing p-value thresholds so a range of estimated degraded area can be resolved. For example, using a threshold of $p \leq 0.1$ results in larger estimates of degraded area and a smaller threshold of $p \leq 0.001$ results in more conservative estimates of degraded area.

In figure 9-16, panel (a) represents configuration of strata across the extent of the study area. Panel (b) depicts strata configuration around one of the rangeland ecoregions in the study area, and panel (c) demonstrates how a particular site within a rangeland ecoregion forms a single strata (in this case mixed-grass prairie). The graph representing points d, e, f, and g refers to the stratum pixels represented in panel (c). Point d represents the trend of the reference pixels (all pixels in panel (c) except the subject pixel). Point e represents the status of reference pixels (mean of all pixels from 2000 to 2012, withholding the subject pixel). Point f represents the status of the subject pixel (mean of the subject pixel from 2000 to 2012). Point g represents the trend of the subject pixel (mean of all pixels from 2000 to 2012, withholding the subject pixel).

Analysis of the status or mean response was necessary because many sites were degraded before 2000. For example, if a site was irreparably degraded in past decades, the trend may be relatively stable. If the reference condition is equally stable (flat trajectory through time, even if production averages much greater values), comparing the degraded site with a flat trajectory to the reference with a flat trajectory would not yield a significant difference. If, however, the status of the same degraded site (mean response through time) was compared with reference conditions, a significant difference may indeed be found. Therefore, it is clear that both trend analysis and mean response (status) must be analyzed for an evaluation of rangeland degradation.

Figure 9-16. Defining status and trends in rangeland degradation, using the Normalized Difference Vegetation Index (NDVI).

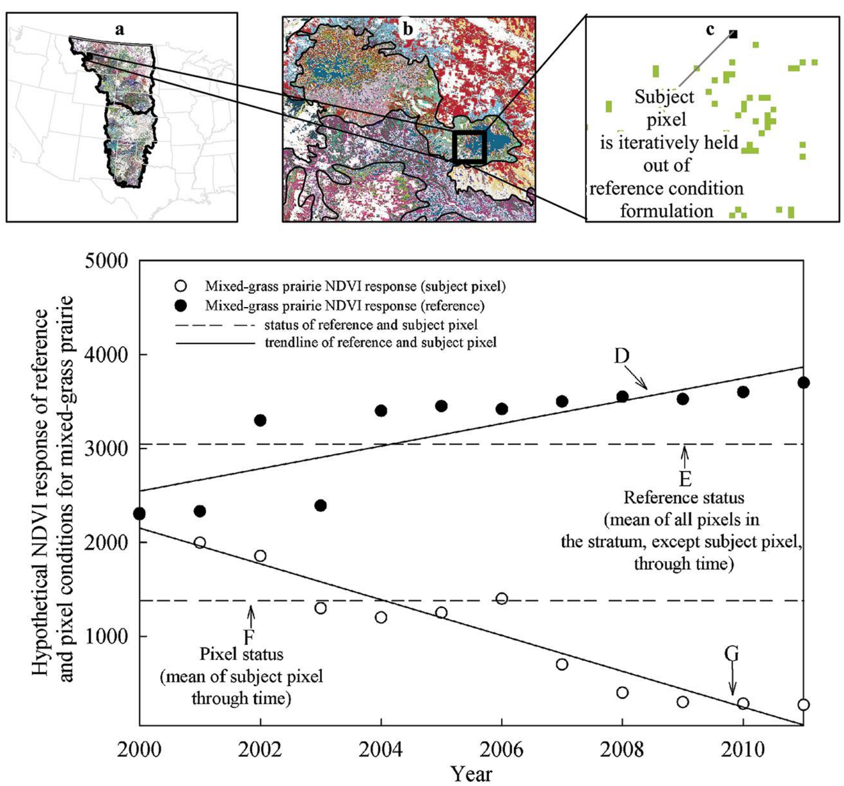
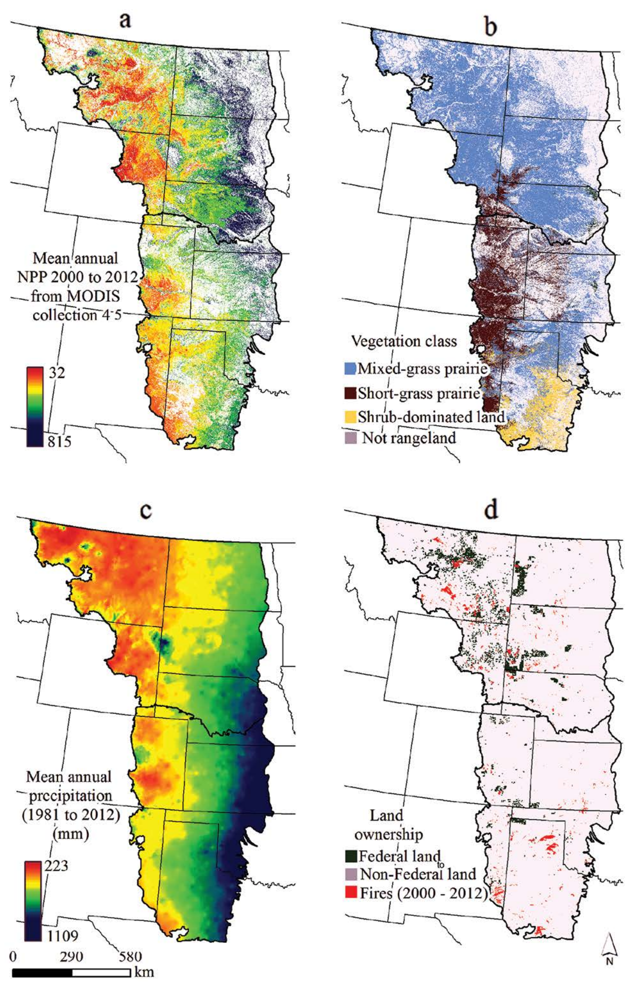
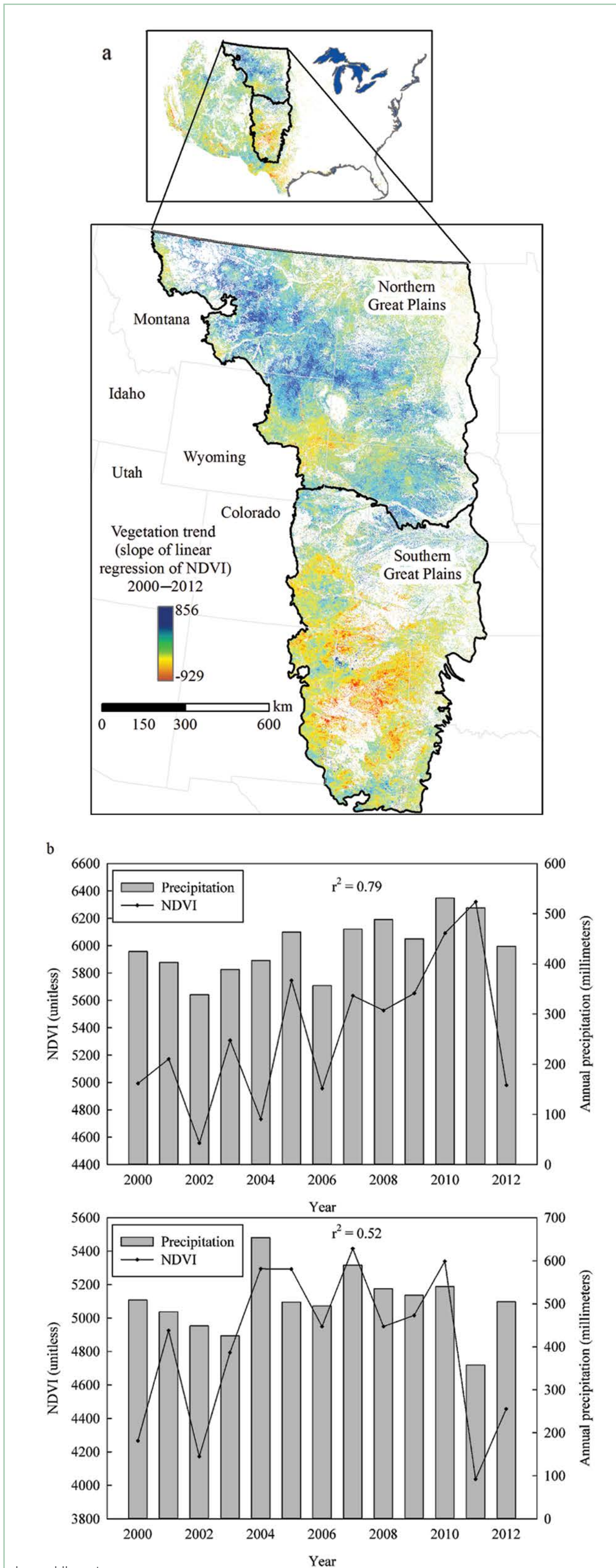


Figure 9-17. (a) Historical trends in the Northern and Southern Great Plains rangeland ecoregions in mean annual net primary productivity (NPP), 2000 to 2012; (b) existing vegetation type (or class), circa 2010; (c) mean annual precipitation[a] 1981 to 2012; and (d) private land ownership[b] (circa 2010) and estimated fire perimeters, 2000 to 2012.



km = kilometers. mm = millimeters. MODIS = Moderate Resolution Imaging Spectroradiometer.
[a] Derived from Parameter-elevation Relationships on Independent Slopes Model data averaged from 1981 to 2012 (Daly et al. 2001).
[b] Private land ownership from the Protected Areas Database of the United States (Foster 2012).
Source: Reeves and Baggett (2014).

Figure 9-18. (a) Spatially explicit Normalized Difference Vegetation Index (NDVI) response, 2000 to 2012, and (b) temporal trajectory of the NDVI response in relation to the annual precipitation for the Northern Great Plains (top) and Southern Great Plains (bottom) rangeland ecoregions, 2000 to 2012.



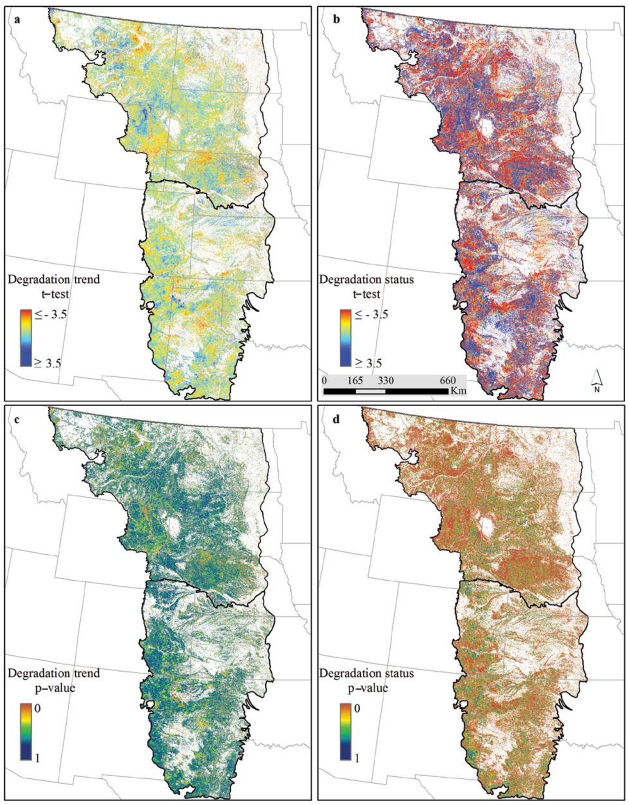
km = kilometers.
Source: Reeves and Baggett (2014).

Results

Vegetation trends observed using the NDVI record between 2000 and 2012 varied considerably between the Northern Great Plains ecoregion and the Southern Great Plains ecoregion (figure 9-18). From a broad perspective, vegetation production in the Northern Great Plains increased during the time period it was examined, but the Southern Great Plains exhibited slightly decreasing production. Despite these generalities, significant intraregional variation exists (figure 9-18).

The trend analysis exhibited very little degradation from 2000 to 2012 (figure 9-19(a) and (c)). In both regions, the losses were less than 1 percent of the total annual average

Figure 9-19. Trend in rangeland degradation in the Northern and Southern Great Plains rangeland ecoregions (a and c), 2000 to 2012, and rangeland degradation status in the Great Plains ecoregions (b and d), 2000 to 2012. Degradation trend is measured by a t-test and p-value that represent the t-test and associated p-values between the slopes of each pixel and reference conditions. Degradation status is the t-test and associated p-values between the mean responses of each pixel and reference conditions. Both the t-test map and the p-value map must be used to interpret degradation. For example, in the status estimate, low t-test values in combination with p-values below a threshold must both be present at a pixel location to be considered “degraded.”



km = kilometers.
Source: Reeves and Baggett (2014).

approximated NPP. While many areas experienced declining trends in NDVI response relative to reference conditions, these declines were not statistically significant. Even so, these areas may be compromised in terms of productive capacity. By contrast, the analysis of the status of rangeland conditions exhibited statistically significant degradation (figure 9-19(b) and (d)). The determination of the status (mean response) of degradation resulted in degraded area estimates ranging from 5.1 to 16.1 percent in the Northern Great Plains ecoregion and 2.6 to 9.1 percent in the Southern Great Plains ecoregion (table 9-5). The level of estimated degradation varies, depending on the level of statistical significance. For example, if the chosen threshold for significance is 0.0001, a much smaller estimate of degraded lands would be present, but a significance threshold of 0.1 would produce larger estimates of degradation.

Given the recent increase in oil and gas production in the Western United States, we expected a greater amount of area experiencing declining trends in vegetation productivity. The lack of detection of more significant degradation trends from 2000 to 2012 could have several, not mutually exclusive, explanations:

1. There were few significant trends to detect.
2. Degradation manifests in focused areas with smaller area than the size of the analysis pixel.
3. The land cover classification used to identify rangeland vegetation is likely incorrect.
4. The reference conditions are inappropriate, possibly as a result of different amounts of precipitation occurring on similar sites, because perceived rangeland condition can be more influenced by climate than management (Mashiri et al. 2008), although we attempted to control for this problem.
5. The magnitude of degradation is not significant enough or the time period for evaluating degradation is too short.

Many concerns regarding land degradation in the United States are site specific and often relate to intensive use by livestock in riparian areas or by recreationists driving off-highway vehicles. This sort of site-specific degradation resulting from intensive use should be differentiated from extensive degradation occurring over large areas. As a result, this study could not detect riparian degradation because of its small areal extent within the region. This finding, combined with those above, suggests other monitoring strategies are needed to augment the national degradation assessment and points to a mismatch in scale between the unit of observation (e.g., degraded riparian areas) and the sensor used to evaluate it (Moderate Resolution Imaging Spectroradiometer [MODIS] 250 m^2 NDVI). Another critical point is that this wide-area degradation assessment does not address rangeland health specifically. For example, a site could be dominated by exotic species, but if it exhibits productive capacity that is not statistically significant from the reference conditions, then it will not be considered “degraded.”

Reeves and Baggett (2014) concluded that most of the degradation found on rangelands in the Great Plains ecoregions occurred before 2000, a reasonable supposition given the lack of significant trends in degradation. Rangelands within the study area do not exhibit widespread declining trends in decreased productive capacity. The remote-sensing approach used here suggests that, overall, the land management policies and techniques in the study area are probably not furthering the extent of degraded lands. Determining the extent to which land use policies are aiding recovery of degraded lands may not be best accomplished with this type of analysis.

The same process was also applied to the entire United States (Reeves and Baggett 2014), with similar results. Table 9-5 presents the results for the two Great Plains rangeland ecoregions and the results for the conterminous United States by the four RPA regions. The trend analysis again indicated negative degradation trends on less than 1 percent in all four RPA regions, but the status of degraded land varied. Both the Northern and Southern Great Plains ecoregions had greater proportional losses than other regions, but losses in the RPA Pacific Coast Region were close behind. These patterns and quantities of degradation make it more difficult for rangelands to recover from drought conditions, and they are especially problematic when one considers the persistent and intense drought conditions currently being observed in the Western United States.

Overview of Droughts in Western Rangelands

- ❖ Vegetation in parts of the Southwestern United States appears to be suffering long-term (multidecadal) drought impacts.
- ❖ Growing conditions and vegetation response are more positive in the Northern Great Plains rangeland ecoregion.
- ❖ Overall, northern Texas, eastern New Mexico, and central California have seen the strongest declines in vegetation abundance.

Persistent droughts covering wide areas have periodically occurred across the extent of U.S. rangelands and are not unusual (Andreadis et al. 2005; Cook et al. 2007; Weakley 1965). Droughts are of grave concern to policymakers, livestock producers, and the agricultural sector, however, because droughts are among the most costly disasters (Andreadis et al. 2005), and they significantly impact numerous goods and services. Severe droughts have occurred in rangelands since recorded history (Woodhouse et al. 2010); droughts in the early 2000s could be some of the worst in 500 years. A review of drought trends by Cook et al. (2007) suggests that the Western United States has recently entered a period of protracted aridity, a perspective accentuated by the particularly troublesome, ongoing situations in Texas and California.

The 2011 drought conditions in Texas are an example of "flash drought," when soils dry very rapidly. These events coincide with high temperatures, low cloud cover, low rainfall, and high winds. Because they generally occur during the growing season, flash droughts can be particularly devastating for agriculture and livestock grazing (Otkin et al. 2013).

Although drought intensity can be gauged through benchmarks such as USDA drought categories, quantifying the duration of drought is more difficult owing to spatial and temporal complexity in droughtlike conditions (Cook et al. 2007). This complexity is exacerbated by differing perceptions of drought, which is a critical variable in determining effects and appropriate response. Using the U.S. drought mapping system (http://droughtmonitor.unl.edu/) as an example, a given region can vacillate among drought-intensity categories annually and even seasonally, reflecting the sometimes-episodic nature of drought when viewed in small timeframes. Episodes have immediate local effects that can stress ranching industries, induce livestock mortality, and trigger disaster-relief programs and government payments. The U.S. Drought Monitor, which is used to define emergency drought periods and relief payments, is focused on episodes of drought as measured in weeks.

A focus on the episodic nature of drought can miss longer term trends in climate, such as increasing temperatures combined with decreasing precipitation. On the other hand, reviewing only trends in climatology will likely miss temporary but severe droughts. This distinction is important to note because longer term climatic trends can have markedly different effects on ecosystems and natural capital than relatively short-lived drought events categorized by varying degrees of intensity. As droughts increase in duration, the ability for ecosystems and industry to recover is decreased and broad shifts in vegetation and collapse of local economies can occur (Fye et al. 2003;

Table 9-5. Status and trend of rangeland degradation by Northern and Southern Great Plains rangeland ecoregions and RPA regions, 2000 to 2012.[a]

Region	Rangeland area	Rangeland area	Status of degraded area	Trend of degraded area
	acres	*hectares*	*percent of rangeland base*	
Northern Great Plains rangeland ecoregion	185,329,036	75,000,000	5.1–16.1	≤ 1
Southern Great Plains rangeland ecoregion	148,263,229	60,000,000	2.6–9.1	≤ 1
RPA Pacific Coast Region[b]	89,163,929	36,083,362	2.8–7.5	≤ 1
RPA Rocky Mountain Region	436,579,568	176,677,483	3.3–8.0	≤ 1
RPA North Region	15,206,828	6,153,985	0.2–0.8	≤ 1
RPA South Region	121,671,174	49,238,577	1.0–3.3	≤ 1

RPA = Resources Planning Act.

[a] The ranges of estimated degraded area were calculated using the thresholds of p ≤ 0.0001 and 0.01 (e.g., 5.1 percent of area corresponds to the threshold of p ≤ 0.0001).

[b] Data for the RPA Pacific Coast Region do not include Alaska and Hawaii.

Source: Reeves and Baggett (2014).

Vetter 2009). Moreover, analysis of longer term trends yields insight to potential future conditions, which is especially important given the likelihood that global change is now altering Earth's biosphere (Morgan et al. 2008).

In this section, we provide a synthesis of both longer and shorter term viewpoints on drought conditions and briefly describe regional impacts on vegetation (Finch et al. 2016). We emphasize that both long- and short-term evaluations of climate and vegetation are useful for characterizing both long- and short-term drought and that long-term trends can have different implications for vegetation and ecosystem properties. We characterize both short-term drought conditions and long-term climatic factors and compare these with estimated vegetation trends.

Climatic Trends Over Western Rangelands and Regional Vegetation Effects

Drought can last for varying periods (e.g., a few years or entire decades), and the methods and data used to quantify scope and magnitude of effects on vegetation vary commensurately. Recognizing the importance of these issues, we sought to characterize both long- and short-term climatic and vegetation conditions in a spatially explicit manner to reveal areas where notable changes have occurred. This spatially explicit analysis is not relevant to individual pastures, but it does apply to regional assessments, especially at the scale of ecological subsections (Bailey and Hogg 1986) because data were aggregated to that level. With this scale of applicability in mind, we had three objectives:

1. Evaluate regional, longer term trends in temperature and precipitation.
2. Evaluate regional, shorter term trends in U.S. Drought Monitor.
3. Evaluate regional, shorter term trends in vegetation.

Data used to accomplish the three objectives included Parameter-elevation Relationships on Independent Slopes Model (PRISM) project data (1982 to 2012), weekly drought maps from the U.S. Drought Monitor (2000 to 2013), and NDVI from the MODIS at 250 m^2 spatial resolution (2000 to 2013).

The PRISM data were used to characterize longer term climate trends over rangelands of the conterminous United States, including monthly precipitation, maximum temperature, and minimum temperature. The metric we developed included quantification of the number of seasonal periods indicative of a drying landscape where seasonal or annual temperatures have been increasing while precipitation has been decreasing. Such an index is a practical way to assimilate large amounts of data for understanding impacts of changing climates on vegetation and other resources (Zargar et al. 2011).

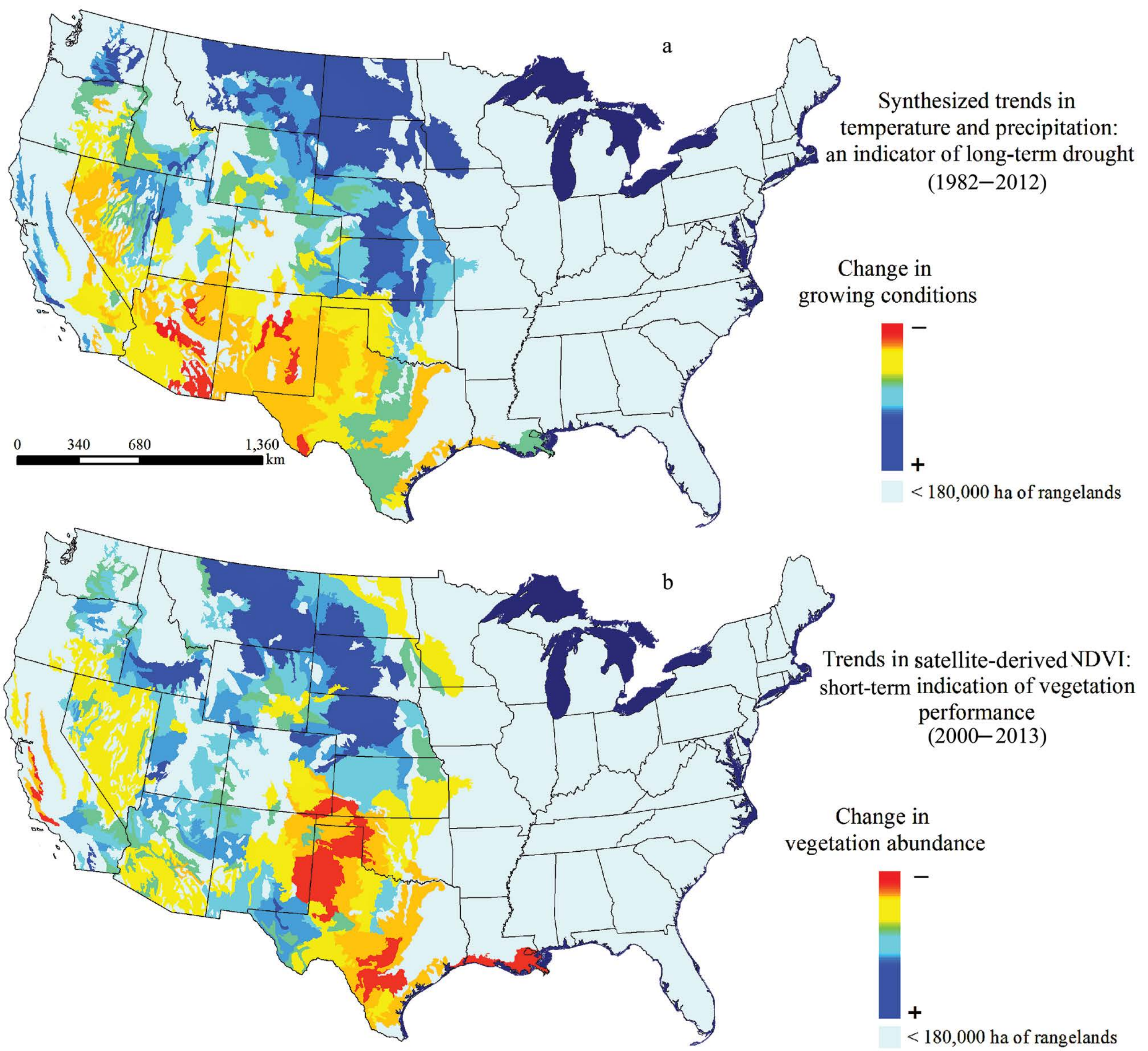
In figure 9-20(a), warmer tones indicate areas where temperature has been increasing while precipitation has been decreasing, and cooler tones represent improved growing conditions. The NDVI trend (figure 9-20(b)) has warmer tones that indicate where vegetation abundance has been decreasing since 2000 (i.e., a "browning" of the landscape) and cooler tones that represent greater vegetation (i.e., a "greening" of the landscape). Since 1982, the Southwestern United States has been exhibiting unfavorable trends in growing conditions resulting from warmer temperatures and decreasing precipitation. Relative to other areas in the Western United States, much of Arizona, New Mexico, Texas, and the Oklahoma Panhandle exhibits the most notable decreasing trends in growing conditions. The reddish regions in north-central New Mexico correspond with the massive die-off (90 percent) of piñon pine and illustrate the magnitude of vegetation change these conditions can induce (Breshears et al. 2005). On the other hand, much of the Northern Great Plains ecoregion has become wetter and slightly warmer, indicating improved growing conditions. It is worth noting that this type of climatic trend assessment will not usually capture the episodic or ephemeral droughts that advance and recede with short time periods. Those events are more appropriately captured in shorter timeframes, such as the weekly spatially explicit data from the U.S. Drought Monitor.

Since 2000, several droughts have occurred across western rangelands. Since 2011, the area occupied by the most significant drought category from the USDA has more than doubled compared with 2000-to-2010 drought records. Ongoing drought conditions over much of Texas and California, combined with longer term deterioration of growing conditions seen in other regions, have negatively affected the growth and abundance of rangeland vegetation. Because rangeland vegetation responds relatively quickly to changing meteorological conditions, it can be efficiently monitored using satellite remote sensing.

Reeves and Baggett (2014) developed an algorithm for quantifying trends in MODIS 250 m^2 NDVI for the United States. For this analysis, vegetation types (Comer and Schulz 2007) associated with negative vegetation trends since 2000 are evaluated. Table 9-6 indicates that many vegetation types have experienced declining trends in production on more than 30 percent of the total area they occupy in the conterminous United States. More than 129 million acres (51 million ha) of vegetation—approximately 19 percent of all rangeland vegetation in the conterminous United States (Reeves and Mitchell 2012)—have exhibited declining trends in abundance since 2000. Many of these vegetation types are common in Texas and California.

From a regional perspective, vegetation has responded in a similar pattern as indicated by the PRISM climatology. Note the decline of rangeland vegetation NDVI in the Southern Great Plains rangeland ecoregion in addition to the marked declines in central California (figure 9-20(b)). Although drought

Figure 9-20. (a) Trends in gridded surface climatology from the Parameter-elevation Relationships on Independent Slopes Model (PRISM), 1982 to 2012, and (b) trends in Normalized Difference Vegetation Index (NDVI) averaged over ecological subsections, 2000 to 2013.[a]



ha = hectare.

[a] NDVI derived from Moderate Resolution Imaging Spectroradiometer 250 m2; ecological subsections from Bailey and Hogg (1986).

events in California in the 20th century were less frequent than in previous patterns, a number of recent drought episodes of significance to natural systems and socioeconomic well-being have occurred (Hughes and Brown 1992). The climatological index derived here using PRISM data does not reflect the recent drought episodes in California due to the relatively longer time period of the climate data compared with the recentness of the drought period. This lack of data illustrates the need to include a variety of data sources during multiple time periods to more completely understand drought effects on vegetation and other resources.

Table 9-6. Trends in top 20 vegetation types exhibiting the greatest proportional decline in area since 2000, by U.S. ecological systems.[a]

Ecological system	Area in decline		
	(acres)	*(hectares)*	*(percent)*
Tamaulipan mixed deciduous thornscrub	557,440	225,588	56
California annual grassland	4,800,071	1,942,520	43
Tamaulipan calcareous thornscrub	1,492,689	604,070	41
South Texas sand sheet grassland	1,073,431	434,402	40
Tamaulipan mesquite upland scrub	8,551,037	3,460,482	37
Western Great Plains mesquite woodland and shrubland	17,441,209	7,058,207	35
Edwards Plateau limestone shrubland	10,234,994	4,141,955	35
Southern California coastal scrub	2,320,018	938,878	33
Tamaulipan savanna grassland	1,568,175	634,618	33
Central mixed-grass prairie	20,939,572	8,473,944	32
Central and southern California mixed-evergreen woodland	1,598,075	646,718	32
Sonora-Mojave semidesert chaparral	1,050,816	425,250	32
Western Great Plains sandhill steppe	9,345,736	3,782,085	30
Southern California oak woodland and savanna	625,666	253,198	29
Chihuahuan-Sonoran Desert bottomland and swale grassland	432,138	174,880	29
Western Great Plains shortgrass prairie	40,770,564	16,499,262	28
California mesic chaparral	3,016,415	1,220,700	27
Western Great Plains foothill and Piedmont grassland	633,287	256,282	26
Southern California dry-mesic chaparral	2,068,517	837,099	25
Sonora-Mojave mixed salt desert scrub	871,845	352,823	24

[a] U.S. ecological systems defined by Comer and Shulz (2007).

The Future of Drought on Rangelands

Drought in North America appears to be strongly related to Pacific Ocean sea surface temperatures and is sensitive to even small temperature changes (Cayan et al. 2010). Change in sea surface temperatures induced the severe drought in California during 2013 and 2014, and the associated circulation patterns were intensified, and perhaps even created, by global warming (Wang et al. 2014). Although changes in sea surface temperatures can be related to present-day precipitation patterns, a different approach for estimating possible climatic changes in the future is needed. Output from GCMs has been the subject of many recent research projects.

Models of NPP predict overall better growing conditions for the Northern Great Plains rangeland ecoregion, but the opposite is true of the Southern Great Plains ecoregion (Polley et al. 2013; Reeves et al. 2014). Overall, rangeland vegetation may be able to offset future drought conditions, because CO_2 enrichment has the general effect of improving water-use efficiency (Morgan et al. 2011), but this effect may not be observed beyond CO_2 concentrations modeled in the study. Reeves et al. (2014) reported that estimated increases in NPP in the Northern Great Plains were best explained by increased growing season length and reductions in NPP in the Southwestern United States were best explained by lack of precipitation and increased evapotranspiration.

Trends indicated by PRISM and NDVI data may continue with persistent and increasing aridity for the Southern Great Plains rangeland ecoregion and central California (figure 9-20). Cayan et al. (2010) predict droughts in this century will extend 12 years or more in the Southwest ecoregion, which will severely tax already limited water supplies (Foti et al. 2012). More frequent drought episodes interspersed with fewer episodes of higher-than-average rainfall indicate vegetation in the Southwestern United States may not recover to what is currently considered a typical or average state (Seager et al. 2007).

Warmer temperatures will exacerbate any deficit in soil moisture, and several studies point toward more frequent and severe drought, along with significant ecological change for the future (Breshears et al. 2005; Cayan et al. 2010; Cook et al. 2007). Drying may be particularly pervasive in the Southwestern United States and northern Mexico and also in the Interior West rangeland ecoregion (Andreadis and Letternmaier 2006; Seager et al. 2007). Intensification of drought episodes in California is expected to continue (Wang et al. 2014). By contrast, drought severity has not increased recently in other regions of the United States, including in the Northern Great Plains ecoregion, indicating that, although these regions will still be subject to periodic drought, they may be better able to recover following drought episodes (Andreadis and Letternmaier 2006; Clark et al. 2002).

Future Work

The conclusions and overall findings from this chapter provide the impetus for future work. We will continue to focus on monitoring vegetation trends and climate trend relationships. We seek to estimate the climate-change scenario that U.S. rangelands are most closely tracking. Further, observed trends will be quantified in terms of regional patterns of forage availability. In a similar fashion, we will evaluate a combination of threats to rangeland sustainability and provide case studies from the Rocky Mountain and Wasatch Fronts and other areas experiencing significant changes throughout the West. Energy development will also occupy a significant portion of future work. We will evaluate areal footprints of energy development in addition to direct and indirect impacts on forage and habitat for a variety of native ungulates. All these factors will continue to change the character of the livestock industry, especially when expressed against the backdrop of a changing climate. Therefore, trends in livestock operations and animal numbers will also be part of future research.

Conclusions

The research presented here offers several additions to the 2010 RPA range assessment (Reeves and Mitchell 2012). First, overall conditions and production of goods and services generally appear to decrease (in some cases sharply) in south and southwestern regions of the rangeland extent. For example, NPP during the next 50 years is estimated to increase or stay level in the Eastern Prairies, Interior West, Northern Great Plains, and Southern Great Plains rangeland ecoregions, but decline in the Southwest and Desert Southwest rangeland ecoregions (especially regions of Arizona, New Mexico, and Texas). The situation for the Interior West rangeland ecoregion is less clear and highly variable, but most projections suggest more significant changes will occur at higher elevations. Perhaps even more noteworthy is the exceptional correspondence between present-day longer term drought trends and projected trends in climate and rangeland resources. Vegetation production has been increasing in the Northern Great Plains ecoregion, but, again, the southern and southwestern areas of the rangeland extent have experienced powerful declines (and even mortality) in productivity. Thus, present-day trends of vegetation production (increases in the Intermountain West and Northern Great Plains ecoregions and decreases in the Desert Southwest and Southwest ecoregions) might well continue into the future for decades.

Second, livestock operations follow similar trends as NPP into the future, but factors such as heat stress and variability in the potential forage supply often act to counteract possible positive outcomes, suggested by increasing vegetation abundance. Once again, in the Northern United States, the vulnerability of cattle operations tends to decrease or remain relatively unchanged, but operations in the Southern United States appear to decrease unanimously across the three scenarios examined.

Finally, the first, rather cursory comparison of soil organic carbon storage and flux from rangelands offered here yield heretofore unavailable insight to comparisons with the forested land situation. SOC estimates were spatially harmonized with the official forest land SOC estimates. Although no statistically significant trends in SOC flux have been detected since 1984 at the State or regional level, degradation patterns revealed in this RPA Update suggest that subregional decreases in SOC are highly likely compared with reference conditions. On the other hand, the lack of statistically significant trends in rangeland degradation (as defined here) suggests that most livestock operations are reasonably managed with respect to preservation of productive capacity.

Chapter 10. Water Resources

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) assessed the vulnerability of U.S. freshwater supplies to shortage in light of future population growth and climate change. Projections of water supply and demand during the 21st century showed that, in the absence of adaptation, serious water shortages are likely in some regions of the United States. In this RPA Update, we focus on four topics. First, we build on analyses from the 2010 RPA and evaluate several possible adaptations designed to lessen identified shortages. Second, we focus on the Upper Colorado River Basin (UCRB) to examine the effects of using a more detailed description of water users on water-demand projections. Third, we report on an analysis that assessed nonpoint source threats to water quality nationwide. Finally, we provide updated estimates of mean annual water supply for the conterminous United States.

Highlights

- In the absence of adaptation, future renewable water sources will be insufficient to avoid a substantial increase in the likelihood of annual water shortages in many areas of the United States. On average, the number of basins likely to experience shortages is projected to increase about fourfold by 2060.
- Future groundwater mining at levels similar to those of the past few decades is by far the most effective adaptation, providing roughly a 20- to 50-percent reduction in the number of basins expecting shortages. Groundwater mining becomes increasingly costly, however, and is not sustainable in the long run.
- A wide range of other adaptations, from reductions in irrigated area to additions in reservoir capacity to added flexibility in managing transbasin diversions (TBDs), have a relatively modest effect on the number of basins projected to incur annual shortages.
- The highest levels of risk of impaired water quality resulting from land and resource use in the conterminous United States generally are found in the eastern half of the Nation.
- Forests are disproportionally important as sources of water, especially in the Northeastern and Western United States, where they provide roughly two-thirds of the annual renewable water supply. Federal lands are the source of more than 60 percent of the water supply in the U.S. West as a whole and the source of more than 75 percent of the water supply of some Western States.

Effects of Adaptation Options on Vulnerability to Scarcity

- In the absence of adaptation, future renewable water supplies will be inadequate to satisfy projected water demands in many areas of the United States. On average, the number of basins likely to experience shortages if only renewable water supplies are available is projected to increase about fourfold by 2060.
- Rising water demand, which is enhanced by rising temperatures, is the primary cause of increased water shortages in most basins.
- Future groundwater mining at levels similar to those of the past few decades is by far the most effective adaptation, providing roughly a 20- to 50-percent reduction in the number of basins expecting shortages. Groundwater mining, however, becomes increasingly costly and is not sustainable in the long run.
- A wide range of other adaptations, from reductions in irrigated area to additions in reservoir capacity and added flexibility in managing TBDs, have a relatively modest effect on the number of basins projected to incur annual shortages.
- Basins under water stress will need to implement a mixture of adaptations, aiming to both decrease water demand and increase the flexibility with which water is stored and delivered to meet those demands.
- Substantial increases in shortage are projected for even the most sanguine projections of future levels of population and climate change, suggesting that adaptation will remain a key feature of future water management.

The 2010 RPA water assessment (Foti et al. 2012) estimated the degree to which water shortage challenges could materialize (see also Foti et al. 2014a, 2014b). The water assessment found that some regions of the United States are likely to face serious water shortages if they fail to adapt to changing circumstances. In this RPA Update, our principal objective is to examine how those projected water shortages would decrease if major adaptations occurred.

Adaptation options being proposed for responding to the effects of climate change on water resources generally are similar to measures that have long been practiced in dealing with population and economic growth (Binder et al. 2010; Lawler 2009; Purkey et al. 2008; Schwarz et al. 2011). Aside from enhancing adaptive capacity (National Research Council 2010), options for responding to impending climate change-induced water shortages can be grouped into two broad categories: (1) those that enhance water supply and (2) those that limit water demand (Bates et al. 2008; Brekke et al. 2009; Hanak and Lund 2012). Water supply options focus on developing new water supplies or improving existing supplies (e.g., enlarging reservoir storage capacity) and on diversifying existing water supplies (e.g., linking supplies via new canals). Demand management options focus on directly reducing or avoiding growth in demand (e.g., limiting groundwater pumping from at-risk aquifers), improving water-use efficiency (e.g., enhancing water recycling at industrial plants), and shifting demand (e.g., facilitating water trades). We examine the effects of several such adaptations.

We also extend the analysis presented in the 2010 RPA water assessment in three ways. First, we report on the relative importance of changes in demand versus changes in supply in causing projected shortages. Second, we examine how projected water shortages would increase if adaptations included in the 2010 RPA—to be specific, increases in water-use efficiency and decreases in irrigated area in the U.S. West—do not occur. Finally, we examine the effect of new estimates of future irrigated area and irrigation water depth recently made available by the Economic Research Service (ERS) (Marshall et al. 2015). The 2010 RPA water assessment adopted a relatively simple approach for estimating future irrigated area and application depth; the ERS used a more sophisticated approach, employing models of crop growth and large-scale farm management.

As in the 2010 RPA, we modeled water demand and supply for assessment subregions (ASRs) of the conterminous United States. Here, we focus on 69 of the 98 ASRs (also called basins) where most shortages were projected and which form a large network of water basins (figure 10-1). The water supply-and-demand conditions of the 2010 RPA formed the *base condition* for comparison with conditions, given selected adaptation options.

Figure 10-1. Assessment subregions (ASRs) of the conterminous United States. The 69 ASRs of the large network are highlighted in gray. Blue lines indicate natural flow links, green lines show artificial links (transbasin diversions), and the magenta line is the delivery to Mexico.

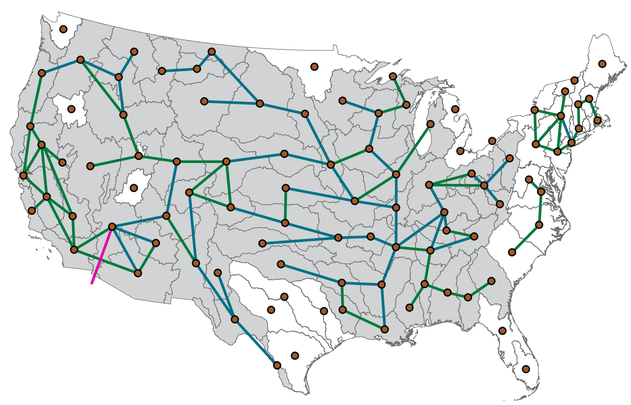


Table 10-1. Adaptation options and other changes.

Demand-related changes	
D1.	Absence of withdrawal efficiency improvements projected in 2010 RPA
D2.	Absence of reductions in irrigated area projected in 2010 RPA
D3.	Reductions in irrigated area 10 percent greater than those of the 2010 RPA
D4.	Irrigation levels projected by Economic Research Service
D5.	Reductions in thermoelectric water use reaching 80 percent in 2100
D6.	Instream flow requirement of 5 percent of mean annual flow rather than 10 percent used in 2010 RPA
D7.	Demands separated into two groups of different priorities
D8.	Flexible transbasin diversions (TBDs)
Supply-related changes	
S1.	Reservoir capacities increased by 25 percent
S2.	Reservoir capacities increased by 50 percent
S3.	TBD capacities increased by 25 percent
S4.	TBD capacities increased by 50 percent
S5.	Groundwater mining allowed
Combination of demand- and supply-related changes	
C1.	Flexible TBDs with TBD capacities increased by 25 percent
C2.	Flexible TBDs with TBD capacities increased by 50 percent

Adaptation Options

The effects of 15 adaptations and other changes were estimated by comparing water shortages of the base condition with shortages when the adaptation or other change is implemented. The base condition reflects expected population and economic growth and projected climate changes, assumes a continuation of past withdrawal efficiency improvements, and assumes that only renewable water sources are available, as modeled in the 2010 RPA. The adaptations include a mixture of demand- and supply-related changes. They range from those that are centrally planned (e.g., major increases in reservoir storage capacity) to those that occur as decentralized responses to changing conditions (e.g., reductions in irrigated area).

The 15 adaptations and other changes are listed in table 10-1; 8 are demand related, 5 are supply related, and 2 combine demand and supply changes. Change D1 removes projected improvement in withdrawal efficiency included in the base condition to see how important those improvements are in avoiding growth in water shortages. Three options were developed to address irrigation, because considerable uncertainty exists about future irrigated area and irrigation water depths; D2 and D3 are variations from 2010 RPA assumptions (D2 increases and D3 decreases irrigated area relative to the base condition), and D4 uses recent projections of irrigated acres and irrigation water depths from the ERS (Marshall et al. 2015) that are significantly different from those of the base condition. Considerable uncertainty also exists about future thermoelectric water use. Option D5 assumes a gradual, linear reduction in thermoelectric consumptive use in all basins; the base condition assumed little future change in thermoelectric consumptive use. Option D6 lowers the instream flow constraint from 10 to 5 percent of mean annual flow. Option D7 arranges demand sectors in two groups: one of high priority (domestic and public; industrial, commercial, and mining; and thermoelectric) and the other of low priority (agricultural irrigation, livestock, and aquaculture); the base condition assigned all demands the same priority. The final demand-related option (D8) allows for interbasin diversions (also called TBDs) without legal constraints; the base condition required that TBDs always be satisfied, subject to water availability.

The supply options primarily involve infrastructure actions, specifically expanding reservoirs (S1 and S2) and diversion capacities (S3 and S4). The fifth supply option (S5) examines the role of groundwater mining, in which *mining* means the relatively permanent drawdown of the water table or reduction in hydraulic head of a confined aquifer. The 2010 RPA focused on only renewable water sources, thus ignoring the role of groundwater mining. Groundwater mining is perhaps the major existing adaptation to water shortage. Here, we estimate the degree to which continued groundwater mining could avoid future shortages. The quantities of water available via groundwater mining were approximated based on recent assessments of past groundwater level changes (Konikow 2013; Russo et al. 2014) in light of past levels of groundwater withdrawal (Kenny et al. 2009) and water yield. Figure 10-2 shows the estimated levels of recent groundwater mining. The final two options (C1 and C2) combine TBD flexibility with capacity expansion.

The adaptations and other changes we examined were selected without consideration of the feasibility that they could be implemented. Our purpose was to obtain an initial indication of how these adaptations, if implemented, could alter the probability of water shortages. That said, it is important to note that the adaptations may differ substantially, one to the next, in cost and social acceptability.

Figure 10-2. Estimated mean annual recent groundwater mining as a percent of total 2005 withdrawal.

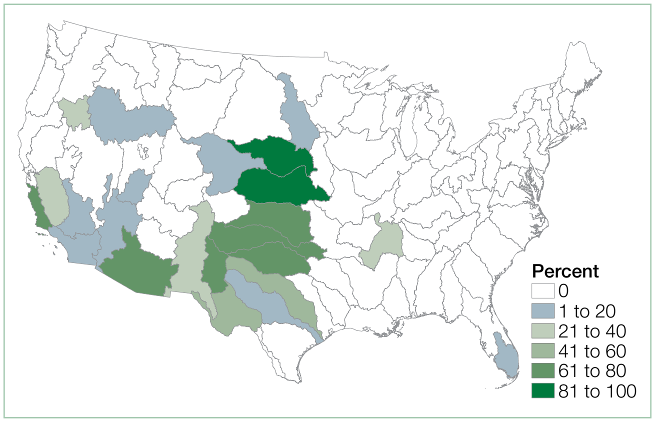
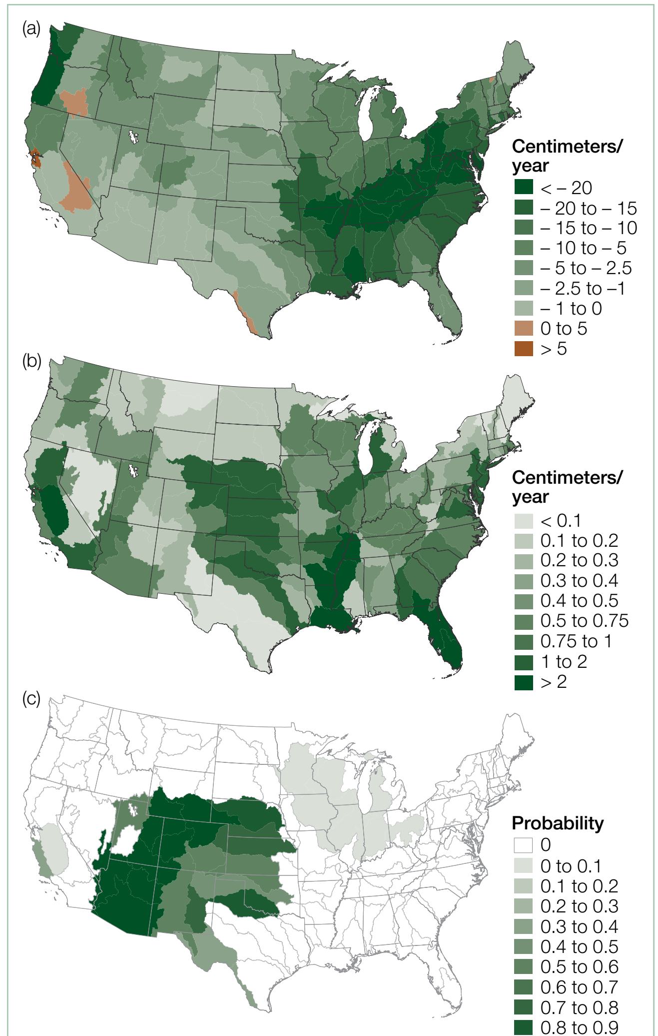


Figure 10-3. Projected change per unit area in (a) water yield and (b) demand, and (c) change in the probability of shortage, from the current period to the 2060 period with the RPA A2-CSIRO future, base condition.



RPA = Resources Planning Act.

Results

Results are summarized for five 20-year time periods: 1986 to 2005, 2011 to 2030, 2031 to 2050, 2051 to 2070, and 2071 to 2090, which are referred to as the current, 2020, 2040, 2060, and 2080 periods, respectively.

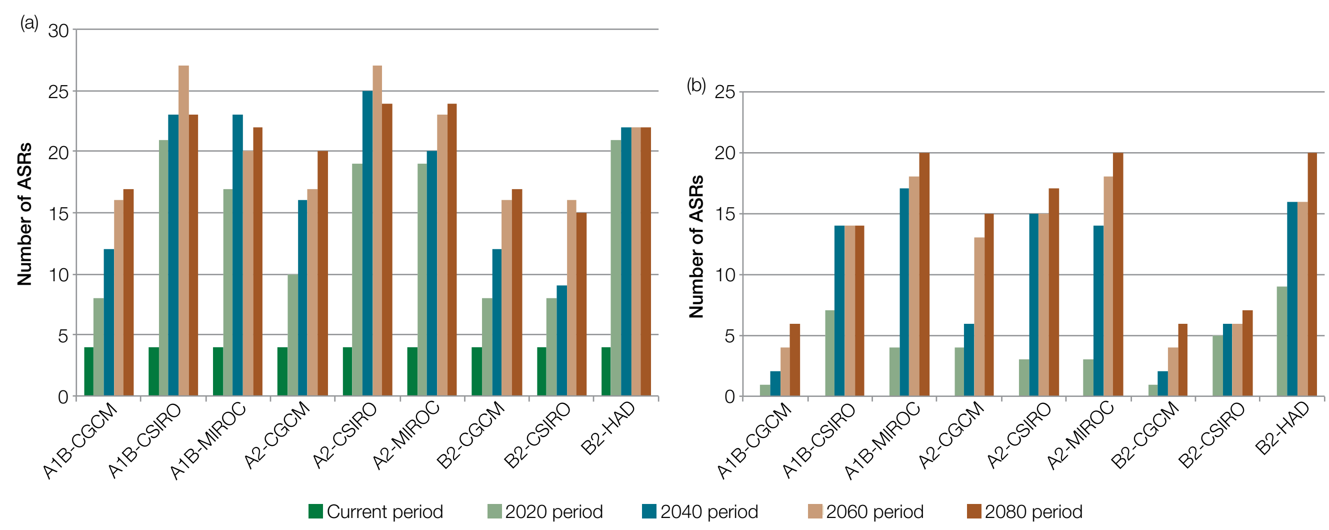
Base Condition

Increases in shortages over time are the result of decreasing water yield and/or increasing water demand. Water-yield decreases result from climatic change (increasing temperatures and, in some cases, decreasing precipitation), and water-demand increases result from a combination of population increases and climate change (Brown et al. 2013). As seen in figure 10-3, which depicts changes from the current period to the 2060 period with the base condition simulated for the RPA A2-CSIRO socioeconomic-climatic future, a combination of yield decreases and demand increases is not uncommon (see Foti et al. [2012] for additional cases). Indeed, the overall picture for all nine RPA scenario-climate combinations is similar to the RPA A2-CSIRO future in figure 10-3: decreasing water yield and increasing water demand in most, but not all, ASRs throughout the 21st century. In general, the magnitude of the decrease in yield is larger in more humid regions (in general, the Eastern United States and the coastal region of the Pacific Northwest, as seen in figure 10-3a), although the greatest percentage decreases tend to occur in the more arid regions (most of the West and the Great Plains) (see Foti et al. [2012] for the percentage changes). The magnitude and percent increase in demand tend to be greatest in the eastern half of the country plus parts of California. Both decreases in water yield and increases in demand tend to be greatest for the RPA A2 scenario, largely as a result of the larger population and temperature increases with that scenario.

The base condition shortage likelihoods presented here are similar to those presented in the 2010 RPA, but they differ slightly due to the use of a different water routing model (Yates et al. 2005), which alters how shortages are shared among basins. Our principal focus here is on how adaptations alter the incidence of shortage, which is unlikely to be significantly affected by the choice of water routing model.

In the base condition, 4 of the 69 ASRs of the network encounter some amount of water shortage (to be specific, in *at least 1 year* of a 20-year period) during the current period (figure 10-4a). Shortages become much more common in future periods, with at least 15 basins facing some level of shortage by the 2060 period with all nine 2010 RPA socioeconomic-climatic futures (figure 10-4a). Differences in projected shortages among the nine futures, of course, reflect differences in water demand and yield, which, in turn, reflect differences in population and economic growth among the scenarios and differences in climate among the general circulation models (GCMs).

Figure 10-4. Number of assessment subregions (ASRs) facing shortage (a) in *at least 1 year* in 20 or (b) in *at least 11 years* in 20, under the base condition, during the current period and four future periods as characterized by nine different socioeconomic-climatic futures.



In contrast with figure 10-4a, figure 10-4b shows the number of basins projected to encounter shortages for more than 50 percent of the time (to be specific, in *11 or more years* of a 20-year period). As figure 10-4b shows, no basins encounter water shortages very often in the current period, but, in the 2060 period, four futures show at least 15 basins encountering such a high incidence of shortage, and, by the 2080 period, three futures show at least 20 basins encountering that high incidence of shortage. These basins, those of more frequent projected shortages, are the ones where adaptation is likely to be most important.

Base condition shortages occur mainly in the more arid parts of the United States, especially in the central and southern Great Plains, southern portions of the Intermountain West, the Southwest, and parts of California. This pattern of shortages is seen, for example, with the RPA A2-CSIRO future in figure 10-3c (note that much of Texas is also projected to incur shortages under the RPA A2-CSIRO and other futures [Foti et al. 2012] but is not part of the network examined here). The general location of projected shortages does not vary across the nine futures and future time periods, but the severity varies, with the greatest shortages projected for the RPA A2 scenario and with GCMs that projected the lowest precipitation levels (e.g., the MIROC model). The generally higher amounts of yield relative to demand in the Eastern United States allow most Eastern ASRs to avoid shortages. Shortages could occur, however, in localized areas or during short time periods that are not revealed at the ASR spatial scale and annual time step used in this analysis (see Foti et al. 2012 for full details on the base condition).

For the network as a whole, increases in shortage are projected to result more from increases in demand than from decreases in supply. For example, on average, across the nine futures, about 60 percent of the shortage increases from the current to the 2060 time periods are due more to demand increases than to supply (to be specific, yield) decreases (table 10-2). The relative importance of demand versus supply changes in causing increases in shortage, however, vary by future and by location. For example, in the 2060 period, demand and supply changes are about equally important with the RPA B2 futures in contrast with the RPA A2 futures in which demand changes, in general, are more important than supply changes (table 10-2).

Table 10-2. Number of assessment subregions (ASRs) with shortage increases, from the current period to the 2060 period, mostly due to changes in demand or in supply for the nine alternative 2010 RPA futures.

Future	Demand	Supply
	number of ASRs	
A1B-CGCM	12	4
A1B-CSIRO	14	13
A1B-MIROC	13	7
A2-CGCM	12	5
A2-CSIRO	17	10
A2-MIROC	16	7
B2-CGCM	9	11
B2-CSIRO	7	9
B2-HAD	10	11

RPA = Resources Planning Act.

Adaptation Results

Our principal objective was to examine the relative effect of 15 adaptation options and other changes on the likelihood of future annual water shortages at the ASR scale. We focus mainly on the general pattern of results, rather than on such details as which specific ASRs are affected by a given adaptation under a specific future climate during a specific time period, because the specifics differ so much by scenario-climate combination and because any decision about the utility of a specific adaptation in a specific location will require a much more detailed and focused analysis. Thus, we aim to provide a general understanding of how various alterations in future water demand and supply compare in their impact on the probability of future water shortages.

Figure 10-5 summarizes the key findings for the four future 20-year time periods. The figure shows the change from the base condition in the number of ASRs (of the total of 69 within the network at issue) with at least 1 year (left-hand column of the figure) or at least 11 years (right-hand column) of shortage for each of the 20-year periods. The top row of graphs in the figure presents the average result across the nine futures, and the other two rows show results for two quite different futures, one (RPA A1B-CGCM) with moderate levels of future shortage and the other (RPA A2-MIROC) with high shortage levels. For example, in the 2040 period with the RPA A1B-CGCM future, 12 ASRs were projected to have at least 1 year of shortage in the base condition; reducing the instream flow requirement from the 10 percent of mean annual yield of the base condition to 5 percent (adaptation D6) lowers the number of ASRs with at least 1 year of shortage by 4.

Looking across the average results for the full set of adaptations (top row, figure 10-5) reveals the following general findings:

- In all future time periods, groundwater mining (S5) has the greatest salutary effect on the likelihood of shortages, but even groundwater mining, at the levels assumed, fails to totally remove the shortages.
- With the exception of groundwater mining, the effects of the adaptations and other changes on the number of basins incurring a given minimum incidence of shortage, in general, are quite modest, in most cases changing the number of basins with some level of shortage by only one or two basins. It is important to realize, however, that, although an adaptation may not eliminate the shortage in a given basin, it may still significantly reduce the shortage.
- For many of the adaptations and other changes, the alteration in the number of basins with a given incidence of shortage is roughly similar between the left- and right-hand columns of figure 10-5. Groundwater mining (S5), for example, drops the number of basins by about five in the 2040, 2060, and 2080 periods in both columns. In a similar way, reducing irrigated area by 10 percent (D3) reduces the number of basins by roughly one to two in both columns. In other words, many of the adaptations, in general, are as effective in removing basins from incurring any amount of annual shortage as they are in removing basins from incurring shortages in more than 50 percent of the years. This level of effectiveness, however, is not true for all adaptations. In particular, increasing reservoir size (S1 and S2) is even less effective in removing basins from the >50 percent list than it is in removing basins from the >0 percent list.

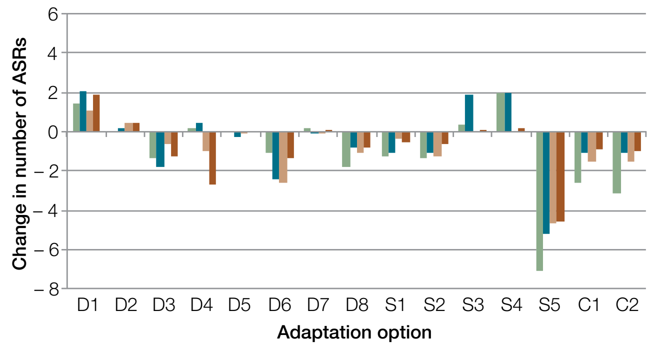
The lower two rows of figure 10-5 demonstrate that results vary substantially among the individual futures. For example, in the right-hand column we see that the absence of the assumed withdrawal efficiency improvements (D1) causes an increase by 2060 in the number of basins with shortage of five basins with the RPA A1B-CGCM future but of only two basins with the RPA A2-MIROC future. The high variation across futures in the number of basins with a given level of shortage in the base condition and with given adaptations highlights the substantial uncertainty about the future shortages that society faces and also the considerable sensitivity of future shortages to the potential effects of climate change. Because of this variability, we focus mainly on the average results (thus, the top row of figure 10-5).

After examining individual adaptations, we found the following findings to be of interest:

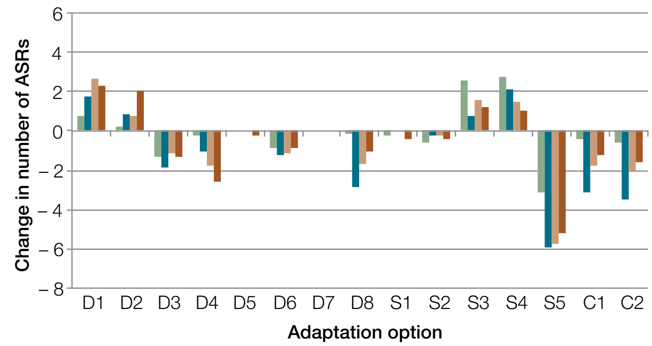
1. Assuming that expected improvements in withdrawal efficiency are not forthcoming (D1), water shortages become more likely. The reductions in water withdrawal per unit of driver in five of the six water-use sectors that were assumed in the base condition have an important impact on projected shortages. Those reductions are as important (or more so) in limiting shortages as nearly all other adaptations. Thus, it is important that these improvements, which are a continuation of well-established trends (Brown et al. 2013), occur.
2. The changes in irrigated area and water application that we examined (D2, D3, and D4) have a modest impact on the likelihood of ASR shortages. If the future western irrigated area remains constant (D2) instead of decreasing as expected in the base condition, shortage likelihoods increase very little. In a similar way, a 10-percent decrease in the irrigated area beyond the levels assumed in the base condition (D3) lowers the number of ASRs with at least 1 year of shortage by less than two in all future periods (figure 10-5a, left-hand column). This relatively small impact is perhaps surprising, given the large amount of water consumed by agriculture. The modest change in the number of basins with shortages, however, obscures the fact that the amount of shortage may fall significantly even though a basin still incurs some shortage. Basins with high projected shortage probabilities tend to also be ones of high-irrigation water demand. Our results indicate that a reduction in irrigated area in excess of 10 percent would be necessary to greatly reduce the number of basins experiencing shortages. Adoption of irrigated area and

Figure 10-5. Change from the base condition in the numbers of assessment subregions (ASRs) with *at least 1 year* (left chart) or *at least 11 years* (right chart) of shortage during each of four future 20-year time periods for each of 15 adaptations or other demand and supply alterations. Charts in row (a) show results for the average of all nine futures; charts in rows (b) and (c) show results for the RPA A1B-CGCM and A2-MIROC futures.

(a) Average of nine futures

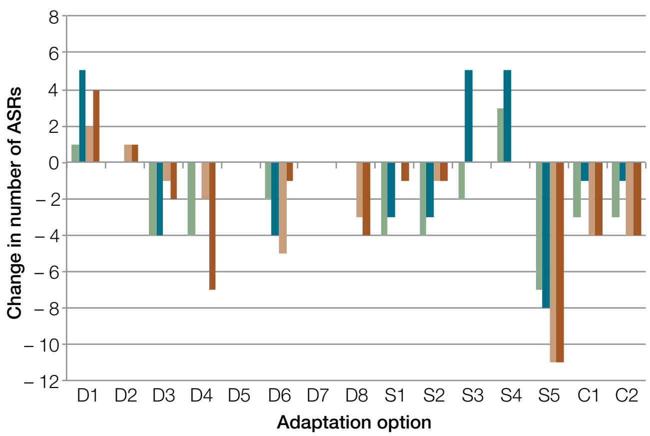


Base condition: 15, 18, 20, and 20 ASRs incur ≥1 year of shortage in periods 2020, 2040, 2060, and 2080, respectively.

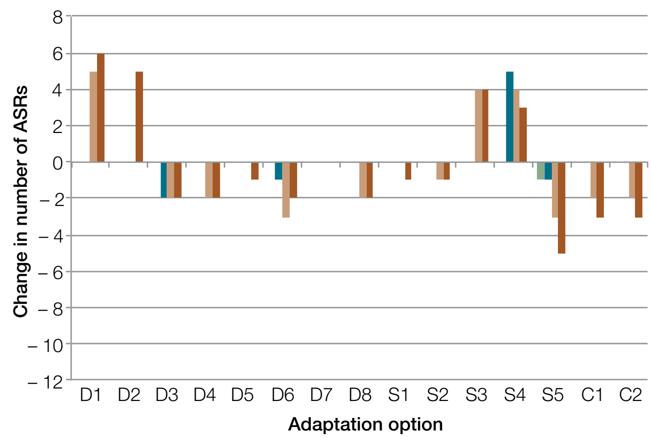


Base condition: 4, 10, 12, and 14 ASRs incur ≥11 years of shortage in periods 2020, 2040, 2060, and 2080, respectively.

(b) RPA A1B-CGCM future

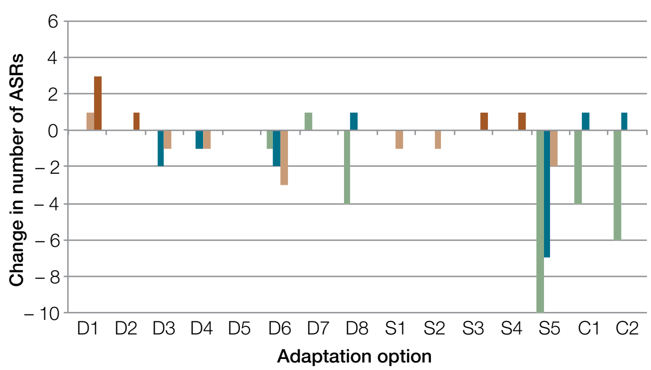


Base condition: 8, 12, 16, and 17 ASRs incur ≥1 year of shortage in periods 2020, 2040, 2060, and 2080, respectively.

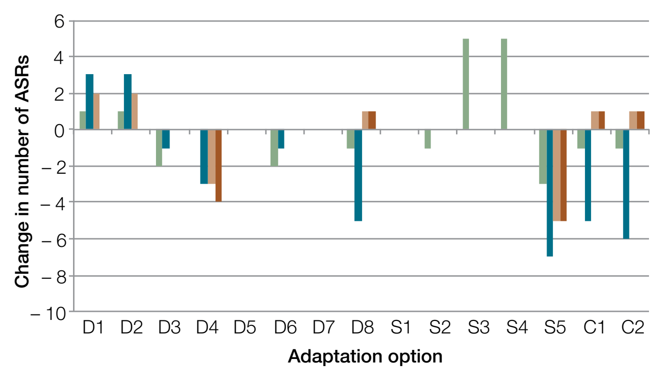


Base condition: 1, 2, 4, and 6 ASRs incur ≥11 years of shortage in periods 2020, 2040, 2060, and 2080, respectively.

(c) RPA A2-MIROC future



Base condition: 19, 20, 23, and 24 ASRs incur ≥1 year of shortage in periods 2020, 204, 2060, and 2080, respectively.



Base condition: 3, 14, 18, and 20 ASRs incur ≥11 years of shortage in periods 2020, 2040, 2060, and 2080, respectively.

2020 period 2040 period 2060 period 2080 period

D1 = Absence of withdrawal efficiency improvements projected in 2010 RPA. D2 = Absence of reductions in irrigated area projected in 2010 RPA. D3 = Reductions of 10 percent in irrigated area beyond those projected in 2010 RPA. D4 = Irrigation levels projected by Economic Research Service. D5 = Reductions in thermoelectric water use reaching 80 percent in 2100. D6 = Instream flow requirement of 5 percent rather than 10 percent used in 2010 RPA. D7 = Demands separated into two groups of different priorities. D8 = Flexible transbasin diversions (TBDs).

S1 = Reservoir capacities increased by 25 percent. S2 = Reservoir capacities increased by 50 percent. S3 = TBD capacities increased by 25 percent. S4 = TBD capacities increased by 50 percent. S5 = Groundwater mining allowed.

C1 = Flexible TBDs with TBD capacities increased by 25 percent. C2 = Flexible TBDs with TBD capacities increased by 50 percent.

water application depths from the ERS analysis (D4) typically has less effect than D3 on the number of basins incurring shortages, except for the 2080 period, when the area and depth changes with the ERS estimates are greatest (in large part due to the effect of increasing temperatures on the utility of irrigation). In this late time period, the ERS projections result in the second lowest number of basins with shortages on average (figure 10-5a, left-hand column). Also, note that adoption of the ERS estimates of future irrigated area and application depth is projected to actually increase shortages slightly in the first two periods due to increases in irrigated area with some futures.

3. Progressive reductions in thermoelectric consumptive water use reaching 80 percent in 2100 (D5) have practically no impact on the likelihood of ASR shortages at the annual time scale. This finding is not particularly surprising because, although thermoelectric plants withdraw a great deal of water in some regions, their consumptive use (and therefore demand as modeled here), in general, is small in relation to that of most other sectors. Of course, as is the case with this entire analysis, this finding reflects the scale of the analysis; water use at thermoelectric plants may have large impacts on local water supplies, especially during months of high electricity demand.

4. Reducing the instream flow constraint by one-half (D6), from 10 percent to 5 percent of mean annual historical flow, is projected to remove one or two basins from the shortage lists (figure 10-5a), although such reductions, depending on the future climate, could be considerably more effective (e.g., figure 10-5b).

5. If sectors are assigned different priorities, a high-priority demand sector in one basin can receive water from a low-priority sector of another basin, as long as the basins are linked and diversion or channel capacity exists for transferring the water. Comparison of the solution when all sectors are of equal priority, as in the base condition, with the solution when they are not equal indicates where interbasin water trades could improve the efficiency of water allocation. We found, however, that separating demand sectors into two groups of different priorities (D7) has little or no effect on the number of basins with shortage. The lack of impact on the number of basins with shortage results from two factors. First, given two groups of demands, an interbasin transfer can occur only if, under the single-priority condition, the shortage amount exceeds the demand of the low-priority sectors, so that high-priority sectors are also shorted. Because low-priority sectors (especially agriculture) typically account for most of total consumptive use, the opportunity for interbasin transfers is limited even in basins with substantial total shortage. Of course, intrabasin transfers, such as between the agricultural and urban sectors, could occur, but they were not modeled here. Second, when a transfer does occur, it may not necessarily change the number of basins with shortage; rather, it may shift which basins incur shortages or reduce the amount of shortage without eliminating the shortage completely. Nevertheless, separating the demands into two groups of different priorities did allow for some interbasin water exchanges, which is not revealed in figure 10-5. Those exchanges result in urban users along the Colorado Front Range using water that previously went to agriculture downstream and in urban users in the Lower Colorado River Basin (LCRB) using water that previously went to agriculture in the UCRB.

6. Removing the constraint to always satisfy the TBDs (subject to water availability) (D8) generally reduces the number of basins with shortage by one to two basins (figure 10-5a), but it has a larger effect in some futures (e.g., figure 10-5b). Removing the constraint causes many shifts among the basins in water use and in shortages, and, although it generally decreases the total amount of shortage in the network, it can also lead to an increase in the number of basins with shortages (e.g., figure 10-5c in selected periods), in which shifting water among linked basins causes shortages in basins that had previously avoided them.

7. Increasing reservoir storage capacity (S1 and S3) can help alleviate water shortage under certain conditions. Additional storage capacity is helpful if (a) some demands cannot be met under current capacities and (b) water is available to be stored in the enlarged reservoir. If water is the limiting factor, increasing reservoir capacity cannot help. In agreement with the analysis of Foti et al. (2012, 2014a), reservoir enlargements do not alleviate future shortages in most basins because of a lack of water. Furthermore, the effectiveness of reservoir enlargements diminishes over time, because storage levels generally fall as water yields diminish. In addition, comparison of the left- and right-hand columns of figure 10-5 shows that enlarging reservoirs is more effective in removing basins from the low-shortage-incidence list (left column) than in removing them from the high-shortage-incidence list, which implies that increasing reservoir storage capacity is least effective where it is most needed—the reason being that basins with a high incidence of shortage suffer most from a lack of water.

8. Expanding TBD capacities while still insisting that the diversions are a higher priority than demands (S3 and S4), in general, is unhelpful, actually tending to increase the number of basins with shortages (figure 10-5). This increase occurs because the situations in which the source basin could have used the diverted water outnumber the situations in which the receiving basin is in greater need of the water.

9. Groundwater mining (S5) is the most effective adaptation among those we examined in reducing the likelihood of shortages. In the 2040, 2060, and 2080 periods, groundwater mining reduces the number of basins with some shortage by about five, on average (figure 10-5a). The average results, of course, mask important differences. Given a relatively low amount of climate change, as in the RPA A1B-CGCM future, groundwater mining nearly completely removes the incidence of shortage in the near term (figure 10-5b), but, with higher levels of climate change and population growth, substantial shortages remain (figure 10-5c). Although groundwater mining fails to fully eliminate all shortages, even in the near future, it should be noted that the levels of groundwater mining assumed here are based on estimates of past levels, and those levels can perhaps be exceeded in some locations, at least in the short term. Being a nonrenewable source of water, however, groundwater mining will eventually fail to solve the water shortage problem, and increasing pumping levels in the near term will hasten the eventual failure. Understanding how long into the future groundwater supplies could be relied on to alleviate water shortages would require modeling aggregate groundwater supplies, which is beyond the scope of this assessment.
10. Removing the constraint to always fully satisfy the TBDs while also increasing TBD capacities (C1 and C2) notably reduces the incidence of shortage. With the flexibility to divert water only when it is needed, increasing the capacity of TBDs can lower the likelihood of shortages beyond the level when TBD capacities are not increased. This combined adaptation removes roughly one to two basins from the shortage lists (figure 10-5a).

Implications

In the absence of adaptation beyond continued improvements in water withdrawal efficiency and a continuation of the past rate of decrease in the western irrigated area, future water shortages are projected to occur in roughly one-fourth of the 69 basins analyzed, on average across the 9 futures. Futures of relatively low levels of population increase and climate change result in only about 5 to 10 percent of the basins projected to incur shortages (e.g., figure 10-5b), whereas futures of relatively high levels of population growth and climate change result in more than 30 percent of basins projected to incur shortages (e.g., figure 10-5c).

Of all the measures of adaptation that we examined, allowing continued groundwater mining has the biggest impact on projected shortages. With this adaptation, when averaged across all nine futures, groundwater mining allows a 20- to 50-percent reduction in the number of basins with shortages (about a five-basin decrease). For futures of less-than-average amounts of climate change, groundwater mining nearly eliminates shortages in all basins where mining is available in the near future (2020) time period. Of course, as the impact of climate change becomes more serious and as population growth continues, more basins are left with some shortages, given the levels of groundwater mining assumed here. As already noted, groundwater mining is not a long-term solution to water scarcity. Further, groundwater mining imposes costs on future water users, who must deal with not only increasing pumping lifts but also the prospect of exhaustion of the recoverable groundwater supply.

All other adaptations tend, on average, across the nine futures to reduce the number of basins with shortage by about 5 to 10 percent (roughly one to two basins). Among the various adaptations, the reduction of instream flow requirement from 10 to 5 percent of mean annual yield and expected improvements in withdrawal efficiency tend to have the greatest impact. Reducing instream flow would tend to harm aquatic life and lower the quality of instream recreation; our finding highlights the potential threat to these concerns. A common past adaptation, increasing reservoir storage capacity, has some effects on shortages in the early decades of the 21st century, but the effects diminish later in the century as water yields diminish in key regions.

As would be expected, the effectiveness of the adaptations differs considerably by location (i.e., basin). For example, groundwater mining is most effective in basins with ample groundwater supplies, and reducing irrigated area is most effective where irrigation accounts for a large percentage of total water use. Thus, in practice, selection of adaptations—both the kind and size or extent—must be sensitive to local circumstances. The purpose here was to obtain a broadbrush idea of the degree to which different adaptations could be successful under alternative future population and climatic conditions. Further, the large scale of analysis—ASRs and an annual time step—fails to capture local or short-term shortages. More indepth analyses would be needed to decide on an adaptation strategy. Whatever the strategy or mix of strategies, however, the analysis here suggests that a very aggressive campaign of adaptation would be needed to fully adjust to the combined effects of population and economic growth and climatic change.

Water Use in the Upper Colorado River Basin

- ❖ Water-demand projections using a computable general equilibrium (CGE) model do not deviate substantially from the 2010 RPA projections for most sectors of the economy.
- ❖ A notable exception is the power sector, in which case water demanded for power generation may be 18 to 29 percent higher by 2060 than previously projected, as a result of feedbacks within the regional economy.

The 2010 RPA water assessment (Foti et al. 2012) examined water vulnerability for the entire United States. Given its national scope, simplifying assumptions were necessary to adequately and consistently address water demand. This section looks at the impacts of climate change and population growth on demand for water in one large watershed, the UCRB, to see what gains could be made by a more detailed description of water users. We extend the 2010 RPA model by using a CGE model to estimate water demand in the UCRB based on the same climate change scenarios, population growth rates, and trends in efficiency of water use by productive sectors of the economy used in the 2010 RPA (see the sidebar Computable General Equilibrium Models).

We summarized the 2010 RPA's water demand and then examined what its projections mean for specific sectors of the economy. This information is used in a CGE model of the UCRB to project future water demands. We compared the 2010 RPA water-demand model with results from a typical CGE (following De Melo and Tarr [1992] and Warziniack [2014]) to determine at what point the two models lead to similar results, at what point they diverge, and the reasons for the differences.

Colorado River Basin

The Colorado River and its tributaries provide water to a semi-arid region that includes seven Southwestern States and the northern part of Mexico and to numerous flora and fauna species. The river basin is a complex network that covers an area of 243,000 square miles, spanning 1,450 miles from the Rocky Mountains to the Pacific Ocean (see figure 10-7). The water of the Colorado River reaches 30 million people, including the people of Denver, Las Vegas, Los Angeles, and Phoenix.

In 1922, the Colorado River Compact divided the basin into the UCRB and the LCRB, divided at Lee's Ferry (just south of the Utah-Arizona border). The UCRB encompasses Colorado, Utah, Wyoming, and the northern parts of Arizona and New Mexico. The LCRB includes the remaining areas of Arizona, California, and Nevada. The framers of the compact assumed that the annual capacity of the river was between 15 and 17.5

Computable General Equilibrium Models

Computable general equilibrium (CGE) models are computational representations of regional economies that optimize economic behavior among regional firms and households and include links between sectors. They are characterized by market prices and connections between economic agents. Firms purchase goods from each other, sell them to regional households, and trade with other regions. Equilibrium conditions for supply and demand of goods and factors of production determine prices within the economy. CGE models are useful when external shocks are likely to cause impacts large enough to affect multiple sectors of the economy and regional prices and when feedback between sectors of the economy are likely to matter. The added features of CGE models, however, require additional assumptions and data to describe interdependencies of firms, households, and outside regions.

A simplified view of the linked economy for the Upper Colorado River Basin (UCRB) is represented in figure 10-6. The regional economy is modeled as a system of interacting institutions. The interactions come through product and factor markets, government redistribution schemes, savings, and investments. Institutions consist of representative households, industrial sectors, factors of production, and levels of government, all making optimal choices while linked one to the other through markets. Complete details of the model and computational code are in Warziniack (N.d.).

Figure 10-6. Simplified view of economic linkages in the Upper Colorado River Basin economy.

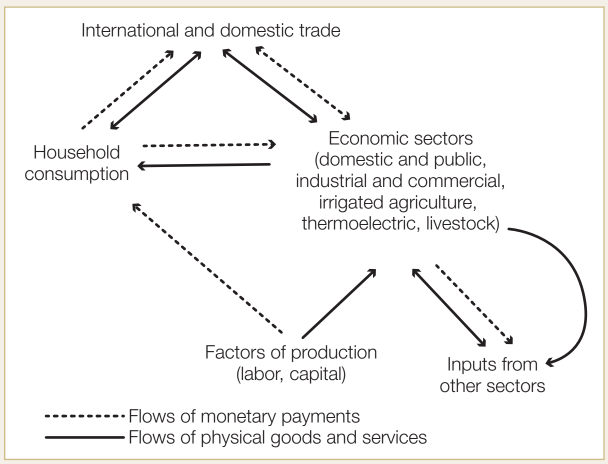
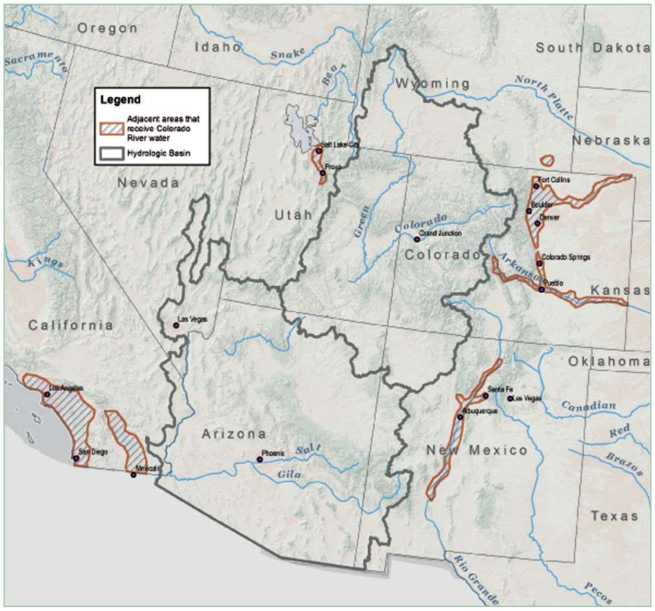


Figure 10-7. Map of the Colorado River Basin.



million acre feet (maf). The compact required the Upper Division States to deliver no less than 75 maf for any period of 10 consecutive years. Distribution of each basin's share between States occurred later through basin-specific agreements. The Boulder Canyon Project Act of 1929 apportioned the LCRB's annual average of 7.5 maf of water as follows: 2.8 maf to Arizona, 4.4 maf to California, and 0.3 maf to Nevada. The 1922 Upper Colorado River Basin Compact allocated water not in total amounts, but by percentages. The apportionments are as follows: Colorado, 51.75 percent; New Mexico, 11.25 percent; Utah, 23 percent; and Wyoming, 14 percent. In addition, the Upper Colorado River Basin Compact apportioned 50,000 acre-feet annually to the portion of Arizona that lies in the UCRB. Mexico was guaranteed 1.5 maf of the Colorado River annually and any other quantities arriving at the Mexican points of diversion that did not exceed 1.7 maf (Umoff 2008).

Recent studies have shown that the flow estimates on which the compact were based were higher than flows seen today (about 14 maf) and will be increasingly inaccurate if higher temperatures and lower precipitation occur during this century. Estimates of future water yield in the basin have varied drastically because of uncertainties in climate models and corresponding assumptions, ranging from 10- to 45-percent reductions in annual water yield relative to today's levels (Christensen and Lettenmaier 2006; Ray et al. 2008; Vano et al. 2012).

The definition of the UCRB used in this study follows that given by the Water Resources Council (1978), which divided the conterminous United States into 18 water resource regions (WRRs) in 1968 and 99 ASRs in 1978 (figure 10-1). The UCRB's geographical boundary is the Upper Colorado WRR and includes the ASRs Green-White-Yampa, Colorado-Gunnison, and Colorado-San Juan.

Water-Use Projections

The 2010 RPA used historical growth and decay rates for consumptive use to project future consumptive water use in five economic sectors: (1) domestic and public, (2) industrial and commercial, (3) thermoelectric, (4) irrigated agriculture, and (5) livestock. Population was the primary driver for the domestic and public and the livestock sectors; total annual personal income was the primary driver for the industrial and commercial sector; and amount of irrigated acres was the primary driver for the irrigated agriculture sector. The primary drivers for thermoelectric were population and kilowatt hours per capita. Secondary factors in determining thermoelectric demand included the amount of power produced from renewable sources, thermoelectric plants that use saline water, and hydroelectric power plants. Population and personal income projections are from the 2010 RPA scenarios described in chapter 2. The number of irrigated acres and gallons per unit were based on historical trends. Values for key drivers and values for gallons per unit of driver are in Warziniack (N.d.).

Income in CGE models is determined by the model, tied to demand for capital and labor in the regional economy. A growing population, without anything else changing in the economy, would imply more abundant labor—wages and income would fall. It is not straightforward to allow for both an external increase in population and an external increase in income. For comparability with the 2010 RPA, we solve the CGE model for each RPA scenario-climate combination assuming either population increases or per capita income increases, and then we compare the results with the 2010 RPA. The choice of population and income growth rates affects the degree to which the CGE results match those in the 2010 RPA. In the RPA A1B scenario, for example, the UCRB population in 2060 is almost double what it is in 2010 and personal income in 2060 is more than four times as large. In the CGE model, personal income grows at roughly the same rate as population. To make meaningful comparisons, we discuss only results from the CGE, by sector, using the same driver that was used in the 2010 RPA for that sector.

Consistent with the 2010 RPA, supply of water is not a constraint in the model. Firms and households can purchase as much water as they want at current prices; total water demand is then found by summing demand from all agents.

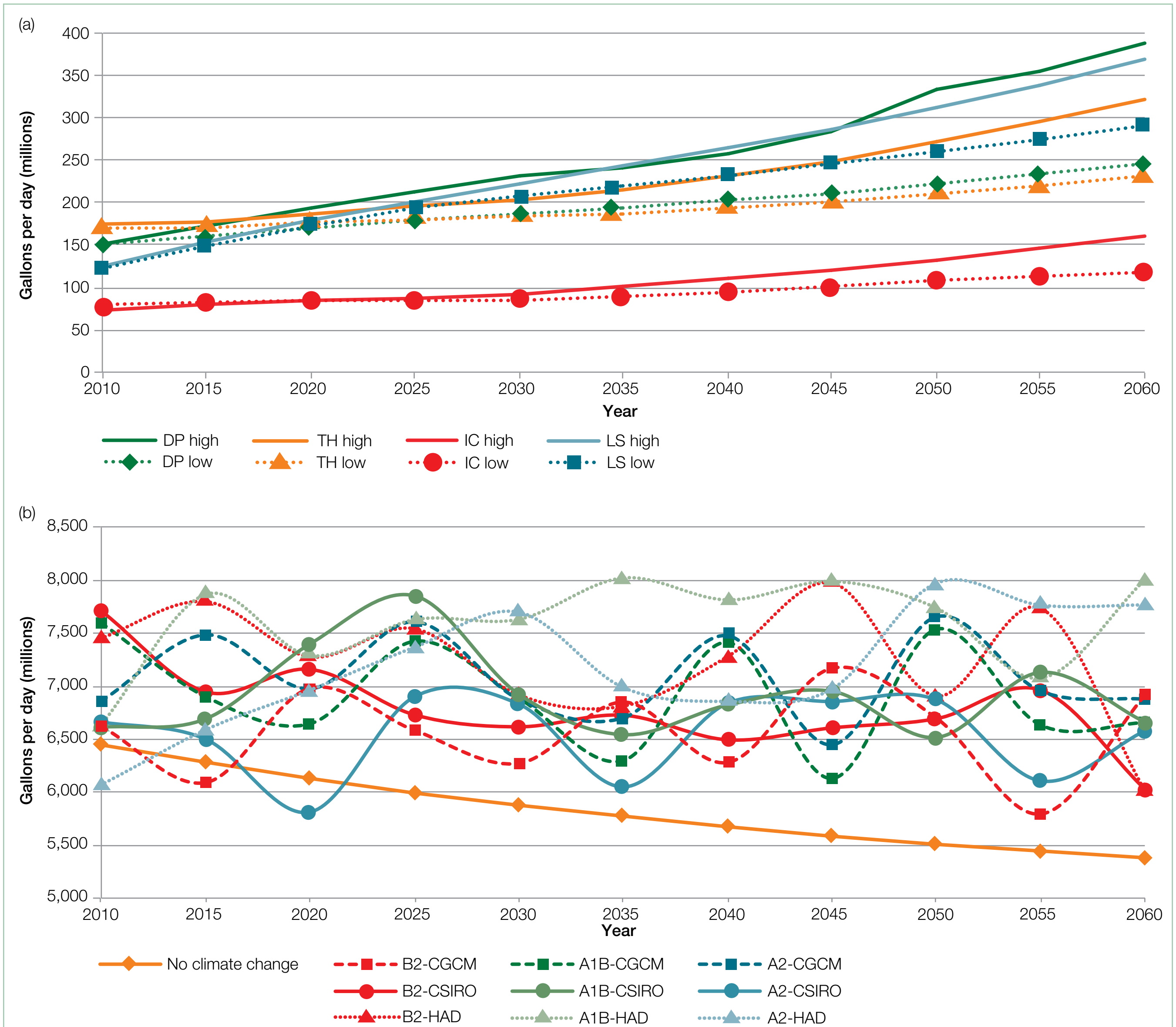
Results

The results from the 2010 RPA water-demand modeling projected increases in the domestic and public, livestock, industrial and commercial, and thermoelectric sectors. Figure 10-8a shows the high and low projections for each sector across the range of 2010 RPA scenario-climate combinations. The high projection generally is associated with RPA A2, and the low projection is associated with RPA B2. Projections for the irrigated agriculture sector were more varied (figure 10-8b). Unlike the other sectors, the no-climate-change scenarios (combined on figure 10-8b into one line) for irrigated agriculture showed a downward trend as the number of irrigated acres decreased over time, while climate effects led to a net increase in irrigation demand, particularly using the MIROC model projections, which show a nearly 30-percent increase by 2060 in the RPA A2 compared with the no-climate-change scenario.

The 2010 RPA water demands serve as a benchmark to evaluate the results of the CGE model. We calculate water demands using the same population and growth rates and then compare the results relative to water demand in the 2010 RPA. Using the population growth rates, we exactly reproduce the results for the domestic and public sector and come very close to reproducing its results for the livestock sector—the two sectors with population as the primary driver. Using the per capita income growth rates, we reproduce the results for the industrial and commercial sector, with some small differences due to changes in economywide prices.

These projections, by design, should match those in the 2010 RPA. Livestock is a small enough sector that indirect and induced effects are likely to be small. Increased demand for industrial and commercial uses increases the demand for other inputs to production. These inputs mostly come from the industrial and commercial sector itself, and the sector's improvements in water efficiency occur fast enough to limit any real increase in water demand.

Figure 10-8. Projections of water demand for (a) domestic and public (DP), thermoelectric (TH), industrial/commercial (IC), and livestock (LS) uses and (b) irrigated agriculture in the Upper Colorado River Basin, 2010 to 2060.



The largest difference in water use between the CGE and 2010 RPA models occurs in the power-generation sector (figure 10-9). A growing population demands more goods, causing regional production to expand. This expansion in production and the ripples it sends throughout the economy lead to more demand for power. The CGE model projects 18 percent (58 million gallons per day, RPA A2 MIROC scenario) to 29 percent (67 million gallons per day, no climate change, and RPA B2 scenario) more water demanded by the power sector than the 2010 RPA model by 2060.

In both the 2010 RPA and CGE models, demand for water by agriculture depends on the scenario (RPA A1B, A2, B2) and not on the climate model. In the 2010 RPA, irrigated acreage declined over time, continuing a decades-long trend. By contrast, irrigated agriculture, much of which is grown in the region, expands in the CGE to meet household demand (figure 10-10). Changes in the amount of water per unit of output follow changes in irrigation depth, but these changes are dominated by the effects of population growth. The CGE model, therefore, projects a greater amount of water demanded by agriculture than does the 2010 RPA.

Figure 10-9. Computable general equilibrium (CGE) results relative to 2010 RPA water results for thermoelectric use in the Upper Colorado River Basin, using the population driver, 2010 to 2060.

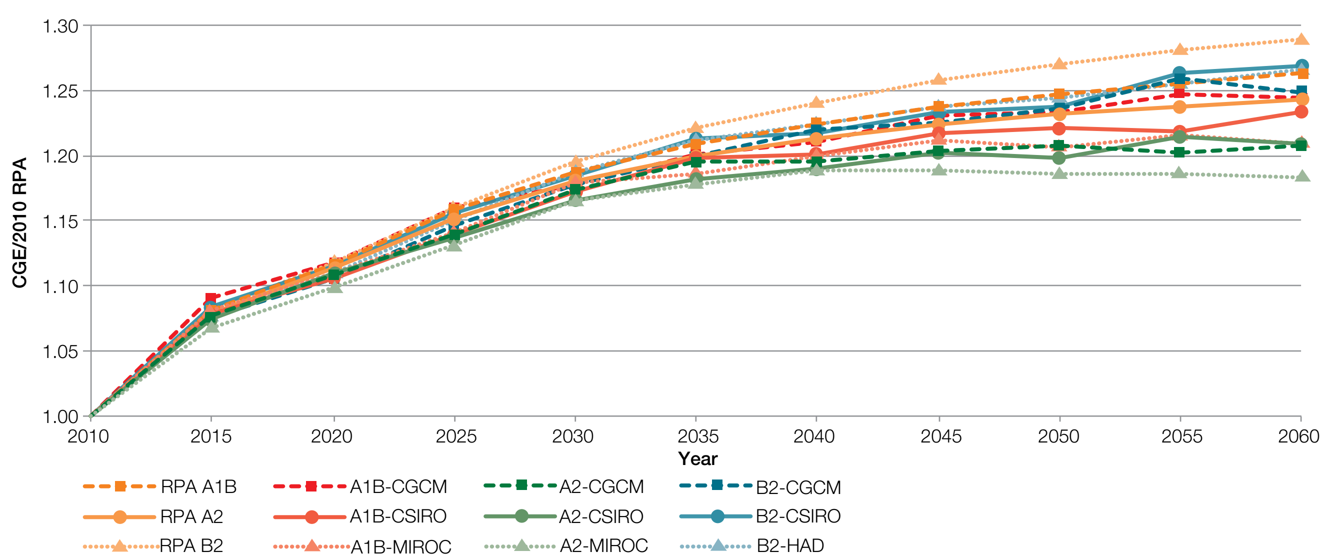
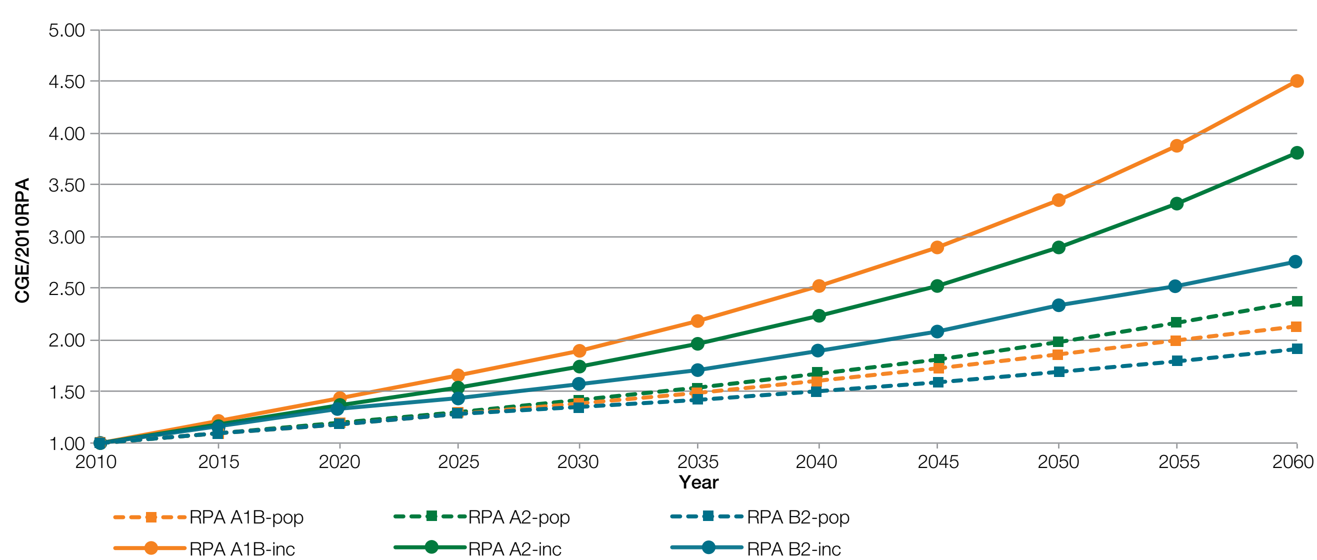


Figure 10-10. Computable general equilibrium (CGE) results relative to 2010 RPA water model for irrigated agriculture, using population (pop) and income (inc) as drivers, 2010 to 2060.



Discussion

The results for the thermoelectric sector highlight the advantages of using the CGE model, namely that indirect and induced effects can be captured. In our example, these effects amount to a potential 29-percent underestimation of water demand in the power sector. With the exception of irrigated agriculture, the CGE produces similar results as the 2010 RPA for water demand in the other sectors. Those similarities are by design—they should have tracked closely and provided a check for our methods.

Water affects nearly every aspect of life and production; changes in its availability and use are complex problems, well suited for analysis with CGE models (Bell and Devarajan 1987). We have focused on changes in population and income drivers, but future water shortages and the policies to address them are likely to be equally complex (e.g., Gomez et al. 2004; Goodman 2000; Roe et al. 2005). Models will be needed that are capable of addressing the linkages between sectors of the economy, the adaptability of households, and the resilience of individual businesses and regional markets (Rose and Liao 2005).

Although the CGE model performs well, this study has highlighted an area for future research that previous CGE models have not addressed: work is needed to develop a CGE model that uses both population growth and income growth to more closely match the assumptions of the RPA scenarios. Other modelers have focused on evaluating water policy, adaptation options, or population growth, but none include all of these simultaneously, nor do they include exogenous income growth.

Assessing Risks to Watersheds

- ❖ The highest levels of risk of impaired water quality resulting from land and resource use in the conterminous United States generally are found in the eastern half of the Nation.
- ❖ High levels of risk from sediment loss tend to occur in concert with high levels of risk from excess nutrients and toxics, in part, because some activities or water uses result in a number of stressors and because some activities tend to occur together.

Brown and Froemke (2012) analyzed the risk of impaired water quality for the more than 15,000 fifth-level (10-digit) watersheds in the conterminous United States, focusing on a set of watershed stressors that are known to affect one or more of three common water-quality problems: sediments, nutrients, and toxics. Watersheds were ordered from the lowest to the highest level of concern by a disturbance index that measures the extent to which the landscape has been altered. The ordering was independent of any reference condition; instead, it indicated each watershed's relative likelihood of impaired water quality.

Nine stressors were used to characterize the risk caused by sediment, nutrients, and toxics. Human-caused stressors were emphasized, with the exception of wildfire (table 10-3). The stressor variables were combined to first develop measures of relative risk for each of the three water quality problems. The three risk measures were then combined to produce an overall measure of risk-impaired water quality. Finally, the risk values were converted to a categorical scale of five risk levels, each representing one-fifth of the risk value range, with 1 indicating the lowest risk and 5 the highest.

Stress levels vary greatly among watersheds, often reflecting intensity of human uses. The highest stress levels for most stressors are found in the Eastern United States, particularly for housing density, road density, cultivation, livestock grazing, animal feeding, and atmospheric deposition. When summarized at the level of the much larger 18 WRRs (figure 10-11), average stress levels also vary substantially, indicating a large-scale heterogeneity in stress levels across the United States. As with the 10-digit watershed scale results, the highest stress levels generally are found in WRRs in the Eastern United States. Of all the stressors, only wildfire leads to higher levels of risk in western WRRs.

The overall risk of water-quality impairment is shown in figure 10-12. The division between the Eastern and Western United States is striking. With the exception of a few watersheds in northern Maine, the Upper Peninsula of Michigan, the northern lake country of Minnesota, and the Florida Everglades, watersheds at relatively low risk are almost entirely in the Western United States. The few watersheds at high risk in the Western United States occur in major agricultural areas or areas of combined urban and agricultural cover, such as California's San Joaquin Valley, the Willamette Valley in Oregon, and the Front Range of Colorado. The blocks of risk level 4 and 5 watersheds in the Eastern States reflect large expanses of agricultural cultivation, higher levels of development density, and high levels of atmospheric deposition.

Figure 10-12 reveals greater heterogeneity in the U.S. West than in the East, with pockets of high-risk watersheds often surrounded by vast low-risk areas. This greater heterogeneity reflects the West's climatic and topographic variability, its heavy reliance on irrigated agriculture, and land ownership patterns that include wide expanses in public ownership.

High-risk levels for one problem tend to be associated with high levels of other problems. Some stressors are associated with multiple problems, such as cultivation being a source of sediments, nutrients, and toxics. Some stressors may also occur

Table 10-3. Watershed stressors that affect sediments, nutrients, and toxics.

Stressor	Measure	Problem		
		Sediments	Nutrients	Toxics
Housing density	Housing units per km² in year 2000	X	X	X
Road density	Meters of road and railroad per km² of watershed land	X		X
Cultivation	Percent of watershed in agricultural land cover	X	X	X
Livestock grazing	Animal units per km² in year 2007	X	X	
Confined animal feeding	Animal units per km² in year 2007		X	X
Mining land cover	Percent of watershed in mining land cover	X		
Potentially toxic mines	Total number of active and inactive mine sites potentially yielding toxics per 1,000 km² of watershed			X
Potentially damaging wildfire	Percent of area with a high risk of losing key ecosystem components in a forest fire	X		
Atmospheric deposition	Mean annual (2000 to 2006) deposition (in kilograms per hectare) of nitrates and sulfates in wet atmospheric deposition		X	X

km² = square kilometers.

Source: Brown and Froemke (2012).

Figure 10-11. Eighteen water resource regions (numbered) and five water supply regions.

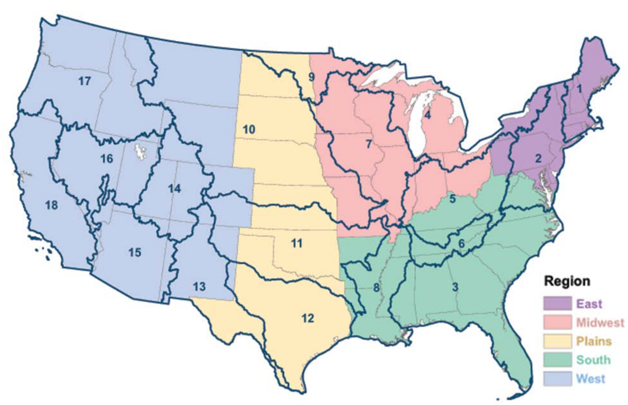
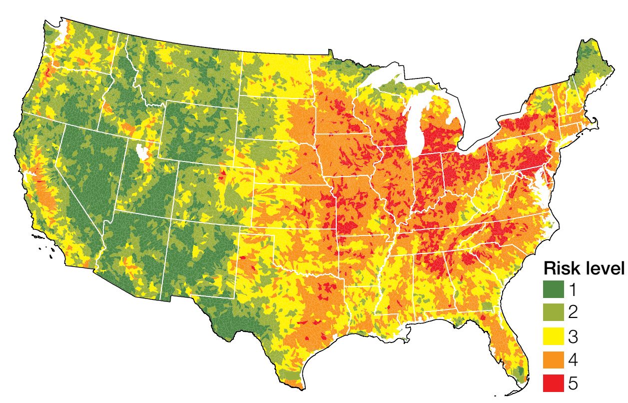


Figure 10-12. Overall risk of water-quality impairment for 15,272 watersheds.



naturally in proximity, such as housing development being in proximity to roads. The strong intercorrelations among the three problems support the approach for summarizing risk in a single measure, as shown in figure 10-12.

Because comparable spatially explicit nationwide datasets of historical levels were not available for some of the stressors used here, it is not possible to compare these results with conditions in previous decades. Recent large-scale trends in the levels of stressors, however, offer some insights into how the risk of water-quality problems may have recently changed. Factors that suggest increasing risk are the steady rise in U.S. population and the increase in the area of housing. Factors that suggest decreasing risk include a gradual decline in farmland area since the 1950s, declines in total pesticide use from peak levels in the 1980s, declining cattle and sheep inventories since the 1990s, significant drops in total atmospheric deposition of nitrates and sulfates during the past two decades in the Northeastern and Midwestern United States, and a leveling of application rates of commercial fertilizers.

Cultivated and urbanized areas are prominent sources of nonpoint-source pollution. Future trends in agriculture land use will depend on a host of factors, including agricultural efficiency, agricultural prices, consumer preferences, and conservation and energy policies, each of which can drive land use in a different direction. By contrast, the U.S. population is projected to continue to grow; an expanding population will require housing and associated infrastructure and thus intensify the risk of impaired water quality. Unlike cultivated and urbanized area, forests yield relatively clean water. It is important to note that in the western third of the United States (WRRs 13–18), where most precipitation occurs in higher, cooler areas, forests account for 66 percent of the renewable water supply (see the next section) and rangelands for another 18 percent, whereas cultivated areas account for only about 3 percent of the water supply. In the middle third of the country (WRRs 7–12), however, where precipitation tends to be distributed more evenly across the landscape, cultivated areas are the predominant source of water, accounting in aggregate for 37 percent of the water supply, whereas forests are the source of only 30 percent. In the eastern third (WRRs 1–6), cultivated lands are the second most prevalent water source (after forests), accounting for 20 percent of the supply. Therefore, in contrast with the western third of the country, other regions are not only more agricultural, but their cultivated areas are relatively more important as sources of renewable water supply, which raises the importance of addressing nonpoint sources of pollution in those areas.

Water Supply of the United States

- Forests are disproportionally important as sources of water, especially in the Northeastern and Western United States, where they provide roughly two-thirds of the annual water supply. Forests provide about one-third of the water supply in the Midwest and Plains Regions.
- Federal lands are the source of 60 percent of the water supply in the West Region as a whole, and the source of more than 75 percent of the water supply of some Western States.

Our renewable fresh water supply (hereafter, "water supply") begins as precipitation falling on land and fresh waters. From there, the water naturally evaporates from the land or vegetation, percolates down to groundwater aquifers, or flows toward the sea via rivers and streams. Water that evaporates has largely escaped our grasp until it falls again elsewhere as precipitation. What remains—until it reaches the sea—is available for use by humans and other species and, in a broad sense, is our fresh water supply (final water supply is also a matter of water management, which we ignored in this section).

We estimated water supply, also called water yield, across the conterminous United States for the period 1981 to 2010. Political, administrative, and land cover boundaries were mapped over the gridded water supply estimates to indicate the amount of water that becomes available in respective land areas. These water supply estimates update those provided by Brown et al. (2008). Compared with Brown et al. (2008), these new estimates incorporate more recent precipitation and temperature data, apply a different water yield model, and use more and newer land cover data. More detailed information and data about the estimates provided in this section are in Brown et al. (2015).

Methods

Water yield was estimated using the Variable Infiltration Capacity (VIC) model at each 1/8º by 1/8º (about 12 km by 12 km) grid cell across the conterminous United States. The VIC model (Cherkauer et al. 2003; Liang et al. 1994; Liang et al. 1996; Nijssen et al. 1997) is a semidistributed, macroscale, grid-based hydrological model that solves the vertical energy and water balances in each grid cell. The model uses daily precipitation, maximum and minimum temperatures, and wind speed, along with land surface and soil data, to simulate daily soil moisture, base flow, and surface runoff, among other fluxes and storages in each grid cell. Climatic forcings and other inputs required to run the VIC model at the 1/8º by 1/8º grid scale for the conterminous United States were obtained from the Surface Water Modeling Group at the University of Washington (http://www.hydro.washington.edu/Lettenmaier/Data/gridded/). The model was then calibrated at the ASR spatial scale using methods outlined by Foti et al. (2012) and Mahat et al. (2015).

The VIC model was implemented at a daily time step during the period from 1981 to 2010 for the conterminous United States. Estimates of yield by cell were aggregated temporarily to the annual time step, and the annual estimates were then averaged. Mean annual yields per cell were aggregated across space to estimate mean annual yield for geographic areas of interest. Aggregating estimates of yield across cells within a boundary indicates the amount of water supply originating within the designated area.

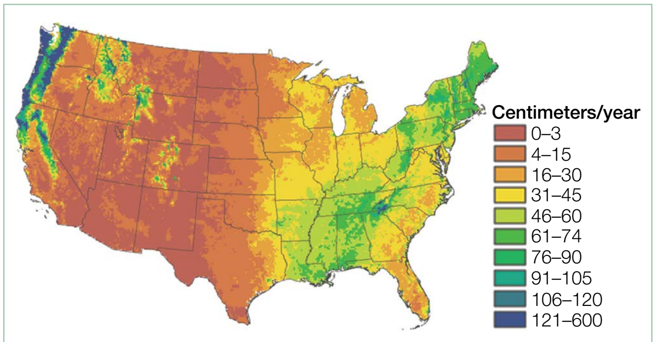
As a source of water supply, Federal ownership was distinguished from non-Federal (State and private) ownership, and four categories of Federal ownership—(1) Forest Service, (2) National Park Service, (3) Bureau of Land Management (BLM), and (4) other—were tracked. The Federal boundaries were taken from the 2005 Federal Lands of the United States database of the National Atlas of the United States (http://nationalatlas.gov/atlasftp.html) at the 100-m grid spatial resolution. This database contains National Forest System proclamation boundaries, which include some adjacent private land. All non-Federal other land is considered State or private.

Land cover was taken from two primary sources: the 2006 National Land Cover Database (NLCD) (Fry et al. 2011) (http://www.mrlc.gov/nlcd06_data.php.at) and the 2012 LANDFIRE (lf 1.3.0) release (http://www.landfire.gov/NationalProductDescriptions21.php). Data from each database were available at the 30-m grid spatial resolution. These data were then resampled to the 100-m grid spatial resolution. From each database, six cover classes were formed: (1) forest, (2) rangeland, (3) agriculture, (4) developed, (5) riparian, and (6) other. For the NLCD, these classes were formed from the original 16 classes. For LANDFIRE, the 6 classes were formed from the original 20 classes of EVT_PHYS (physiognomy) data, with the original Exotic tree-shrub and Exotic herbaceous classes apportioned to forest, rangeland, or riparian, as indicated by the EVT_GL specifications. In addition, we used the 2008 Forest Service's Forest Inventory and Analysis (FIA) forest cover data (http://data.fs.usda.gov/geodata/rastergateway/biomass/) available at the 250-m grid spatial resolution.

Results

Mean annual 1981-to-2010 water yield depths for the conterminous United States estimated using the VIC model are shown in figure 10-13. In the Western United States, the highest yields are concentrated in the mountainous areas of the north Pacific Coast, the Sierras of California, and the northern and central Rocky Mountains. Away from these mountain areas, mean annual yields tend to be ≤ 15 centimeters per year. Yields are uniformly ≤ 15 centimeters per year in the Great Plains and the Southwest. Yields east of the Great Plains tend to exceed 30 centimeters per year, except for areas along the eastern edge of the region, some areas near the Great Lakes, and areas along the south Atlantic Coast, including Florida.

Figure 10-13. Mean annual water yield depth in the conterminous United States.



Water supply volumes across the conterminous United States are presented in the following two subsections, first by land ownership and then by land cover.

Water Supply by Land Ownership

Federal land occupies 24 percent of the conterminous U.S. land area and yields 23 percent of its mean annual water supply. Federal land contribution to water supply differs greatly by agency, however, because of differences in the amount of land each agency manages and differences in the elevations of those lands and the rainfall that occurs there (table 10-4). For example, Forest Service lands yield 18 percent of the water supply of the conterminous United States from 11 percent of the land area, whereas BLM lands yield 2 percent of the water supply from 9 percent of the land area.

Separating the conterminous United States into five regions (see figure 10-11 and the notes of table 10-4 for region definitions), we find that in all regions except the West, the great majority of the land is in private (or State) ownership (figure 10-14a). Percentages of land under Federal management are as follows: 3, 10, 7, 4, and 50 in the East, South, Midwest, Plains, and West Regions, respectively (table 10-4). Proportions of the water supply originating on Federal land roughly match the proportions of the land in Federal ownership except in the West Region, where much of the high country is in national forests or parks (figure 10-14b). The following percentages of water supply originate on Federal lands: 3, 11, 7, 4, and 63 in the East, South, Midwest, Plains, and West Regions, respectively (table 10-4).

Table 10-4. Percent of land and water supply by land ownership and region.

Land ownership	Region					
	East	South	Midwest	Plains	West	All
	percent of land					
Forest Service	2	7	6	2	21	11
Bureau of Land Management	0	0	0	0	23	9
National Park Service	0	1	0	0	3	1
Other Federal	1	2	1	1	4	2
State and private	97	90	93	96	50	76
	percent of mean annual water supply					
Forest Service	3	8	6	3	49	18
Bureau of Land Management	0	0	0	0	6	2
National Park Service	0	1	0	0	6	2
Other Federal	1	2	1	2	1	1
State and private	97	89	93	96	37	77

East: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.

South: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.

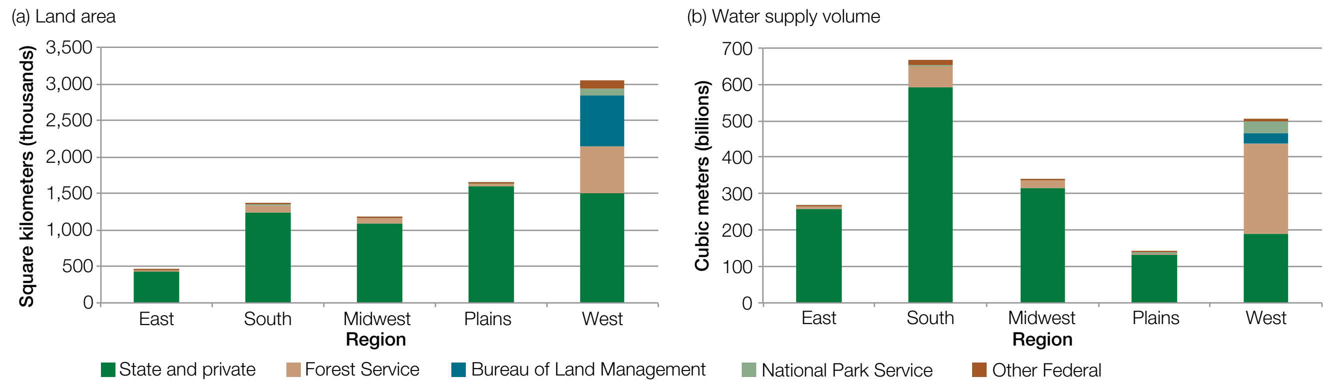
Midwest: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin.

Plains: Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, Texas.

West: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming.

Other Federal = all other Federal agencies.

Figure 10-14. (a) Regional land area and (b) water supply by land ownership.



Water Supply by Land Cover

Based on NLCD land cover data, forests occupy 26 percent of the land area of the conterminous United States but yield 46 percent of the mean annual water supply, whereas rangelands occupy 37 percent of the land but yield only 14 percent of the water supply (table 10-5).

Across the regions, forests occupy from 8 percent (Plains Region) to 58 percent (East Region) of the land, based on NLCD designations, and yield from 19 percent (Plains Region) to 60 percent (East Region) of the water supply (table 10-5). The proportions of water supply roughly match the proportions of land by cover type except for the Plains and West Regions, where, for the regions as a whole, forests are disproportionally important and rangelands are relatively unimportant (figure 10-15). For example, in the West Region, forests are the source of 58 percent of the water supply but occupy only 23 percent of the land. The relative roles of forests and rangelands in yielding water supply in the Plains and West Regions reflect the dryness of much of the western rangeland areas versus the relatively high rainfall of the forest areas.

Results by land cover depend on which land cover data are used, which, in turn, reflects the different definitions used to distinguish among cover types. In contrast with the NLCD land cover data, the LANDFIRE land cover data indicate that forests occupy 29 percent of the land of the conterminous United States, which provides 50 percent of the water supply (table 10-6), whereas rangelands occupy 30 percent of the land and provide 7 percent of the water supply. Further, based on the FIA cover data, forests occupy 34 percent of the land, which provides 59 percent of the water supply.

Table 10-5. Percent of land and water supply by National Land Cover Database cover type and region.

Cover type	Region					
	East	South	Midwest	Plains	West	All
	percent of land					
Forest	58	44	25	8	23	26
Rangeland	4	9	3	49	62	37
Agriculture	17	23	52	33	8	23
Developed	11	9	9	5	3	6
Riparian	7	14	8	3	1	5
Other	3	3	3	2	3	3
	percent of mean annual water supply					
Forest	60	46	28	19	58	46
Rangeland	4	8	3	31	30	14
Agriculture	15	22	50	35	4	22
Developed	11	9	10	8	3	8
Riparian	7	12	7	5	1	7
Other	3	3	2	2	4	3

East: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.

South: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.

Midwest: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin.

Plains: Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, Texas.

West: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming.

Figure 10-15. (a) Regional land area and (b) water supply by National Land Cover Database cover type.

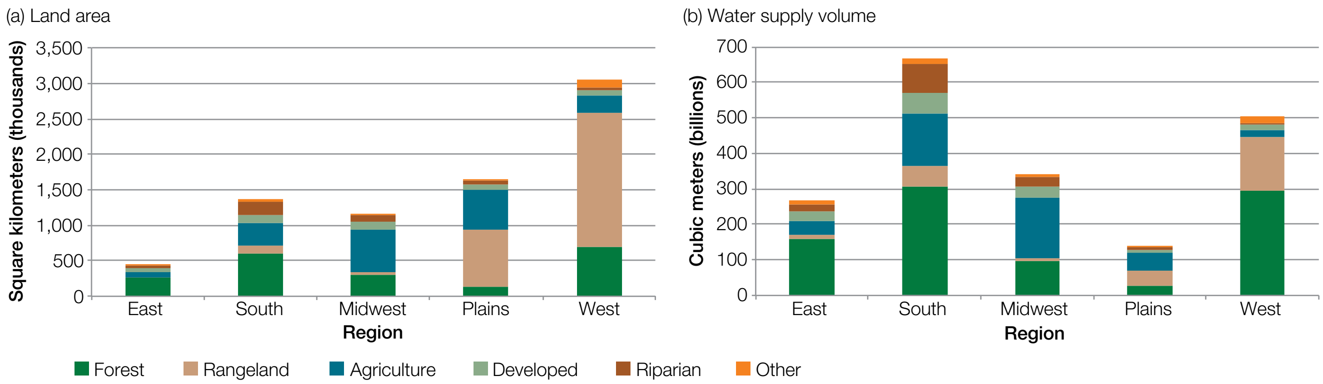


Table 10-6. Percent of land area in forest and water volume from forests, by region and cover data source.

Data source	Region					
	East	South	Midwest	Plains	West	All
	percent of land					
NLCD	58	44	25	8	23	26
LANDFIRE	60	50	27	11	27	29
FIA	66	66	28	11	30	34
	percent of mean annual water supply					
NLCD	60	46	28	19	58	46
LANDFIRE	62	51	30	22	64	50
FIA	69	66	30	27	75	59

FIA = Forest Inventory and Analysis. NLCD = National Land Cover Database.
East: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
South: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.
Midwest: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin.
Plains: Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, Texas.
West: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming.

Among the three sources of forest cover data, the NLCD data indicate the smallest amount of forest area in all five regions (table 10-6). The FIA data indicate the largest amount of forest cover in four of the five regions. Reasons for the difference in estimates of forest cover differ by location, but typically the gains in forest cover in switching from NLCD to LANDFIRE, and from LANDFIRE to FIA, occur as riparian areas (especially in the South and Midwest Regions) or rangeland (especially in the Plains and West Regions) are reclassified as forest area. In concert with the area estimates, the water supply originating in forests is lower if NLCD cover data are used than when using the other two cover data sources. The differences are especially large in the South and West Regions. For example, in the West Region, forests provide 58, 64, and 75 percent of mean annual water supply based on the NLCD, LANDFIRE, and FIA forest designations, respectively (table 10-6).

Forested watersheds provide roughly two-thirds of the water supply of the East and West Regions, roughly one-half of the water supply in the South Region, and somewhat less than one-third of the water supply of the Midwest and Plains Regions. Because forests, in general, are also the source of the highest quality runoff (Brown and Binkley, 1994), it is not an exaggeration to say that forests play an extremely important role in the provision of water in the United States. Public lands provide about 60 percent of the water supply in the West Region (but much lower proportions in the other regions), and considerably more than 60 percent in some Western States. For example, public lands provide at least 75 percent of the water supply in Colorado, Idaho, Nevada, Utah, and Wyoming. See Brown et al. (2015) for results by State and by WRR.

Future Work

The modeling framework for the assessment of water shortages is now being enhanced in the following ways: (1) adoption of the VIC water yield model, allowing for estimation of water yields at the monthly time step; (2) reduction of the spatial scale from 98 ASRs to the 204 4-digit basins of the conterminous United States; (3) use of updated water-demand estimates; and (4) use of a newer generation of global climate models and related emission scenarios (IPCC 2014)). This enhanced framework will allow for an updated and more detailed assessment of options for adapting to impending water shortages across the United States.

The CGE model will be used to project water demands for other watersheds in the United States, focusing first on those watersheds most vulnerable to shortage. An important next step will be to use the water-yield projections to constrain water use and to use the CGE model to analyze economic responses and welfare effects of these constraints.

Conclusions

Offstream water-demand increases and water-yield decreases will combine to raise the likelihood of future water shortages in parts of the United States. Such shortages can be ameliorated by adaptations that lower demand or increase supply. The most potent adaptation is a continuation of groundwater mining, while supplies last. Other more effective adaptations to impending water shortage include reductions in instream flow, improvements in the efficiency of offstream water use, and increases in transbasin diversion capacity coupled with increased flexibility in the rules controlling such diversions. All adaptations are costly, but some are more so than others. Some of the more effective adaptations—especially continued groundwater mining and reductions in instream flow—are either unsustainable or impose great environmental cost and, thus, may not be tenable. These drawbacks heighten the importance of other adaptations, which typically will need to be used in concert to significantly reduce impending shortages. Adaptation options could be prioritized based on their ability to improve water-use efficiency and enhance water management flexibility at reasonable cost.

Forests are especially important for water supply, both because they are the source of most of the water runoff in much of the country and because, in general, they are the source of the cleanest runoff. Protected lands, such as most Federal land, also help maintain water quality. Most of the runoff in the western part of the country originates on protected forest lands, helping to assure its continued relatively high quality. As private lands continue to be developed, protected lands will rise in importance as sources of high-quality water.

Chapter 11. Wildlife, Fish, and Biodiversity

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) reviewed recent trends in wildlife, fish, and biodiversity, showing varied responses, depending on the resource, suggesting varied conditions that depend on region, species group, or habitat type. For this RPA Update, we focused on four topics that were motivated by questions stemming from 2010 RPA findings or that were designed to improve on the resource analysis capability originally reported in the 2010 RPA. First, we extended the work that documented elevated housing growth in the amenity-rich areas near protected areas. Although the 2010 RPA speculated that other natural resources may be impacted by development near protected lands, for this RPA Update, we specifically tested whether biodiversity (as reflected by bird communities) on the boundary of and internal to protected areas was affected by housing development near public lands. Second, we provided a more detailed case study of wildlife habitat stress attributable to climate change across the RPA Rocky Mountain Region. This work improved on the

Highlights

- Increasing housing development near protected areas has affected bird communities at the boundary of and within protected areas. Bird species that thrive under human settlement (many of which are exotic) benefited from such development at the expense of bird species of conservation concern.
- Wildfire management affects our assessment of climate stress to wildlife habitat. Suppression of fires in semidesert systems increased stress because of turnover in the historical vegetation types. An absence of suppression in more mesic systems increased stress because of changes in habitat productivity. Geographic variability in habitat stress and its sensitivity to fire management suggest that wildlife-oriented strategies for adapting to climate change will have to be tailored to the circumstances specific to each landscape.
- Areas supporting high counts of federally listed threatened or endangered species have remained consistent over time. Our new data, however, indicate the emergence of new areas of concentration in the interior highlands and plateau regions of the Central United States.
- Residents of watersheds that support a high density of at-risk aquatic species also often share an interest in drinking-water protection. Watersheds with high rates of urbanization and low percentages of protected lands could serve as criteria to target watersheds where shared funding can jointly benefit seemingly competitive stakeholder groups.

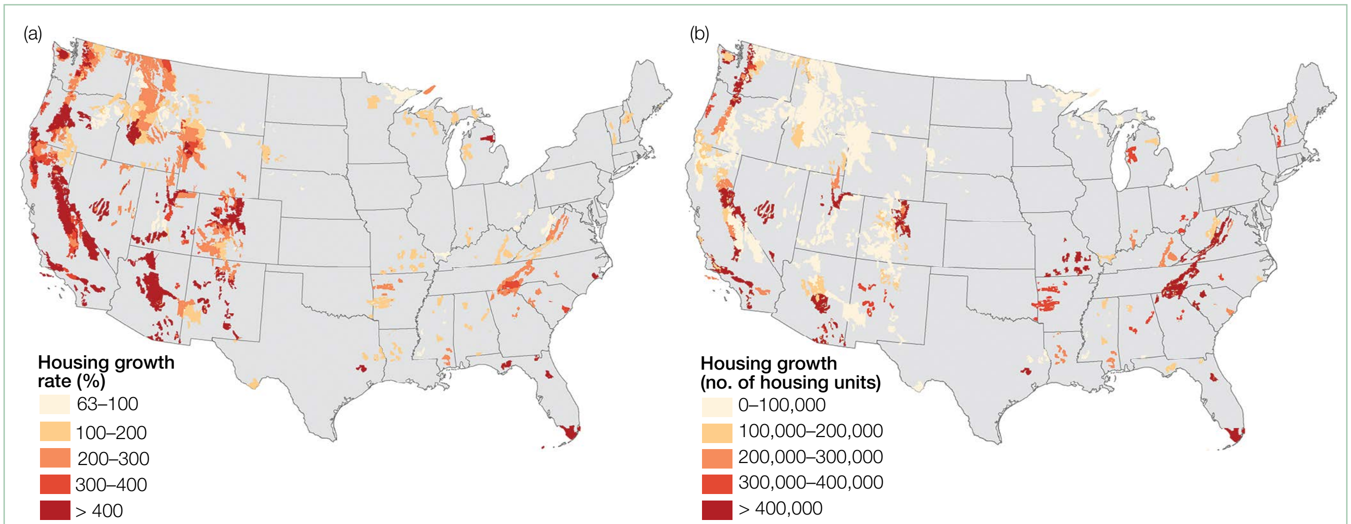
analyses presented in the 2010 RPA by increasing the spatial resolution of the analysis grid, incorporating the results from a new dynamic vegetation model, and examining the effects of wildfire management on evaluations of wildlife habitat stress. Third, we updated the status of imperiled species, using a new approach for assessing the distribution of formally listed and imperiled species that was based on an equal-area grid. Finally, the 2010 RPA noted that taxonomic groups associated with aquatic habitats had higher proportions of imperiled species than other kinds of species. Because of the high degree of imperilment among aquatic taxa, we analyzed at-risk aquatic species occurrence and drinking-water protection as an example of the potential joint benefits that can accrue to both drinking-water quality and species conservation.

Bird Diversity at the Boundary: How Are Birds Responding to Housing Development in and Near National Forests and Other Protected Areas?

- ❖ Bird communities varied, depending on whether surveys were conducted within protected areas, on the boundary of those areas, or outside the areas.
  - Species that thrive in the presence of humans were a more abundant component of bird communities outside and on the boundary of protected areas.
- ❖ The density of housing outside protected areas can affect the composition of bird communities within the areas.
  - Surveys conducted in protected areas with higher home densities outside their boundaries tended to support lower proportions of species of conservation concern.
- ❖ Housing near protected areas can strain the biodiversity conservation benefits within the areas.
  - Without effective measures to manage the rates and locations of exurban development, the conservation benefit of protected areas will likely diminish.

Privately owned forest, grassland, and shrubland habitats are being used more intensively as housing and road development increases to support growing human populations. As reviewed in the 2010 RPA, such development has been particularly strong in proximity to national forests, wilderness areas, and national parks (Radeloff et al. 2010) because of the high natural amenity values that attract housing development on inholdings and adjacent private lands. This work found housing growth rates were greater in the West on a relative scale (figure 11-1a) and greater in the East on an absolute scale (figure 11-1b). Areas that showed both high relative and absolute rates of housing growth included the southern Appalachians; the foothills and front ranges near major metropolitan areas in Colorado, Utah, and Washington; montane habitats in the arid Southwest; and southern California.

Figure 11-1. (a) Relative and (b) absolute housing growth rates within a 50-kilometer (~31-mile) buffer around the outer boundary of each national forest, wilderness area, and national park during the period 1940 to 2000.



Source: Radeloff et al. (2010).

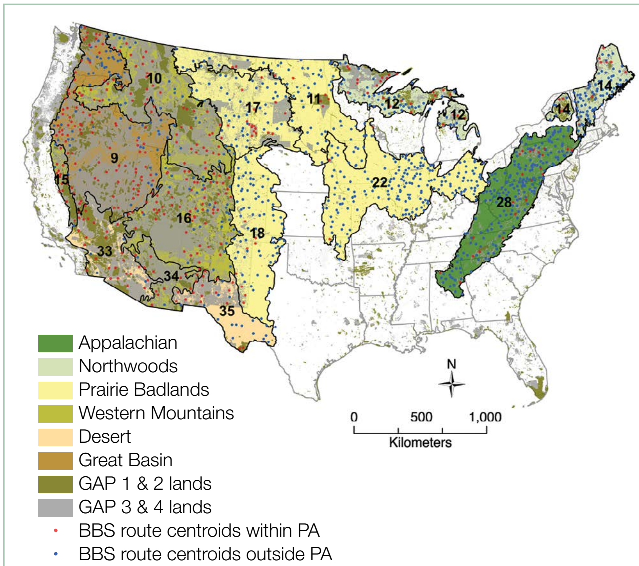
Expanding human populations and attendant land use changes have long been known to be primary factors driving changes in biological diversity (Foley et al. 2005; Sala et al. 2000). As private lands bear the growing burden of human-associated ecosystem stresses, public lands become increasingly important to the conservation of biological resources (Flather et al. 2009; Robles et al. 2008). Despite a common perception that public lands are critical to sustaining our biological heritage, little effort has been directed at understanding the proximity effects of private land use intensification on forest and rangeland biodiversity. In light of the perceived role that protected lands play in conserving biodiversity, Wood et al. (2014) investigated whether increased housing development in and near these lands had detectable effects on bird diversity.

Four primary data sources were used to address this question. First, measures of bird diversity were derived from the North American Breeding Bird Survey (BBS), an annual roadside survey that has been conducted since 1966 (Sauer et al. 2008). Second, protected lands data were obtained from the U.S. Geological Survey National Gap Analysis Program Protected Area Database (version 1.2, released in April 2011), which accounts for private inholdings within the administrative boundaries of public lands (http://gapanalysis.usgs.gov/padus/). Third, housing data were derived from the U.S. decennial census and processed at the partial block group level as described in Hammer et al. (2004). Finally, land use and land cover data were based on the 2001 National Land Cover Database data at 30-meter resolution (Homer et al. 2004). These data sources were linked via the digital BBS route paths, using a buffer set at the bird-detection distance specifications of the BBS—400 meters on either side of the route.

For each BBS route, we calculated the proportional abundance and the proportional richness of several bird groups as our response variables. These bird groups included synanthropes, land cover affiliates, and species of greatest conservation need. Synanthropes are native and nonnative species that are associated with human-modified environments during the breeding season. Land cover affiliates are species that are associated with the dominant natural land cover type of a BBS route, which included forest and woodland, grassland, or shrubland breeders. The species of greatest conservation need bird group was defined by combining the bird species identified as species of greatest conservation need in each individual State Wildlife Action Plan (Association of Fish and Wildlife Agencies 2011). Bird survey routes were classified as within protected areas (defined as more than 50 percent of the BBS route occurring within protected lands), at the boundary of protected areas (defined as between 0.1 percent and 49.5 percent of the BBS route occurring within protected lands), or on private lands outside protected areas (defined as 0 percent of the BBS route occurring within protected lands); these three categories were used as treatments for analyses. To address our main question, we quantified the effect of housing density within (i.e., associated with private inholdings), at the boundary, and outside protected areas on the proportional abundance and richness of synanthropes, land cover affiliates, and species of greatest conservation need.

Within the conterminous United States, we selected six regional study areas based on Bird Conservation Regions (BCRs) (figure 11-2) that are ecologically unique regions with similar climate, vegetation, land use, and avian communities and that were developed by the U.S. North American Bird Conservation Initiative Committee (2000). We excluded BCRs from our analysis when (1) a region had few protected areas, which caused an insufficient sample of routes within protected areas, and (2) a region had steep elevation gradients, so that routes within protected areas could not be matched ecologically with routes outside protected areas.

Figure 11-2. Distribution of 1,225 Breeding Bird Survey (BBS) centroids within and outside protected areas (PA) throughout six broad regions of the United States that were made up of aggregations of Bird Conservation Regions (BCRs) as follows: Appalachian Region (BCR 28); Northwoods Region (BCRs 12 and 14); Prairie Badlands Region (BCRs 11, 17, 18, and 22); Western Mountains Region (BCRs 10, 15, 16, and 34); Desert Region (BCRs 33 and 35); and Great Basin Region (BCR 9). The U.S. Geological Survey National Gap Analysis Program (GAP) Protected Area Database was used to define lands having permanent protection from conversion of natural land cover and being mandated to maintain a natural state (GAP 1); lands having permanent protection from conversion of natural land cover and being mandated to maintain a primarily natural state but permitting management practices that may degrade the quality of existing natural communities (GAP 2); an area having permanent protection from conversion of natural land cover for most of the area but permitting extractive uses (GAP 3); and lands having no known mandate to prevent conversion of natural habitat types to anthropogenic habitat types (GAP 4).



Sources: U.S. North American Bird Conservation Initiative Committee (2000); Wood et al. (2014).

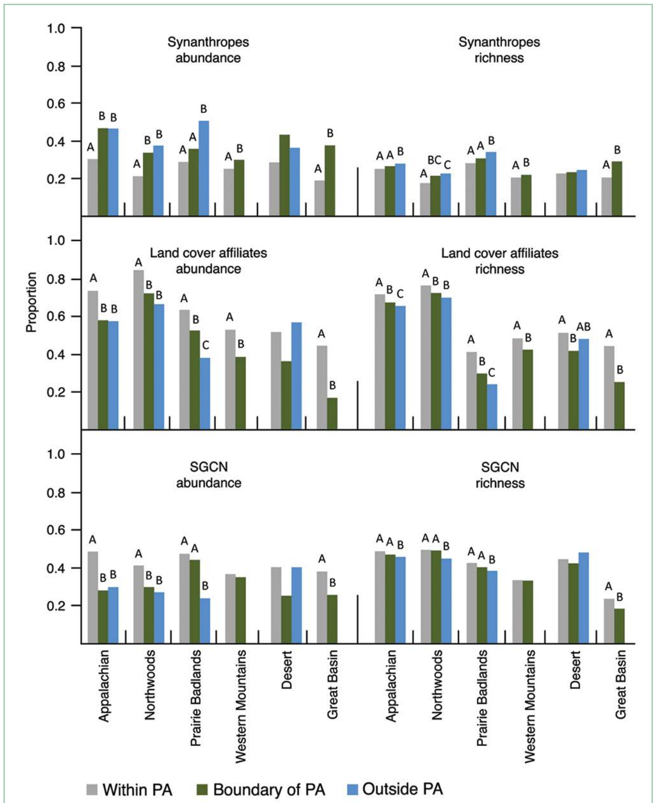
Results

Bird communities varied considerably among treatments in all BCRs except for the Desert and Western Mountains, where they were similar. The avian communities within protected areas were largely different from communities on private lands outside of protected areas and to a lesser extent from those communities along the protected-area boundaries, where the differences were less pronounced. The proportional abundance and proportional richness of synanthropes were significantly higher outside protected areas or at the boundaries than within the areas (figure 11-3). The only exception to this pattern was the Desert Region, where both the proportional abundance and proportional richness of synanthropes were similar among treatments (figure 11-3). Although the differences were qualitatively apparent, sample sizes were small for the Desert Region and, thus, affected our ability to detect differences among treatments.

Conversely, the proportional abundance and proportional richness of land cover affiliates and species of greatest conservation need were significantly higher within protected areas than either at the boundaries of those areas or outside the areas (figure 11-3). This pattern was true for all bird conservation regions, except in the Western Mountains and Desert Regions, where the proportional abundance and richness of these bird groups were similar among our housing treatments, particularly among species of greatest conservation need (figure 11-3).

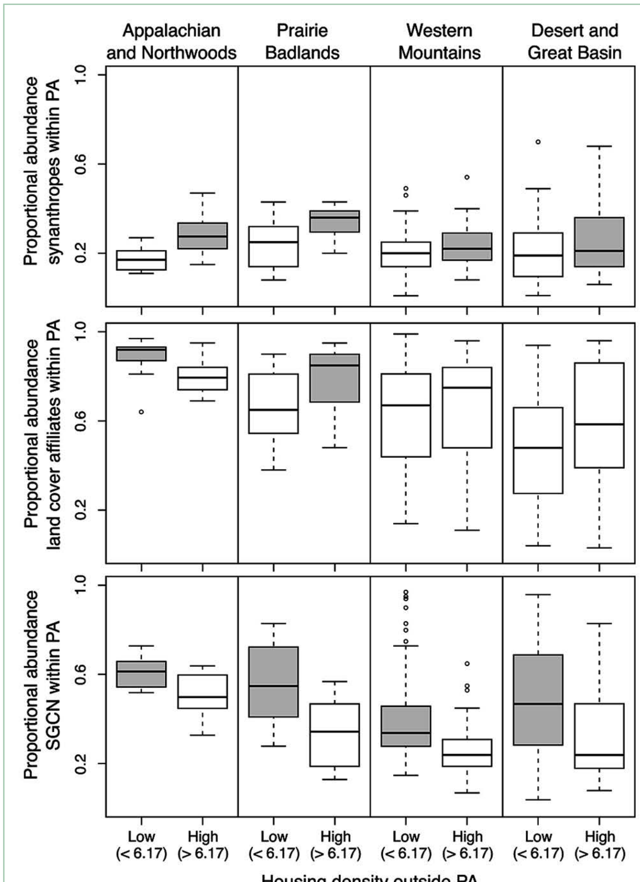
Although housing within protected areas, in general, was the best supported variable influencing protected-area bird groups, in all regions, high-intensity housing outside protected areas was associated with higher proportional abundance of synanthropes within protected areas in all regions (figure 11-4). In contrast, high-intensity housing outside protected areas resulted in lower proportional abundance of species of greatest conservation need within protected areas (figure 11-4). We observed similar relationships for land cover affiliates in the Appalachian and Northwoods Regions (figure 11-4). In the Prairie Badlands

Figure 11-3. Mean proportional abundance and richness response of synanthropes, natural land cover affiliates, and species of greatest conservation need (SGCN). The three treatment types are (1) within protected areas (PA), (2) on the boundary of PA, and (3) outside PA. Histograms sharing the same letter (A, B, C) indicate the response does not differ significantly among treatments. Histogram bar sets with no letters indicate no significant response difference among any treatments.



Source: Wood et al. (2014).

Figure 11-4. Box plot summaries of the proportional abundance of synanthropes, natural land cover affiliates, and species of greatest conservation need (SGCN) within protected areas (PA) of four regional areas. Housing outside PA was categorized as low (< 6.17) or high (> 6.17) based on the definition of the wildland urban interface (6.17 houses per square kilometer or 1 house per 40 acres). Boxes shaded in gray indicate that the proportional abundance of a protected-area bird group was significantly different between housing-intensity levels.



Source: Wood et al. (2014).

Region, however, land cover affiliates within protected areas unexpectedly were proportionally more abundant when housing intensity was high on private lands outside the areas. We detected similar patterns for the association between the proportional richness within protected areas and high-intensity housing outside the areas, but the differences were weaker than proportional abundance.

The positive benefits observed among land cover affiliates within protected areas of higher density housing outside protected areas may be an artifact of our sample; however, the results also may be a real biological response. This pattern has been described as an "oasis effect" caused by the presence of novel habitats and food/water supplementation associated with housing development (Lerman and Warren 2011; Robb et al. 2008), particularly when it occurs in harsh environments (Bock et al. 2008). Our findings of the positive association between richness of land cover affiliates within protected areas and housing outside protected areas in the central prairies and western mountains of the United States are consistent with this oasis effect. We should also note, however, that this effect may be short lived with continued increases in housing eventually having a negative effect on bird communities, suggesting that there may be housing density thresholds that, when exceeded, can cause avian community structure and abundance to suffer (Pidgeon et al. 2014; Suarez-Rubio et al. 2013).

Implications

Our results suggest that housing development both within and at the boundary of protected areas impacts avian community structure. Housing on private inholdings or outside protected areas was often positively associated with the proportional abundance and proportional richness of synanthropic species and negatively associated with the proportional abundance and proportional richness of land cover affiliates and species identified by State agencies to be of conservation concern. Our results suggest that protected areas of the United States are successful at maintaining natural land cover and harboring avian communities of conservation concern compared with surrounding private lands. Thus, protected areas of the United States may serve as sources for regional avian metapopulations (Robinson et al. 1995).

Our results, however, also support findings that housing development near protected areas has created strains on protected areas themselves. A novel finding from our study was that, in addition to the pressure of private land development on biodiversity outside protected areas, this same development pressure threatens biodiversity within protected areas. Synanthropic species were proportionately more abundant (and more species rich) within protected areas when housing densities on private lands at the protected-area boundary were higher. In a similar way, the proportional abundance of species of conservation concern was consistently lower when housing density was higher at the boundary of protected areas. Although housing growth has recently slowed compared with the rapid growth in the 1970s (Radeloff et al. 2010), our findings suggest that even marginal increases of housing growth on the boundary of protected areas could degrade avian communities within the protected areas. Without effective measures to manage the rates and locations of exurban development, the conservation benefit of protected areas will likely diminish.

Climate Change Effects on Wildlife Habitat in the RPA Rocky Mountain Region

❖ An index of climate-induced stress to terrestrial wildlife habitat indicates that stress in the RPA Rocky Mountain Region is geographically varied.

- Areas of low climate stress to wildlife habitat occur in southern Arizona and New Mexico, and areas of high climate stress are associated with the desert and semidesert ecoregions of Arizona, Idaho, and Nevada and the temperate steppe ecoregion of Colorado and Wyoming.

❖ Stress to wildlife habitats is affected by wildfire and fire management.

- Strategies to actively suppress fires result in higher stress among the Intermountain semidesert and desert ecoregions, whereas strategies directed at not suppressing fires result in higher stress among the steppe-coniferous and open woodland ecoregions.

❖ These varied patterns indicate that there will be no general strategy for addressing climate change stress to terrestrial wildlife habitats.

- Strategies will need to be tailored to the circumstances, including fire history and changing climate, that characterize various landscapes.

The RPA Rocky Mountain Region (see figure 2-1 in chapter 2) is a mosaic of public and private land. Federal (national forests, national parks and monuments, wildlife refuges), State, and local governments manage 75 percent of this region. Any management or policy response to climate change directed at conserving wildlife resources will need to be integrated across administrative boundaries if landscape-scale phenomena like wildlife species movement via corridors are to be adequately addressed. A regionally consistent information base facilitates the collaboration necessary for managing wildlife species and their habitat. In the 2010 RPA, we used a nationally consistent approach to assess the impact of climate change on wildlife, the Terrestrial Climate Stress Index (TCSI) (Joyce et al. 2008). That analysis identified areas of relatively high and low habitat stress across the conterminous United States and concluded that locations where current conservation issues were most pronounced tended not to overlap with the location of high future stress associated with climate change. This situation potentially complicates efforts of managers to prioritize wildlife conservation actions. That analysis did not explicitly incorporate wildfire as an important driver of change to wildlife habitat. Here, we focus on climate change and wildfire effects on the RPA Rocky Mountain Region, a landscape on which fire greatly influences the distribution of vegetation types.

Within the RPA Rocky Mountain Region are found the driest areas (Southwest) and some of the coldest areas (high-elevation Rocky Mountains) of the United States. Only 20 percent of the region is forest land, and the remaining habitat ranges from woodland and shrubland types to grasslands grading into desert vegetation. These habitats are influenced by climate and the elevational gradients in mountainous terrain. Climate change will affect wildlife directly through temperature and moisture changes and indirectly by altering habitat availability and quality as driven by natural disturbances and land use change. This region is also noted for the influence of fire on vegetation distribution; fire regimes range from frequent surface fires to crown fires that occur infrequently. Wildfire area has increased in size annually and is projected to continue to increase further. This disturbance is of concern because it can change a landscape in a short period of time, by comparison with gradual changes in mean climate. The United States has a long history of suppressing wildfires. We explore how changing wildfire regimes and climate change may interact to affect habitat.

Terrestrial Climate Stress Index

The TCSI is the sum of three separate metrics that reflect changes in (1) climate regime (temperature and precipitation), (2) biomass production, and (3) vegetation type area. We used a historical period of 1950 to 1999 to define baseline conditions that, when compared with measures during a future period of 2050 to 2099, defined the magnitude of change for each metric during a 100-year period. The geographic extent of our analysis is the 12 States within the RPA Rocky Mountain Region. In the 2010 RPA, the spatial scale of analysis was a grid cell of nearly 2,500 square kilometers (km^2) (~954 square miles [mi^2]]. In this analysis, the scale is finer—an equal-area hexagon grid with each cell approximating an area of 69 km^2 (~27 mi^2).

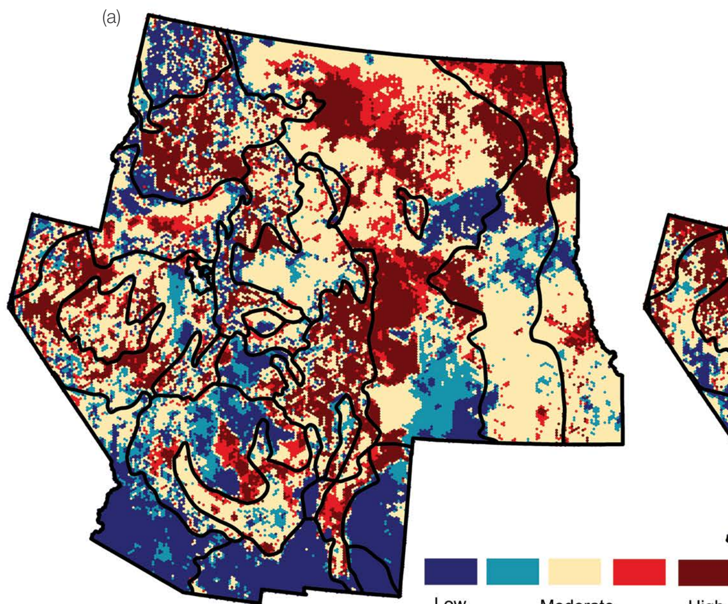
We used climate projections from three general circulation models (GCMs) (MIROC2medres, UKMO HadCM3, and CSIRO-MK3.0) forced by three 4th Intergovernmental Panel on Climate Change Assessment scenarios: A1B, A2, and B1 (Bachelet et al. 2014). Future projections of biomass and shifts in vegetation types were obtained from the dynamic global vegetation model MC2—a model that projects vegetation response to climate change and disturbance (fire, drought) based on biogeographic and biogeochemical processes in ecosystems (Bachelet et al. 2014). The MC2 model, which is a revision of the MC1 model that was used in the 2010 RPA, is designed to provide a more accurate representation of fire and vegetation dynamics (Bachelet et al. 2014). Within the MC2 model, the balance between trees and grass is determined by simulated competition between these two life forms, as mediated by fire. At the prairie-forest boundary of the eastern Great Plains, frequent surface wildfires historically have maintained grassland types. Under fire suppression and climate change, MC2 projects woody expansion onto the Great Plains (Bachelet et al. 2014). Fire suppression is assumed to be highly effective and only catastrophic fires can escape (Bachelet et al. 2014). Examples of such large fires can occur in western mountainous areas when warmer, drier conditions result in the drying of abundant fuels.

Regional High- and Low-Stress Areas

The TCSI can be used to identify areas of high and low habitat stress across the Rocky Mountain region (figure 11-5), where high stress is defined as the top 20 percent highest scoring grids and low stress is the 20 percent grids with the lowest TCSI scores. We show the ensemble TCSI score for the A2 scenario (estimated as the mean across the three climate models) and for each of the two fire scenarios (suppression and no suppression of wildfire). The areas of highest stress, as estimated by the index, are represented in red in figure 11-5. The influence of topography can be seen across the mountainous West as high-stress areas transition to low-stress areas in a relatively short distance (a matter of a few grid cells) in response to steep-elevation gradients characterizing these montane systems. Across the plains, areas of high or low stress are more expansive, reflecting a more homogenous landscape.

Common areas of low stress across both fire scenarios are projected to occur in southern Arizona and New Mexico, the plateau region of northeastern Arizona and southeastern Utah, and the high plains of southeastern Colorado and western Kansas. Future shifts in climate (temperature and precipitation) are greatest in the southwest part of the region (not shown), because temperature is expected to rise and precipitation is expected to decline. In the northern part of the Rocky Mountain Region, the projection is for temperature to rise and precipitation to increase slightly. Even though the greatest changes in

Figure 11-5. Terrestrial Climate Stress Index (TCSI) for the RPA Rocky Mountain Region under the A2 scenario and three climate models in which (a) fire is not suppressed and (b) fire is suppressed. High stress is defined as those grid cells with TCSI scores in the top 20 percent; low stress is defined as scores in the lower 20 percent. Ecoregion provinces (thick black lines) after Bailey (1995).



RPA = Resources Planning Act.

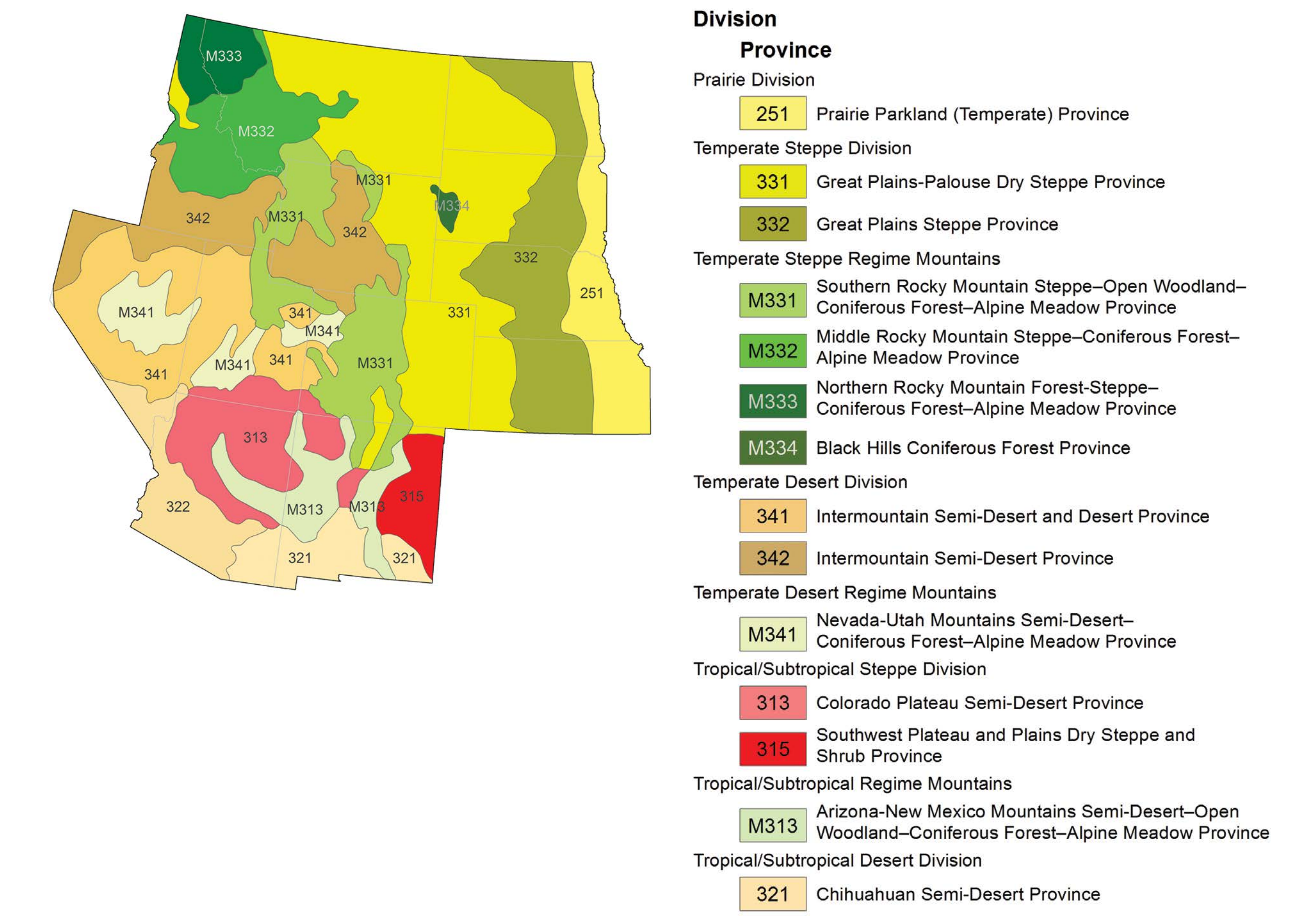
climate are projected to occur in the Southwest, the occurrence of high-stress areas is also influenced by future changes in biomass production and vegetation types as mediated by disturbances such as fire. Future biomass production changes and vegetation type shifts are greater in central to northern parts of the region than in the Southwest; as a consequence, these central to northern areas are projected to have higher stress (figure 11-5).

Ecoregional Pattern of High-Stress Areas in the RPA Rocky Mountain Region

The regional expectation of high stress is defined by the high-stress cut point used to quantify the degree of relative climate stress—20 percent. We explored the percent of high-stress areas within each ecoregion province in the RPA Rocky Mountain Region (figure 11-6). Only one province (the Great Plains-Palouse Dry Steppe) shows a pattern of high-stress area that approximates (within ± 5 percent) the regional 20-percent expectation under both suppression and no-suppression fire scenarios (figure 11-7). For all other provinces, departure from the regional expected value is greatly influenced by the ecosystem geography of the province.

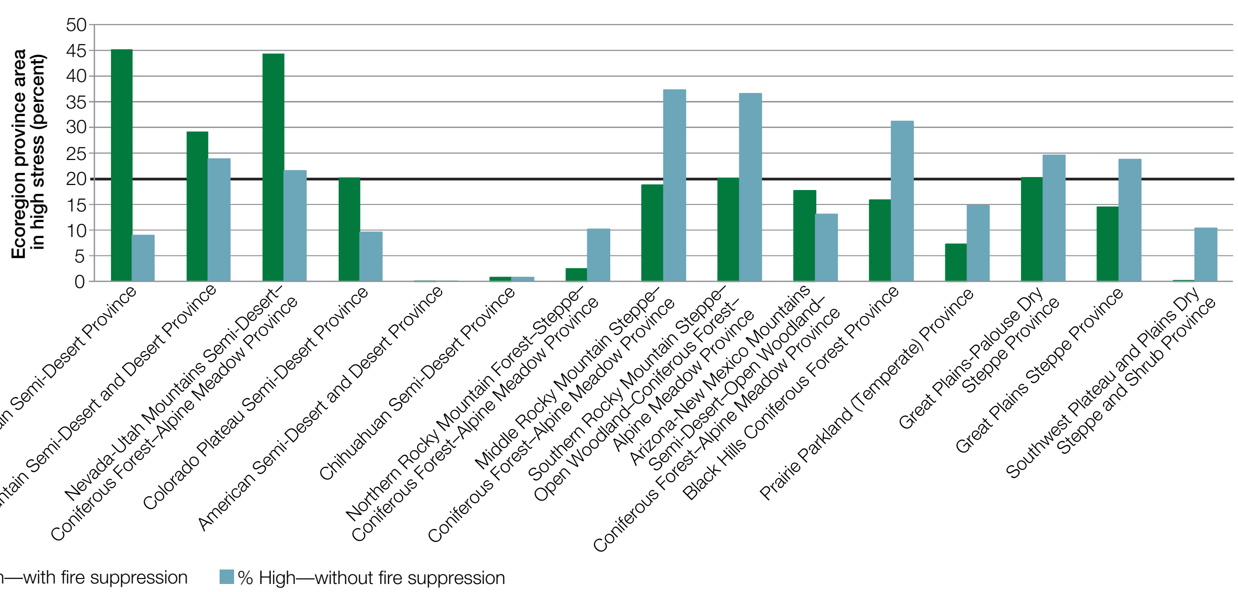
One measure of how sensitive our estimates of climate stress are to the wildfire scenarios is captured by the difference in the percent of high-stress areas within a province under suppression and no-suppression fire scenarios (figure 11-7). Under this definition of sensitivity, the Intermountain Semi-Desert, Intermountain Semi-Desert and Desert, and the Nevada-Utah Mountains Semi-Desert–Coniferous Forest–Alpine Meadow provinces all showed notably (greater than ± 15-percent difference between fire scenarios) greater high-stress areas with fire suppression when compared with the no-suppression scenario. This higher stress associated with fire suppression was caused primarily by complete turnover in historical vegetation types when temperate forest and woodlands replaced temperate shrublands. Conversely, forested provinces in the mountainous temperate steppe (i.e., Middle Rocky Mountain Steppe–Coniferous Forest–Alpine Meadow, Southern Rocky Mountain Steppe–Open Woodland–Coniferous Forest–Alpine Meadow, and Black Hills Coniferous Forest) showed that high climate stress was more prominent on the landscape without fire suppression when compared with the suppression scenario. Although some shifts occurred among vegetation types, when fire is not suppressed, changes in climate and increased wildfire result in biomass declines in the mountain provinces. Fire suppression affects habitat quality, particularly when woody encroachment occurs. Bachelet et al. (2014) report that fire suppression in MC2 results tends to increase the woody component of arid western ecosystems.

Figure 11-6. Baileyecoregion divisions and provinces in the RPA Rocky Mountain Region.



RPA = Resources Planning Act.
Source: Bailey (1995).

Figure 11-7. Percent of Bailey ecoregion provinces classified as high climate stress according to Terrestrial Climate Stress Index based on the A2 emissions scenario. Paired bars compare estimates with and without fire suppression. Bar heights reflect the ensemble mean across three climate models. Bolded horizontal line defines the regionwide 20 percent expectation.



Source: Ecoregions defined by Bailey (1995).

Implications

Identification of areas of relatively high and low habitat stress can provide managers and planners with information on the potential for climate-induced stress to wildlife habitats within regions and States. Spatially explicit information on habitat stress attributed to climate change can be integrated with the location of current conservation issues to evaluate the coincidence of future climate change threats with important wildlife conservation issues. These results suggest that the historic influence of fire on vegetation types is important to consider in projecting the future effects of climate change on wildlife habitat. For situations in which a particular fire regime has been a major influence in sustaining a vegetation type, such as surface fires and grasslands, the effect of a changing climate and a changing fire regime will have different responses depending on the management of wildfire. These findings indicate no general strategy will be effective for addressing climate change stress to terrestrial wildlife habitats. Rather, strategies will need to be tailored to the circumstances that characterize various landscapes (as reflected in ecoregional provinces here). As in our previous analysis, these results also indicate that locations where current conservation issues were most pronounced (e.g., concentrations of at-risk biodiversity; see figure 11-9) tend not to overlap with the location of high future stress associated with climate change. If our model is an accurate reflection of the geography of stress to wildlife communities, then these differences will further complicate the efforts of managers to prioritize wildlife conservation actions.

We highlight four limitations that are important to keep in mind when interpreting the implications of our analysis. First, our index was designed to capture the projected shifts in natural vegetation in response to climate change, but it did not incorporate land use as a factor affecting wildlife habitat availability. Second, invasive plant species are expected to affect broad areas under climate change (Walther et al. 2009), but we do not yet know how to incorporate their effect on wildlife habitat quality. Third, the vegetation dynamics model used here does not simulate wetland vegetation types that serve as an important terrestrial-aquatic transition, that support a high biological diversity, and that may be particularly vulnerable to climate change effects in drier ecosystems (Johnson et al. 2005; Perry et al. 2012). Fourth, our analysis bracketed potential future climates based on three scenarios: (1) B1, with the lowest future emissions; (2) A2, with the second highest future emissions used in the IPCC (2007); and (3) A1B, with a middle future projection. In addition, for each scenario, we used three GCMs with different sensitivities to atmospheric carbon dioxide and implemented two management scenarios (fire suppression or no fire suppression). Additional scenarios with different emission levels would fill in the range of our analysis and provide additional detail on the behavior of the TCSI.

Trends and Geography of At-Risk Biodiversity

- ❖ The rate of listing Federal threatened and endangered species is accelerating in response to efforts to process listing decisions on the backlog of candidate and proposed species by 2018.
- ❖ Areas of listed species concentration have become refined, but they still emphasize similar areas of geographic concentration.
    - New occurrence data for listed species revealed that areas of concentration in Hawaii, the southern Appalachians, peninsular Florida, coastal areas, and the arid Southwest have remained largely unchanged; an emerging area of concentration is indicated in the interior highlands and plateau region of southern Illinois, Indiana, and Missouri; northern Arkansas; and western Kentucky.

As the number of species considered to be rare increases, the likelihood of species extinction also increases. Demographic and environmental events, such as failure to find a mate, disease, disturbance, habitat loss, and climate change, interact to increase extinction risk as populations become smaller. Because important ecosystem functions (e.g., productivity, nutrient cycling, or resilience) can be degraded with the loss of species, there is concern that the goods and services humans derive from ecological systems will become diminished as more species become rare. For this reason, the RPA Assessment has long tracked national trends in the number of species that are formally listed as threatened and endangered and has also tracked the geographic patterns associated with where listed species occurrence is concentrated as indicators of ecosystem well-being.

A change in the rate of listing and a new analysis of listed species occurrence are the focus of this section. First, a recent settlement agreement was reached between the U.S. Fish and Wildlife Service (FWS) and the Center for Biological Diversity and Wild Earth Guardians (U.S. Court of Appeals for the District of Columbia 2013) to process the backlog of species awaiting listing decisions under the Endangered Species Act (ESA). This agreement will result in a more rapid pace of species additions to the list of those determined to be threatened or endangered than has been observed in the recent past. Upwards of 750 species will be considered for listing by 2018. Second, past RPA Assessments have geographically depicted areas of species concentration based on county-level occurrence data. Because counties vary greatly in size, identification of species concentration hotspots has been confounded by area effects. It has long been known that species accumulate with area nonlinearly (Flather 1996) and the accumulation rate varies among ecosystems (Rosenzweig 1995). Therefore, it is difficult to control for these area effects in a manner that leads to a general, unambiguous county ranking of increasing species concentration (Joppa et al. 2013). For this RPA Update, we analyzed the occurrence records of formally listed species on an equal-area grid across the United States, thus removing the area effects that have confounded past efforts.

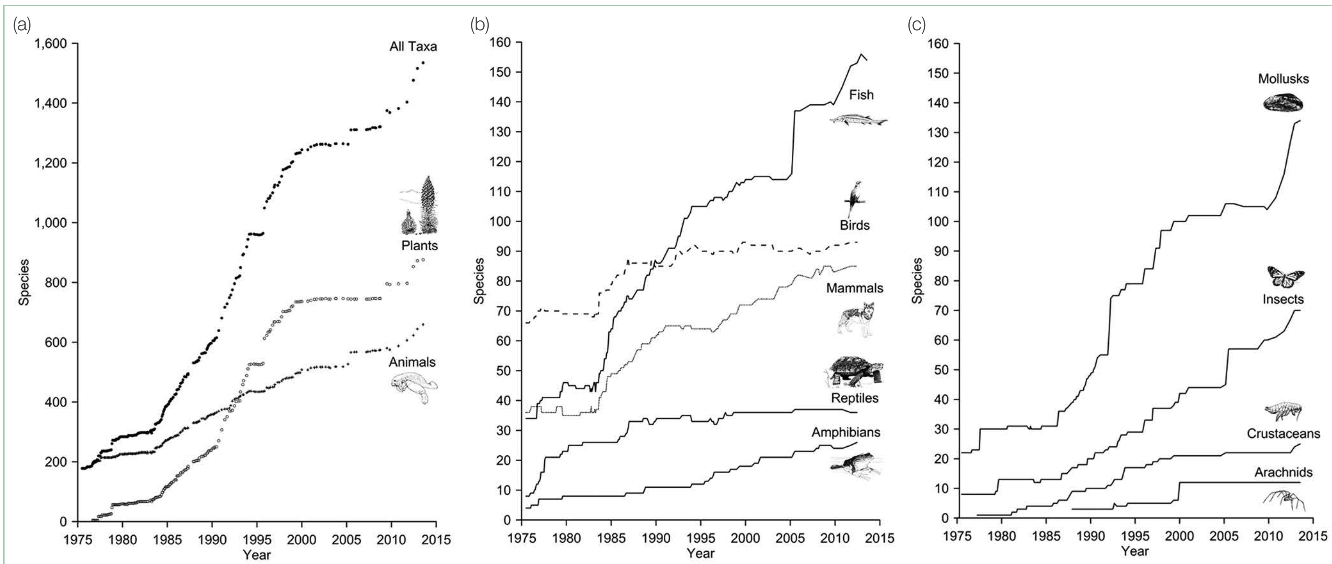
Recent trends in species listings and their geographic occurrence were derived from two existing data sources. First, trends in the number of species by broad taxonomic groups were compiled from the FWS's *Endangered Species Bulletin* and online resources that keep the current count of U.S. threatened and endangered species, subspecies, and distinct population segments (http://ecos.fws.gov/ecp0/reports/box-score-report). These data enabled us to document the cumulative number of listed species by major taxonomic groups from July 1, 1976, through July 14, 2014. Second, NatureServe's Central databases (NatureServe 2014) were used to compile lists of threatened and endangered species and species considered to be imperiled, according to NatureServe's global conservation status ranks (http://www.natureserve.org/explorer/ranking.htm). These lists were compiled on a systematic equal-area grid of 647.5 km^2 (250 mi^2) using contemporary (post-1970) occurrence records. Imperiled species include those determined to be critically imperiled (G1) or imperiled (G2)—a set that has been shown to be a less biased reflection of the true number of species of conservation concern than the number formally listed under ESA—the latter being affected by budget constraints, bureaucratic processes, and variation in listing policy over time (Master et al. 2000). Imperiled species are also thought to define the pool from which new ESA listings will be drawn and their geographic occurrence is thought to presage where new hotspots may emerge in the future (Evans et al. 2016). Maps of ESA-listed species or imperiled species were generated by classifying species counts within grid cells into approximate percentile classes to highlight those cells with relatively high species counts.

Results

As of July 14, 2014, 1,535 species were formally listed as threatened or endangered within the United States. That total represents a net gain of 167 species since the 2010 RPA (figure 11-8). The increase was distributed equally among animals (+84) and plants (+83). Among animal groups, there were notable increases in mollusks (+30), fish (+15), and insects (+10). The listing rate has increased to an average of 45 species per year—nearly doubling the recent average listing rate reported in the 2010 RPA (Flather et al. 2013). This increase is attributed, in large part, to the focused efforts of the FWS to make listing decisions about the more than 700 species named in the settlement agreement. Processing this pool of species by 2018 will likely result in even greater listing rate increases in the near term.

The distribution of ESA-listed species based on county occurrence data has been shown to vary geographically, with prominent hotspots of threatened and endangered species occurring in Hawaii, the southern Appalachians, peninsular Florida, coastal areas, and the arid Southwest that have remained largely unchanged since the late 1990s (Flather et al. 2013). The

Figure 11-8. Cumulative number of species listed as threatened or endangered (accounting for delistings) from July 1, 1976, through July 14, 2014, for (a) plants and animals, (b) vertebrate groups, and (c) invertebrate groups.



Source: Data from USFWS (2014).

higher resolution associated with the systematic grid data did refine the areas of listed species concentration (figure 11-9), but, broadly speaking, the regions supporting relatively high numbers of species have remained surprisingly consistent with earlier geographic descriptions, particularly among the Eastern States with smaller counties. Notable differences with county-based maps include a general de-emphasis of areas in the arid Southwest and the emergence of listed species concentrations associated with the interior highlands and plateau region of southern Missouri, northern Arkansas, western Kentucky, and southern Illinois and Indiana. It is also noteworthy that many regions outside the areas of concentration contain very few listed species. Overall, 54 percent of U.S. lands have no occurrence records of listed species.

Given the diversity of land form and land cover in areas supporting high numbers of listed species, it is not surprising that taxonomic composition varies among hotspots (figure 11-10). Since the early 1990s, **plants** have outnumbered animal species listed (figure 11-8a), and they are concentrated in areas characterized by high levels of endemism—species that uniquely occur in a restricted geographic area—including Hawaii, the Mediterranean climates of California, and the plant communities associated with the Florida peninsula inland scrub. Among animals, **invertebrates** dominate the pool of listed species in the interior highland ecoregions. More species of freshwater and anadromous **fish** receive ESA protections than any other vertebrate group, and they tend to concentrate in the arid Southwest, the Pacific Northwest, and the southern Appalachians. Herptiles (**amphibians** and **reptiles**) have fewer listed species than other vertebrate groups (figure 11-8b) and never attain large counts in any locale; however, they are prominently represented in coastal areas of the Southeast, as are **birds** and **mammals**.

Where are new areas of projected species concentration likely to emerge in the future? The recent settlement agreement (U.S. Court of Appeals for the District of Columbia 2013) makes this question particularly relevant. A mapping of occurrence among species identified in the settlement agreement (figure 11-11a) indicates that species likely to receive protections under ESA in the near term will both emphasize existing areas of concentration (e.g., the southern Appalachians) and also lead to the potential emergence of new areas of concentration (e.g., the southern Great Basin and the Ouachita and Boston Mountains of western Arkansas and eastern Oklahoma). We can get a sense of whether new areas of concentration will emerge in the longer term by mapping the occurrence of imperiled species that are neither formally listed under ESA nor part of the settlement agreement (figure 11-11b). Although not all species currently classified as imperiled are necessarily at risk of extinction (and therefore may not warrant protection under ESA), new listings under ESA will likely come from the pool of species considered imperiled by NatureServe, based on recent comparisons between listed and imperiled species (see Evans et al. 2016). The southwestern Basin (southern Arizona) and Range (New Mexico and western Texas) and portions of the Colorado Plateau (southeastern Utah) could emerge as new hotspots of listed species in the more distant future.

Figure 11-9. Geographic distribution of species formally listed as threatened or endangered under the Endangered Species Act. Data are derived from the National Heritage Programs as maintained by USDI FWS (2014) and mapped onto a systematic equal-area grid (647.5 square kilometers [250 square miles]) of the United States. Alaska and Hawaii are displayed on a different scale for presentation purposes.

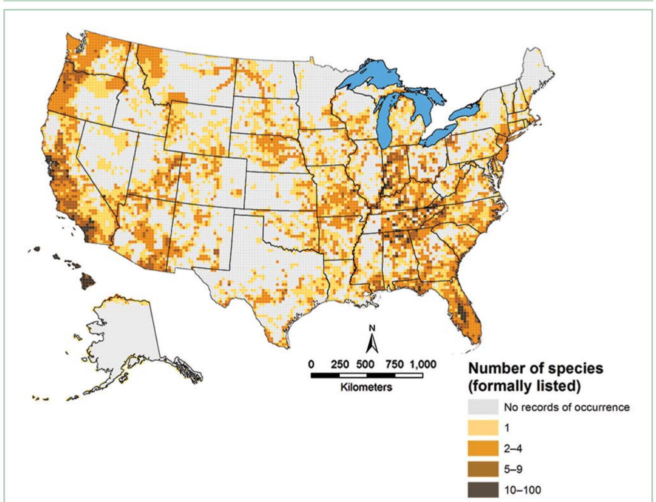


Figure 11-10. Variation in the taxonomic composition of species occurring in hotspots—areas of concentration of listed species. Hotspot boundaries are based on or are modifications of Bailey Ecoregions. Data are derived from the National Heritage Programs as maintained by NatureServe (2014) and mapped onto a systematic equal-area grid (647.5 square kilometers [250 square miles]) of the United States. Hawaii is displayed on a different scale for presentation purposes and Alaska is not displayed because it lacks hotspots.

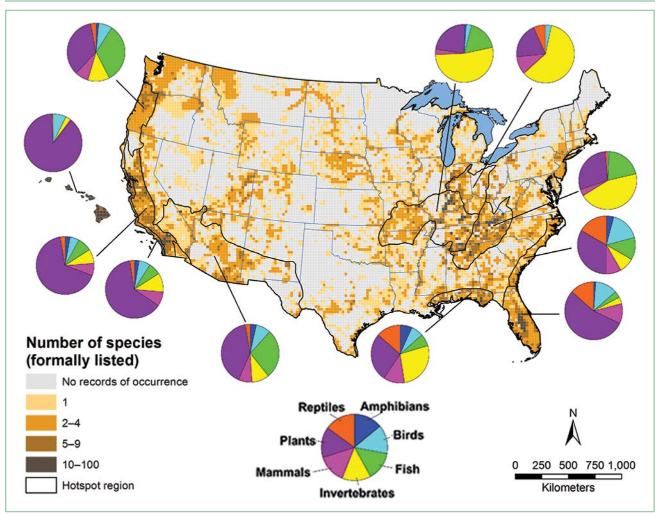
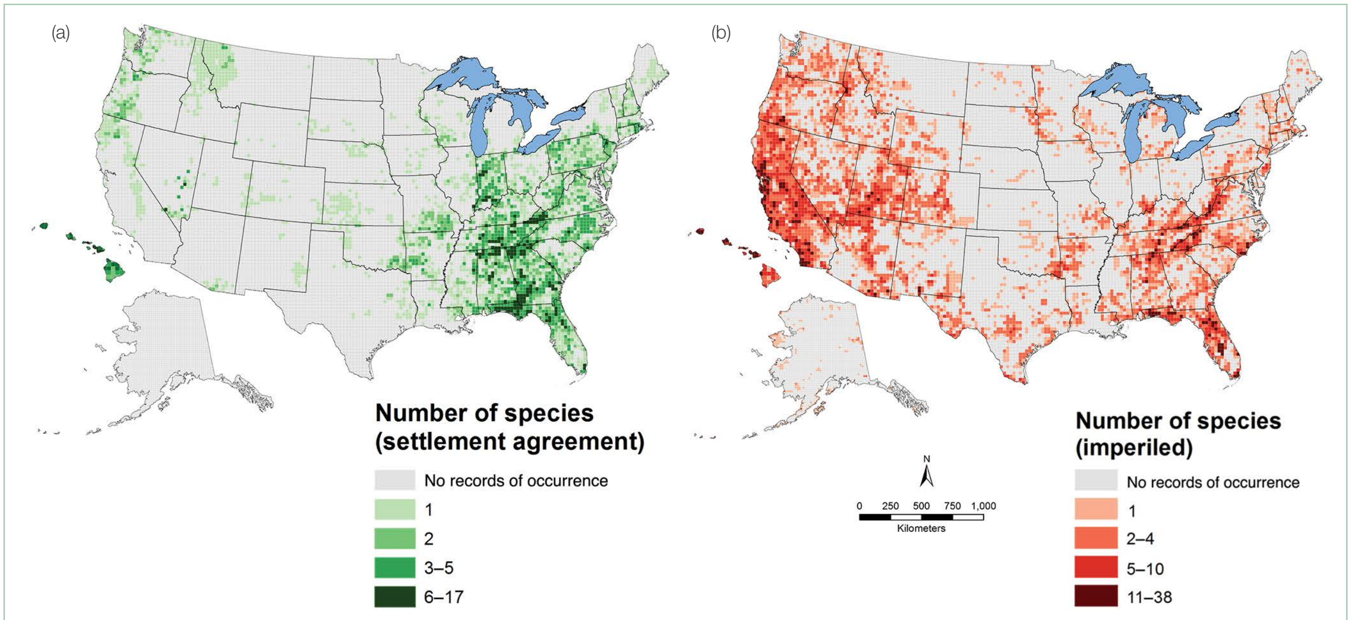


Figure 11-11. Geographic distribution of species (a) involved in the settlement agreement and (b) critically imperiled (G1 ranking) and imperiled (G2 ranking) that are not currently listed as threatened or endangered or being considered for listing under the settlement agreement. Data are derived from the National Heritage Programs as maintained by NatureServe (2014) and mapped onto a systematic equal-area grid (647.5 square kilometers [250 square miles]) of the United States. Alaska and Hawaii are displayed on a different scale for presentation purposes.



Implications

The geographic occurrence of listed and imperiled species across the United States is far from random, with available data showing that species of conservation concern concentrate in distinct regions of the country (figures 11-8 to 11-11). Although the conservation implications of these endangerment hotspots have been discussed in the past (see Dobson et al. 1997; Flather et al. 1998), conservation science has struggled with how to use this information to move beyond the species-by-species conservation strategies that have thus far dominated conservation efforts. One approach that has recently been formalized in the Forest Service Planning Rule that governs biodiversity conservation on lands it administers is based on the notion of coarse-filter conservation strategies (USDA Forest Service 2012c).

In general, coarse filters reflect higher level processes and patterns and are based on attributes that can be measured easily and inexpensively, relying on existing inventories (e.g., remotely sensed imagery, digital elevation models, weather station data) and describing broad characteristics of the environment. As such, coarse filters are but another kind of surrogate that attempts to identify the environmental cues —the amounts and spatial distribution of biophysical factors—that allow for inference to the state of most species inhabiting a particular ecosystem.

Although the coarse-filter methodology is intuitively appealing, the approach has been tested only rarely (Groves 2003) and with equivocal conclusions. The performance of coarse filters has been found to vary among the types of species composing the assemblage—working well for small-bodied, abundant species but failing to capture the habitat needs for large-bodied or rare species (Noon et al. 2003). This latter group often comprises the set of species that are of conservation concern, including those formally listed as threatened or endangered.

The failure of coarse filters to reliably predict the presence and persistence of rare species does not invalidate its use as a strategy to conserve at-risk species. Coarse-filter conservation strategies may be best thought of as conserving important biophysical templates that drive the overall pattern of biological diversity or concentrations of rare species (Anderson and Ferree 2010; Beier and Brost 2010) across broad landscapes. Thus, the occurrence pattern of threatened and endangered species (figure 11-9) or at-risk species in general (figure 11-11), coupled with information on their taxonomy and life histories, the portfolio of threats that triggered their listing or contributed to their rarity, and key biophysical attributes (e.g., climate, geophysical setting, vegetation, and land use) associated with their occurrence, could help define key ecosystem units that could be the focus of conservation efforts. Evidence in the literature suggests that such a strategy may have merit. The approach has been used to define "environmental domains" within broad geographic regions that represent key drivers of biodiversity and may perform particularly well defining domains that cover the occurrence of rare species (Trakhtenbrot and Kadmon 2005, 2006).

Although the idea of using data on species occurrence and the biophysical characteristics of the areas where they occur to define the geographic bounds for ecosystem planning is relatively new, aspects of this approach are starting to be implemented. The FWS has initiated an ecosystem-based approach for 48 species on the island of Kauai in the Hawaiian archipelago. These 48 species have been used to define species groups based on broad climate and physiography, shared threats, and shared critical habitat under the premise that focusing management and restoration efforts within these broad ecosystem types will be more effective at recovering species than would a species-specific strategy (USDI FWS 2010). Such thinking is also behind a push to consider species conservation across large multiple-use, multiowner landscapes under what has been called "collaborative adaptive management" (Scarlett et al. 2013). Moreover, the Forest Service has recently used the conceptual underpinnings of the coarse-filter approach to motivate landscape-scale conservation as reflected in the agency's efforts to restore the longleaf pine ecosystem and its associated species of conservation concern across the Southeastern United States (Evans et al. 2016).

Coarse filters and landscape-level conservation appear to hold much promise for the management of at-risk species (e.g., Ricketts et al. 2005; Wyman 2010). We need to acknowledge, however, that they currently represent conservation hypotheses for how species conservation may be accomplished more efficiently. Conservation practitioners and researchers alike are in need of a broader set of case studies from which to document and judge what can be gained from management with a more systems-oriented focus on the conservation of at-risk biodiversity.

At-Risk Aquatic Species and Drinking-Water Protection

❖ Two-thirds of watersheds that support a high proportion of at-risk aquatic biodiversity have a collateral stake in drinking-water protection.

- These watersheds are concentrated in the Southeast and the Mediterranean climates of California.

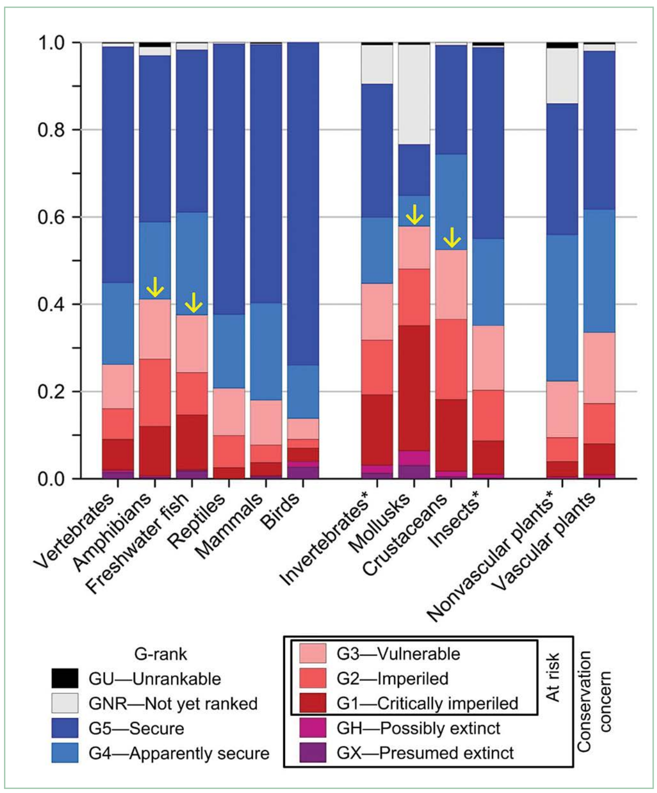
❖ Joint-benefit watersheds that also have low levels of land protection and high rates of urbanization can serve as targets for land use and conservation planning.

- Explicit identification of watersheds with joint benefits has the potential to leverage scarce funding resources and facilitate action among traditionally contentious stakeholders.

One main finding from the 2010 RPA (Loftus and Flather 2012) and of this RPA Update is the disproportionately high number of species considered to be of conservation concern among those that are primarily associated with aquatic ecosystems. Among aquatic animal groups (amphibians, freshwater fish, mollusks, and crustaceans), the proportion of species of conservation concern always exceeds the average observed across all vertebrates and invertebrates (figure 11-12). This information, coupled with the occurrence pattern of these species, has long been used to highlight, in a geographically explicit manner, areas that should receive conservation planning focus (Flather et al. 2009; Scott et al. 1987).

Concurrent with efforts to conserve lands for biodiversity protection are renewed efforts to conserve lands for drinking-water protection (Wickham et al. 2011). These efforts are motivated by amendments to the Safe Drinking Water Act that shifts focus from monitoring to detect contaminants to protecting source water (U.S. EPA 1997). Source water protection recognizes that the quality of untreated water entering a drinking-water treatment plant could be translated into (1) risks associated with waterborne pathogens, (2) pollutant levels initially entering the

Figure 11-12. The proportion of species occurring in the United States assigned to each NatureServe conservation status rank. Asterisks (*) indicate those taxonomic groups with uncertain proportions (many species are awaiting conservation assessments). Yellow arrows indicate the proportion of species of conservation concern for species groups that are primarily associated with aquatic ecosystems. Data are derived from the National Heritage Programs as maintained by NatureServe (2014).



drinking-water supply, and, ultimately, (3) the costs associated with water treatment. As a consequence, land conservation and restoration are seen as potential mechanisms to capture the benefits associated with the ecosystem services linked to the provision of clean water (Postel and Thompson 2005).

With this renewed focus on maintaining the ecological condition associated with the uplands of source-water watersheds, land and resource management is now an overlapping concern for both biodiversity conservation and drinking-water protection. This overlapping concern sets up an opportunity in which management costs can be shared while realizing important joint benefits. Wickham and Flather (2013) undertook an analysis to determine if opportunities exist to align biodiversity and drinking-water protections goals and, if such opportunities exist, to identify where they occur geographically.

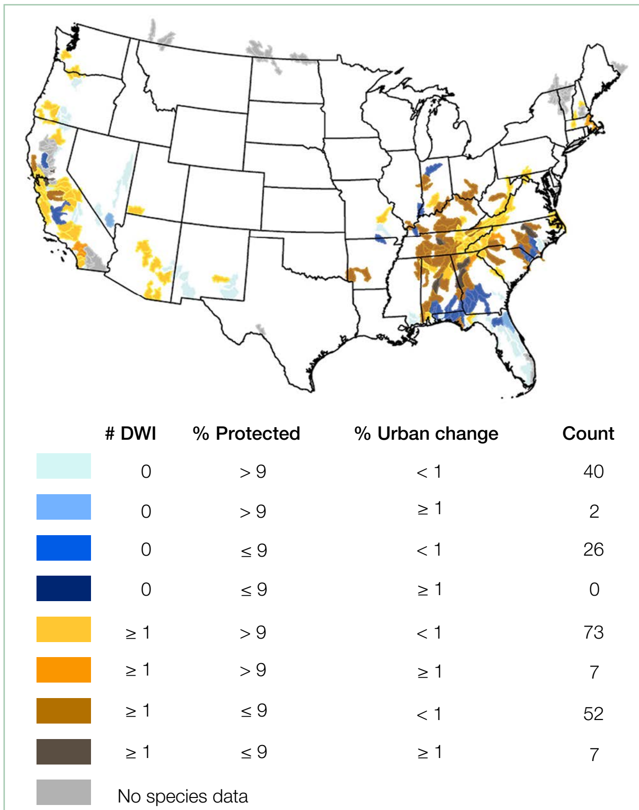
Four datasets (aquatic species occurrence, drinking-water intake locations, protected lands, and urban land cover) were used to analyze the coincidence of biodiversity and drinking-water services within eight-digit hydrologic units (watersheds). Aquatic species distributions by watershed were compiled from NatureServe's Central Databases (NatureServe 2010), data that were also used in support of the 2010 RPA (see Loftus and Flather 2012). Because watersheds capable of supporting more species also would be expected to support a greater number of rare species, we quantified the proportion of species that were potentially vulnerable to extinction (G1-G3, see figure 11-12) as our measure of at-risk aquatic biodiversity in each watershed. Drinking-water intake (surface water only) locations were provided by the U.S. Environmental Protection Agency Office of Ground Water and Drinking Water (see Wickham et al. 2011). Protected land area within watersheds was derived from the Protected Areas Database (ver. 1.2; http://gapanalysis.usgs.gov/padus/data/download). Finally, urban land cover area and urban land cover change within each watershed were derived from the National Land Cover Change Data (ca. 2001 to 2006; Fry et al. 2011).

We focused our analysis on those watersheds that were in the top 10 percent (≥ 90th percentile), as measured by the proportion of aquatic species that are classified as at risk. We refer to these watersheds as hotspots of at-risk aquatic biodiversity. We then determined which of those hotspot watersheds had (1) one or more drinking-water intakes, (2) limited protected lands (proportion of protected land in the watershed was less than the national median [< 9 percent]), and (3) relatively high urban development (≥ 1-percent gain in urban land during a 5-year period).

Results

Two-thirds (139 of 207) of the watersheds that support a relatively high proportion of at-risk aquatic biodiversity have a collateral stake in drinking-water protection, as indicated by the presence of at least one drinking-water intake. These watersheds are concentrated in the Southeastern United States and the Mediterranean climates of California (figure 11-13). We further partitioned this subset of hotspot watersheds into those with limited amounts of protected land to highlight those areas that may benefit from land acquisition or conservation easement. Of the 139 watersheds, 59 (40 percent) have less than the U.S. median level of protected lands. We further ranked watersheds according to level of threat as reflected by the degree to which land was undergoing relatively rapid urbanization. This ranking resulted in a final set of seven watersheds that have shared aquatic biodiversity/drinking-water values, relatively low proportions of protected lands, and a relatively high rate of urbanization. Most of these watersheds (5 out of 7) occur in the Southeast, with a secondary concentration in California.

Figure 11-13. Watersheds that support a relatively high proportion of at-risk aquatic biodiversity (in the 90th percentile) categorized by whether drinking-water intakes (DWI) are present, whether the percentage of protected areas is limited, and whether relatively high urban development exists. # DWI is the number of drinking-water intakes. Count is the number of watersheds in each set.



Source: Wickham and Flather (2013).

Implications

This analysis identifies areas where land conservation actions are likely to support drinking-water security and aquatic species protection by applying a simple dichotomy (with or without drinking-water intakes) to those watersheds that support a high proportion of at-risk species (i.e., biodiversity hotspots). More than 65 percent of hotspot watersheds also have drinking-water intakes, and their distribution across the conterminous United States points primarily to the Southeast and, secondarily, to portions of California as areas with a shared (biodiversity and drinking-water) interest in watershed-level land management.

One potential benefit of integrating concerns for drinking-water quality with biodiversity conservation in land management planning is the increased likelihood of stakeholder buy-in. Often efforts to conserve biodiversity are seen to conflict with other societal needs because these effort are often associated with restricting land uses that can reduce the provision of other goods and services. Defining joint benefits explicitly among traditionally contentious stakeholders has the potential to leverage scarce funding resources and facilitate action that results in win-win outcomes. The focus on drinking-water intakes and aquatic biodiversity was intentionally simplistic to illustrate how land management and conservation planners could identify watersheds that benefit both human well-being and biodiversity conservation. It is certainly plausible, and perhaps expected (see Naidoo and Ricketts 2006), that additional shared benefits could be realized under a more comprehensive treatment of the full suite of services derived from ecosystem.

Future Work

If resource planners are to make informed decisions about which lands, species, or habitats should be prioritized for biodiversity conservation, we will need to further our capability to describe and model biodiversity response to human land and resource use. Future work to support the 2020 RPA Assessment will focus on furthering this capability in three areas.

First, housing growth in and near protected areas is shown in this RPA Update to affect bird communities both at the boundary of protected areas and inside those areas. An unanswered question is how future housing growth trends, along with future land use activities, will affect bird communities within and near protected lands. The focus of this effort will be on anticipating where housing growth and land use intensification are likely to have the greatest negative impact on native bird communities and those bird species that are of greatest conservation concern. By anticipating these hotspots of bird community degradation, we hope to identify areas where focusing land use and resource policy and management could buffer biodiversity loss and maintain the conservation value of those protected areas.

Second, we will extend the analysis of climate-induced stress to terrestrial wildlife habitat across the RPA Rocky Mountain Region to the entire conterminous United States. Such information will contribute to spatially explicit identification of where wildlife resources may be particularly vulnerable, or particularly resistant, to habitat stresses attributable to climate change. Such analyses will inform efforts to strategically acquire or manage lands that will help facilitate wildlife adaptation to climate change and will be particularly relevant to State wildlife agency efforts to update their State Wildlife Action Plans to better address the impacts of climate change on wildlife resources.

Finally, the depiction of at-risk biodiversity on a systematic grid reported in this RPA Update leads logically to efforts directed at understanding and anticipating where species rarity and extinction risk are expected to increase in the future. This work will focus on testing whether knowledge of how climate regime, land use intensification, land ownership, and human population change in the future can be used to anticipate where concentrations of at-risk species are likely to emerge. In addition to being rare, these species are often secretive and difficult to detect. Therefore, analyses such as those proposed here could help direct future surveys by identifying areas that "look like" they should support more at-risk species than current inventories indicate are supported. These predictions could help geographically target inventory investments to those areas that are most likely to harbor undetected at-risk biota.

All three of these efforts are geared toward expanding our capacity to model biodiversity response to changes in the environment in a spatially explicit manner. Armed with such decision-support tools, the RPA Assessment should be better positioned to inform agency planning efforts as defined in the 2012 Planning Rule (USDA Forest Service 2012c) and to address the requirement to provide those conditions that will maintain the integrity of ecological systems.

Conclusions

The status and trends of wildlife, fish, and biodiversity reported in this RPA Update do not substantively alter the conclusions of the 2010 RPA. The RPA Update does provide a refinement of wildlife, fish, and biodiversity response to human uses and management of natural resources. This refinement takes two forms: one is a simple improvement in the spatial resolution of resource response; the other involves an elaboration of the questions that were initially posed in the 2010 RPA.

Increasing spatial resolution of resource response enabled us to look more closely at the geography of at-risk species occurrence and the patterns of terrestrial wildlife habitat stress attributed to climate change. Species currently listed under the

ESA are concentrated in hotspots that occur in the southern Appalachians, peninsular Florida, coastal areas of the southeast Atlantic Ocean and eastern Gulf of Mexico, California Mediterranean climate regions, and the Hawaiian archipelago. These hotspots have long been known to house high numbers of listed species. These data, coupled with information on the location of species that will likely be added to the list in the future, reveal the emergence of new areas of concentration that include the interior highlands of Arkansas, Illinois, Indiana, Kentucky, and Missouri and the southern portions of the Great Basin.

Our assessment of climate-induced stress to terrestrial wildlife habitat also benefited from a finer analysis resolution. The 2010 RPA found that areas where habitat was thought to be particularly vulnerable to climate change were associated with the RPA Rocky Mountain Region, a region where the Forest Service and other public land management agencies have important land stewardship responsibilities. Furthermore, our focus on this region was motivated by fire—a disturbance process that is expected to increase under climate change—and its importance in shaping the ecological systems found in this region. In addition to providing a much refined picture of the TCSI that could inform agency forest plan development, we also learned that the geographic distribution of highly stressed habitats was very much affected by how wildfire was managed across this landscape.

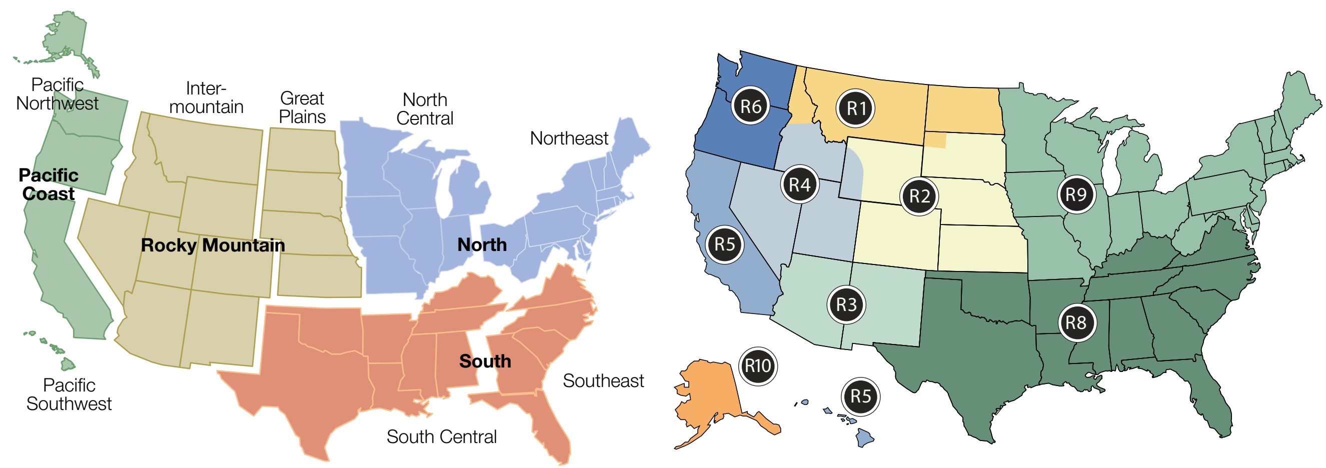
The 2010 RPA alluded to the potential impacts associated with increasing housing development in the high-amenity areas that are associated with public lands like national forests and grasslands. A number of impacts to biodiversity that occur in these protected areas were explored through a series of case studies in the 2010 RPA, but we lacked a systematic evaluation of impacts across the country. For this RPA Update, we completed a study that was designed specifically to explore the nature of housing development impacts on bird communities both at the boundary of protected areas and within those areas. Our analysis demonstrated that not only does housing near protected lands affect bird communities locally (i.e., at the boundary), but it also affects bird communities away from the boundary within protected lands. This latter finding provides evidence that housing impacts extend well beyond their local footprint. Thus, to maintain protected areas as refugia for biodiversity, prioritizing conservation actions on private lands is necessary. The focus on private lands suggests that the agency's State and Private Forestry program should be a major participant in efforts to address these concerns. In locations where private-land housing is dense (e.g., Appalachians), land use planning and homeowner education are important. In locations where private-land housing is low, the conservation options are more diverse. Alternative strategies for preserving land near protected areas (e.g., conservation easements, cluster housing) could be pursued also with the intent to maximize unfragmented natural land cover while minimizing the footprint of housing development.

We also examined in more detail the relationship between drinking water and at-risk aquatic biodiversity. Our analysis identifying geographic coincidence between watersheds with drinking-water intakes and areas supporting high concentrations of at-risk aquatic biodiversity suggests that both biodiversity and ecosystem services can benefit simultaneously from land conservation efforts. Such opportunities point to important shared conservation costs that can be leveraged among stakeholder groups that will benefit jointly. We suspect that such shared benefits among stakeholder groups that are often viewed as confrontational are more common than past experience would suggest.

Chapter 12. Outdoor Recreation

Outdoor recreation is a key part of America's social and economic fabric. The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) provided information about available outdoor recreation resources in the United States, described the status and historical trends in outdoor recreation participation, regionally and by different demographic groups, and projected national recreation participation through 2060. This RPA Update provides regional recreation participation projections for the four RPA regions—the North, South, Rocky Mountain, and Pacific Coast Regions (figure 12-1). In doing so, we are able to examine whether climate change is likely to have different impacts across both recreation activities and regions. We also examine recreation visitation to national forests and grasslands, summarizing regional and national estimates of visitation, activity participation, demographic characteristics, and perceptions of satisfaction and crowding among national forest visitors.

Figure 12-1. RPA Assessment regions and subregions (left) and National Forest System regions (right).



R1 = Region 1, Northern Region. R2 = Region 2, Rocky Mountain Region. R3 = Region 3, Southwestern Region. R4 = Region 4, Intermountain Region. R5 = Region 5, Pacific Southwest Region. R6 = Region 6, Pacific Northwest Region. R8 = Region 8, Southern Region. R9 = Region 9, Eastern Region. R10 = Region 10, Alaska Region. RPA = Resources Planning Act.

Highlights

- Growth in outdoor recreation participation will vary across activities and regions.
- Climate change could have large effects on participation in some outdoor recreation activities.
- Future recreation activity participation will be highly influenced by minority population growth, increasing age levels, increasing urbanization, and changes in economic conditions.
- Minority recreation visitors, both racial and ethnic, continue to be underrepresented relative to the general population in their use of national forests for outdoor recreation.
- Overall, recreation visitors to national forests, nationwide and across the RPA regions, judged their experience as satisfactory.

Regional Recreation Participation in the Future

- ❖ Outdoor recreation participation will continue to grow nationwide and across the RPA regions, but rates will vary across regions.
- ❖ Climate change is expected to have varying effects on recreation participation; participation in a few activities could change by large amounts because climate differences impact both opportunities and demand.
- ❖ Population growth drives participant increases in many outdoor recreation activities, but increasing population density and diminishing access have negative effects on participation in many activities.
- ❖ Future recreation activity participation will be highly influenced by minority population growth, increasing age levels, increasing urbanization, and changes in economic conditions.

Adult recreation participation (ages 16 and above) was examined for 17 recreation activity composites organized into 7 activity groups (table 12-1). Per capita participation and average annual days per participant were modeled and simulated for each of the four RPA regions (figure 12-1) and at the national level. The total number of participants and total annual days of participation were estimated by multiplying each of the RPA scenario population projections by corresponding projections of scenario participation rates and average days per participant. Activity-specific numbers of participants, per capita participation, total activity days, and days per participant were projected through 2060 for the three RPA scenarios without climate variables (i.e., assuming historical climate). The models were then run with climate variables for each of the nine RPA scenario-climate combinations (see table 1-2 in chapter 1), allowing for a comparison of the potential effects of climate change on recreation participation (Bowker and Askew 2012; Bowker et al. 2012).

Projection models relate recreation participation directly to factors known to correlate with recreation choices. The rate of outdoor recreation participation and also the participation intensity, or consumption, are correlated with multiple factors, including race, ethnicity, gender, age, income, and supply or proximity to settings (Bowker et al. 1999; Bowker et al.

Table 12-1. Total number of participants in outdoor recreation activities, 2008.[a]

Outdoor recreation activity group	2008 total number of participants (millions)				
	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
Developed site usage					
Visiting developed sites: family gatherings, picnicking, developed camping	81	63	17	31	194
Visiting interpretive sites: nature centers, zoos, historic sites, prehistoric sites	67	51	15	26	158
Observing nature					
Birding: viewing and/or photographing birds	37	27	7	13	82
Nature viewing: viewing, photographing, studying, or nature gathering related to fauna, flora, or natural settings	80	63	18	31	190
Backcountry activities					
Challenge activities: caving, mountain biking, mountain climbing, rock climbing	9	7	4	5	25
Horseback riding on trails	6	6	2	3	16
Day hiking	33	20	10	17	79
Primitive area use: backpacking, primitive camping, wilderness	36	28	12	18	91
Motorized activities					
Motorized off-roading	17	17	6	9	48
Motorized water activities	26	21	5	10	62
Motorized snow activities	7	1	1	1	9
Consumptive activities					
Hunting: small game, big game, migratory birds, other	11	11	3	3	28
Fishing: anadromous, coldwater, saltwater, warmwater	29	28	7	10	73
Nonmotorized winter activities					
Developed skiing: downhill skiing, snowboarding	12	4	3	5	24
Undeveloped skiing: cross-country skiing, snowshoeing	5	1	1	1	8
Nonmotorized water activities					
Swimming: swimming, snorkeling, surfing, diving, visiting beaches or watersides	62	47	11	25	144
Floating: canoeing, kayaking, rafting	18	12	3	6	40

RPA = Resources Planning Act.

[a] Activities are individual or activity composites derived from the National Survey of Recreation and the Environment (NSRE). Participants are determined by the average weighted frequency of participation by activity for NSRE data from 2005 to 2009 and the adult (>16) population in the United States in 2008 (235.4 million).

2006; Cicchetti 1973; Hof and Kaiser 1983; Leeworthy et al. 2005). The projection models incorporate this information in conjunction with external projections of other relevant factors over time, including population growth, to simulate future recreation participation and consumption. Such modeling allows for changes in recreation participation and consumption behavior over time to be assessed in light of previously unseen changes in factors driving this behavior; e.g., large changes in demographic, economic, land use, and climate factors.

Key variables drive the future trends in recreation participation. Population growth often is the most important driver and, therefore, RPA A2, with the largest projected population growth, often has the greatest changes, whereas RPA B2 has the smallest. Income growth also has differential effects on participation. In activities that require more capital or income for effective participation, such as developed skiing, challenge activities, horseback riding activities, hunting, and motorized activities, the combination of moderate population growth and higher income growth in RPA A1B results in larger participation changes than in RPA A2.

The effects of population growth are often offset by more indirect effects. Land and water availability positively influences activity participation. A growing population, combined with an assumed stable public land base and declining private natural land base, results in declines in per capita recreation opportunities. Those declines tend to have negative effects on recreation participation. For example, declines in the per capita availability of forest land, rangeland, and Federal land correlate positively with participation declines in spatially extensive activities such as horseback riding, hunting, motorized off-road driving, visiting primitive areas, and viewing and photographing nature. Increasing population density tends to have a negative effect on recreation participation as a result of crowding. In most cases, population growth is sufficient to result in overall growth in the total number of participants and total days of participation, even when participation rates and/or average days of participation are projected to decline.

Climate variables were added to the projection models to test whether participation and participation intensity were sensitive to climate change effects. Temperature, precipitation, and evapotranspiration variables were tested, with a single climate variable introduced into each recreation activity model. The effectiveness of the climate variables is limited because they represent climate within specified distances from the residence of the recreationist, not at the recreation destination. Research has shown, however, that the vast majority of outdoor recreation takes place within a few hours' drive of one's residence (Hall and Page 1999). Therefore, for most recreation visits, the origin and destination are within the same geographic area as the climate data. For others, the relevance of the climate data is likely to vary by activity and could be sensitive to locations where the climate has significant variation across the recreation market area (e.g., mountainous areas). The "with climate change" model results reported here represent the average of the activity projection results from the three general circulation model (GCM) climate outcomes for each RPA scenario. More details about the GCMs selected for each RPA scenario and the selection and use of climate variables in the participation models are addressed in Bowker et al. 2012.

Adding climate variables to the national projection models (Bowker et al. 2012) resulted in a slight increase or decrease in the metrics compared with the "no climate change" projection for most recreation activities, although more substantial negative effects were found for snowmobiling and undeveloped skiing. The climate variables also resulted in some substantial differences across the RPA regions in comparison with the results without including climate effects. These differences can be attributed in part to unique region-specific climate variables that led to differential effects across regional and national models.

Regional Activity Projections

Detailed results for participation rates, participants, days per participant, and total days of participation by RPA region and activity for each of the RPA scenarios and their associated climate models are reported in Bowker and Askew (In press). The following discussion presents projected participation rates and mean days of participation per participant across each of the RPA scenarios with no climate change (i.e., historical climate trends are assumed to continue) and with climate change (represented by the average of projection results from the three GCMs). Results are shown for each RPA region along with the national estimate for comparison across the 17 activity combinations. Climate models for the South Region were not estimated for winter recreation activities. Projected total participants and total days across regions, RPA scenarios, and activities are summarized after the participation rate and days per participant discussion.

Developed Site Usage

Activities qualifying as developed site usage are grouped into two aggregates: visiting developed sites and visiting interpretative sites. Visiting developed sites was among the most popular of the 17 activities analyzed, with participation rates in 2008 near or exceeding 80 percent for all four regions and the Nation (table 12-2). Participation rates grow slightly without climate change. Including climate effects associated with warmer and drier conditions leads to rate declines in the North and South Regions. For the Pacific Coast Region, growth in annual days per participant is positive and considerably higher than for all other regions. Increased household income in that region associated with RPA A1B appears to be the factor most likely driving this change. All the projections at the national level and for the North and Rocky Mountain Regions show declines in days per participant. In nearly all region and scenario combinations, the declines are intensified by the impact of climate change.

Another popular recreation activity accessible to most people is visiting interpretive sites, specifically natural, historic, and prehistoric sites. At the regional level, 2008 participation rates ranged from 64 percent for the South Region to 71 percent for the Rocky Mountain Region; the national rate was 70 percent (table 12-3). Projections show growth across all scenarios, with the most growth in RPA A1B, the scenario with the highest income growth. Climate change has a relatively minor effect on participation rate projections in all regions except the North Region, which shows no change. Moderate growth in the annual days per participant is projected for all regions. Projections for the Pacific Coast Region are highest, ranging between 15 and 25 percent. The influence of climate change marginally boosts the days per participant projected for the Nation and in the North Region, decreases the number of days for the Pacific Coast and South Regions, and has almost no effect in the Rocky Mountain Region. Warmer and drier conditions increase the days per participant in the North Region, and higher summer temperatures decrease the number of days in the Pacific Coast Region.

Observing Nature

Nature observation participation includes those who participate in birding (viewing and/or photographing) and those who participate in nature viewing in general, which consists of gathering mushrooms and berries or viewing and/or photographing birds, other wildlife, natural scenery, and so on. These activities can be undertaken casually in one's backyard or on a trip encompassing great distances. In 2008, about one-third of the population participated in birding in all of the RPA regions (table 12-4). In the absence of climate change, projections show an increased participation rate. Climate change has a small effect on those projections for the South, Rocky Mountain, and Pacific Coast Regions. The most notable change occurs in the North Region, where an increase in the participation rate without climate change turns into a decline with the addition of

Table 12-2. Developed site projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.825	1	0	1	(4)	(4)	(3)
RPA South Region	0.799	2	1	1	(0)	(2)	(1)
RPA Rocky Mountain Region	0.815	2	1	1	2	0	1
RPA Pacific Coast Region	0.812	2	0	1	2	0	1
Nation	0.819	3	1	1	1	(0)	0
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	12	(3)	(3)	(3)	(10)	(9)	(5)
RPA South Region	11	0	0	0	3	3	1
RPA Rocky Mountain Region	13	(1)	(2)	(1)	(5)	(5)	(3)
RPA Pacific Coast Region	13	13	5	6	11	4	4
Nation	12	(2)	(2)	(1)	(3)	(3)	(2)

RPA = Resources Planning Act.

Table 12-3. Interpretive site projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.686	9	5	6	9	5	6
RPA South Region	0.639	9	7	6	7	4	5
RPA Rocky Mountain Region	0.713	10	8	7	9	7	6
RPA Pacific Coast Region	0.696	5	2	3	5	2	2
Nation	0.669	9	5	6	8	4	5
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	8	7	2	3	13	8	5
RPA South Region	7	12	9	7	11	8	6
RPA Rocky Mountain Region	9	5	3	3	5	2	2
RPA Pacific Coast Region	9	25	14	15	21	11	11
Nation	8	8	3	4	11	6	6

RPA = Resources Planning Act.

warmer and drier spring seasons. Nationwide, birders in 2008 participated about 98 days annually, with a range of 80 to 107 days across the regions. In contrast with the mostly positive projections for birder participation rates, the days of birding per person are projected to decline across all regions except the Rocky Mountain Region. The large decline in the South Region is correlated with an increase in the rate of population growth and to a strong negative relationship with increasing income through 2060. The negative effects of population growth are related to increasing population density and the increasing proportion of Hispanic residents in the overall population. Lower birding days per participant for Hispanic groups have a stronger negative effect over time as their share of the population grows. The addition of climate change induces an overall decline in days per participant with varying degrees by region. The negative impact of year-round warming in the South Region reduces the days of birding by at least 10 percent per person in comparison with models excluding climate effects.

The national participation rate in 2008 for nature viewing was more than 80 percent, with comparable rates among the regions (table 12-5). All the projection estimates reveal relatively small changes in the participation rate over time. Participation is already high, so little room exists for significant growth. The intensity of nature viewing is greatest in the North Region in 2008, exceeding the annual days per participation in the Rocky Mountain and Pacific Coast Regions by nearly 20 days (table 12-5). The projection of participation days shows a moderate decline of between 6 and 14 percent across all scenarios and areas. The inclusion of climate variables induces a small additional decline for most regions.

Backcountry Activities

Backcountry activities, typically requiring travel to a dispersed setting, include challenge activities, horseback riding on trails, day hiking, and primitive area use. Challenge activities such as mountain climbing, rock climbing, and caving require physical endurance and specialized training and equipment. These special requirements lower the national participation rate to about 10 percent (table 12-6). The activity is most popular in the Rocky Mountain Region, where the terrain and sites

Table 12-4. Birding projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.382	8	6	6	(4)	(6)	1
RPA South Region	0.342	10	8	8	12	10	9
RPA Rocky Mountain Region	0.331	6	6	6	6	6	5
RPA Pacific Coast Region	0.343	2	1	2	4	3	2
Nation	0.346	8	4	4	2	(1)	1
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	100	(3)	(3)	(2)	(4)	(3)	(3)
RPA South Region	107	(19)	(17)	(13)	(29)	(28)	(20)
RPA Rocky Mountain Region	80	6	4	8	1	(0)	5
RPA Pacific Coast Region	86	(7)	(8)	(6)	(9)	(11)	(7)
Nation	98	(4)	(6)	(2)	(5)	(6)	(3)

RPA = Resources Planning Act.

Table 12-5. Nature viewing projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.815	4	2	2	(0)	(2)	(1)
RPA South Region	0.791	3	0	1	1	(2)	(1)
RPA Rocky Mountain Region	0.829	4	1	2	4	1	2
RPA Pacific Coast Region	0.817	2	(1)	0	1	(2)	(1)
Nation	0.805	3	1	1	3	0	1
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	176	(8)	(8)	(7)	(9)	(8)	(7)
RPA South Region	173	(10)	(12)	(8)	(12)	(13)	(9)
RPA Rocky Mountain Region	157	(9)	(11)	(6)	(10)	(11)	(7)
RPA Pacific Coast Region	157	(11)	(13)	(9)	(13)	(14)	(11)
Nation	170	(11)	(9)	(8)	(13)	(10)	(9)

RPA = Resources Planning Act.

afford many opportunities year round. Without accounting for climate change, the Rocky Mountain Region and the South Region show similar growth in the participation rate, whereas the North and Pacific Coast Regions are likely to experience declines. These declines are correlated with a decrease in per capita opportunities, whereas increases in the South and Rocky Mountain Regions are supported by income growth. The inclusion of climate variables has little effect on projections for most regions and scenarios, except for the South Region, where climate effects result in declines in participation rate growth from 7 to 13 percent. The challenge activities support a relatively low annual number of days per participant. The projections are relatively static for the Nation and for the North and Pacific Coast Regions, regardless of whether climate variables are included. The 6- to 8-percent decline in days per participant shown for the Rocky Mountain Region is correlated with increased population growth that reduces the per capita availability of resource opportunities for challenge activities. The South Region, where warmer temperatures in the fall contribute to increased per participant days, was the only region to show increases in annual days per participant, ranging from 7 to 15 percent with no climate change and up to 16 to 38 percent with climate change. Income growth was a key driver of the increase.

The participation rate for horseback riding on trails ranged between 6 and 9 percent (table 12-7). The projected participation rates show large variability across RPA regions and RPA scenarios. Across RPA scenarios, RPA A1B, with higher income growth and moderate population growth, had the most positive impact, but moderate growth in income and high population growth contribute to more negative effects for RPA A2. Per capita participation is also negatively correlated with increasing proportions of minority residents, especially Hispanic groups, who historically have had low participation rates. The large decline in the Rocky Mountain Region also appears to be influenced by increasing population density, especially in RPA A2. Adding climate effects stimulates a significant increase in horseback riding participation for the North Region and substantial decline in the Rocky Mountain Region. These changes appear as a result of warmer and drier summer

Table 12-6. Challenge activities projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.095	(4)	(9)	(9)	(10)	(10)	(10)
RPA South Region	0.086	18	11	9	5	(2)	2
RPA Rocky Mountain Region	0.177	14	8	8	18	7	11
RPA Pacific Coast Region	0.135	(6)	(7)	(10)	(3)	(7)	(7)
Nation	0.107	18	7	7	18	6	7
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	4	(1)	(1)	(0)	(2)	(0)	0
RPA South Region	4	15	7	7	38	28	16
RPA Rocky Mountain Region	9	(7)	(8)	(6)	(6)	(8)	(6)
RPA Pacific Coast Region	4	(2)	(2)	(2)	0	0	0
Nation	5	(1)	(2)	(1)	1	0	0

RPA = Resources Planning Act.

Table 12-7. Horseback riding projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.059	16	3	4	42	22	19
RPA South Region	0.071	8	(9)	(5)	7	(11)	(5)
RPA Rocky Mountain Region	0.093	(3)	(16)	(10)	(13)	(24)	(17)
RPA Pacific Coast Region	0.072	17	2	4	14	(2)	4
Nation	0.070	19	1	3	27	9	8
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	13	3	3	3	(4)	(4)	(1)
RPA South Region	18	26	(1)	9	(36)	(53)	(32)
RPA Rocky Mountain Region	35	10	(11)	(6)	11	(13)	(5)
RPA Pacific Coast Region	8	56	19	23	56	16	27
Nation	16	3	3	3	(11)	(10)	(7)

RPA = Resources Planning Act.

seasons, which have a positive correlation for the North Region and a negative correlation for the Rocky Mountain Region. The popularity of horseback riding on trails in the Rocky Mountain Region is reflected in the high level of days of annual participation—more than double any other region. The positive effects of income growth in all regions, except the North, contribute to the high level of projected days for RPA A1B. For other RPA scenarios, a stronger income effect in the Pacific Coast Region is sufficient to offset the negative effects of education level, race/ethnicity, and population growth affecting projections for the South and Rocky Mountain Regions. The effects of climate were fairly profound in the South Region, where horseback riding days per participant drop by more than 50 percent on average across the three RPA scenarios. Population density and, more importantly, extreme maximum temperatures are the driving factors.

Nationwide, approximately 1 out of 3 adults participated in day hiking during 2008 (table 12-8). There is considerable variation in 2008 participation rates across regions, as the Rocky Mountain Region participation rate is almost double the South Region rate. The results without climate change show participation rate increases across all regions except for the Pacific Coast Region under RPA A2. The growth is dampened by climate effects in the North and South Regions. The North Region shifts from gradual increases to a small downturn in the projected participation rate as warmer and drier conditions are projected. The average annual days people hike vary little across regions from the national average of almost 23 days. National day hiking intensity appears unaffected by both the RPA scenarios and climate change. Although climate seems to induce marginal decreases in hiking days per participant in the North and South Regions, those declines appear to be offset by positive effects in the Rocky Mountain and Pacific Coast Regions.

Approximately 38 percent of adults backpacked, camped in primitive settings, or visited wilderness in 2008 (table 12-9). By 2060, overall adult participation rates are expected to decline somewhat across all regions and RPA scenarios, with the exception of RPA A1B in the Rocky Mountain Region. Projection models with climate effects increase the rate of decline in most regions, especially in the North and Rocky

Table 12-8. Day hiking projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.327	7	5	6	(2)	(5)	(1)
RPA South Region	0.252	16	13	12	7	6	7
RPA Rocky Mountain Region	0.461	12	7	8	13	6	9
RPA Pacific Coast Region	0.447	2	(1)	1	(1)	(3)	(2)
Nation	0.333	10	8	7	6	3	5
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	22	(5)	(1)	(1)	(7)	(1)	(1)
RPA South Region	23	(4)	(5)	(3)	(5)	(6)	(3)
RPA Rocky Mountain Region	20	(5)	(7)	(4)	0	(1)	1
RPA Pacific Coast Region	26	3	(4)	(1)	6	(3)	2
Nation	23	6	6	6	6	6	7

RPA = Resources Planning Act.

Table 12-9. Primitive area projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.367	(2)	(5)	(4)	(23)	(25)	(14)
RPA South Region	0.353	(3)	(7)	(6)	(4)	(8)	(6)
RPA Rocky Mountain Region	0.541	1	(4)	(2)	(8)	(13)	(9)
RPA Pacific Coast Region	0.460	(4)	(11)	(7)	(3)	(9)	(7)
Nation	0.383	(1)	(5)	(5)	(3)	(8)	(6)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	11	(10)	(11)	(10)	(21)	(20)	(18)
RPA South Region	15	1	1	0	(8)	(8)	(4)
RPA Rocky Mountain Region	14	(15)	(16)	(14)	(14)	(16)	(13)
RPA Pacific Coast Region	14	17	5	8	12	2	3
Nation	13	(1)	(1)	(1)	(4)	(4)	(3)

RPA = Resources Planning Act.

Mountain Regions. Projected drier conditions in the summer and fall strengthen falling per capita primitive area participation. Although the South Region reported the lowest primitive area participation rate in 2008, it conversely had the highest annual days of participation. The North and Rocky Mountain Regions show relatively large reductions in projected days with and without climate effects. The projections vary little across scenarios within regions, except for the Pacific Coast Region, where the high income RPA A1B scenario is considerably higher. The Pacific Coast Region was also the only region showing positive growth in 2060 in days per participant, although climate change had a dampening effect on growth. Drier seasonal conditions resulted in further declines in annual days of participation in both the North and South Regions.

Motorized Activities

The motorized activities category incorporates off-road driving, motorized water use, and motorized snow use. The participation rate for motorized off-road driving varies across regions, from 18 percent in the North Region to 27 percent in the Rocky Mountain Region (table 12-10). A downturn in the proportion of adults who participate is likely by 2060 across most RPA regions and scenarios. The South Region shows the sharpest declines, particularly in RPA A2. The RPA A2 declines are correlated with projected high concentrations of population and reduced land access per person. The projected growth in the Hispanic population could contribute to reductions across the country, because their participation rates for motorized activities are relatively low, particularly in the South and Pacific Coast Regions. The downturn for off-road driving in 2060 is also reflected in the annual days per participant. Although participation in all scenarios and regions is projected to decline, the effects of climate change accentuate the decline in the South Region by an additional 16 to 24 percent; an expected increase in the number of days with excessive heat contributes to the decline.

Motorized water activities consist of motorboating, waterskiing, or the use of personal watercraft. In 2008, the participation rate was approximately 26 percent, with little variation across regions (table 12-11). Increases in participation rates in all

Table 12-10. Motorized off-road projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.176	(1)	(9)	(7)	(8)	(16)	(10)
RPA South Region	0.213	(12)	(25)	(17)	(14)	(27)	(18)
RPA Rocky Mountain Region	0.271	4	(13)	(6)	5	(13)	(6)
RPA Pacific Coast Region	0.224	(1)	(21)	(11)	0	(20)	(9)
Nation	0.204	(0)	(18)	(8)	(0)	(18)	(8)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	16	(11)	(11)	(11)	(13)	(11)	(11)
RPA South Region	33	(2)	(3)	(2)	(24)	(27)	(18)
RPA Rocky Mountain Region	17	(8)	(11)	(6)	(10)	(12)	(7)
RPA Pacific Coast Region	13	(10)	(13)	(7)	(10)	(11)	(8)
Nation	22	(7)	(7)	(6)	(4)	(4)	(5)

RPA = Resources Planning Act.

Table 12-11. Motorized water projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.268	14	(2)	3	35	15	16
RPA South Region	0.270	10	(5)	(3)	13	(3)	(2)
RPA Rocky Mountain Region	0.259	15	0	1	2	(11)	(9)
RPA Pacific Coast Region	0.256	21	(0)	4	20	(1)	3
Nation	0.263	15	(2)	1	10	(7)	(3)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	15	7	(1)	0	9	(1)	1
RPA South Region	18	(1)	(9)	(6)	(1)	(9)	(7)
RPA Rocky Mountain Region	13	9	(1)	1	8	(1)	0
RPA Pacific Coast Region	12	16	(2)	2	15	(2)	1
Nation	15	4	(6)	(2)	2	(8)	(4)

RPA = Resources Planning Act.

regions are highest under the RPA A1B scenario, likely related to its high income growth. Higher population growth, resulting in increasing population density and a decline in water area per capita, and lower economic growth contribute to reductions in projected participation rates for most RPA A2 scenarios. Climate change has a strong positive effect on participation rates in the North Region and, by contrast, a strong negative influence in the Rocky Mountain Region, both resulting from an increase in warmer and drier summer conditions. Days per participant are highest in the South Region, yet the South is the only region projected to experience a decrease across all scenarios by 2060, with and without climate change. The income effect from RPA A1B is associated with the largest relative increase in days per participant for all regions, with the largest increases concentrated in the Pacific Coast Region. Overall, the climate variables minimally affect annual participant days.

The last motorized activity, motorized snow or snowmobiling, reported one of the lower participation rates at the national level, at about 4 percent (table 12-12). Because climate is not favorable for this activity in the South Region, no projections were estimated. Future participation rates for snowmobiling activities face larger declines than most other outdoor recreation activities, especially when considering climate change. Only the RPA A1B scenario for the Pacific Coast Region reflects a positive change in the participation rate under any scenario. The snowmobiling participation rate is negatively correlated with level of education, median age, and the Hispanic proportion of the population. All these factors are anticipated to increase over time as the population grows, leading to diminishing participation rates in snowmobiling. Warmer and drier climate conditions in the North Region contribute to participation rate declines exceeding 60 percent by 2060. The negative trend in projected snowmobile participation rates continues for days per participant across all regions and scenarios. Population growth is the primary negative driver nationwide and in the Rocky Mountain and Pacific Coast Regions in particular. The impact of climate variables on regional projections is limited. Yet, the national estimates suggest considerable effects from warmer and drier conditions as snowmobilers recreate fewer days per year.

Consumptive Activities

Consumptive activities traditionally include all types of hunting and fishing. Participation rates for legal hunting ranged from 7 percent in the Pacific Coast Region to 16 percent in the Rocky Mountain Region (table 12-13). Hunting is projected to experience participation rate declines of 18 percent or more across all regions and scenarios, declining more than 40 percent in some regions under the high population growth expected with RPA A2. The factors contributing most to this decline are a reduction in the per capita access to opportunities, increases in population density, non-White ethnicity, and education. Warmer and drier conditions associated with climate change appear to exacerbate declines nationwide and for all regions. Annual hunting days per participant are also projected to decline in all future scenarios, except in the South Region, in which case a decrease in days with extremely low temperatures leads to a small percentage increase in 2060 participant days. Higher annual temperatures in the North Region result in further decreases by an additional 8 percent more than estimates without climate effects.

Fishing includes anadromous, coldwater, warmwater, and saltwater fishing. Nationwide, fishing is more than twice as popular as hunting, but the intensity of use is similar across both fishing and hunting (table 12-14). Projected fishing participation rates in 2060 show decreases across all regions when climate effects are not included. The largest declines among scenarios are attributed to the higher population growth for RPA A2. This population growth negatively affects the participation rate through increased population density in general and decreased per capita availability of fishing venues. Projected decreases of 12 to 20 percent are reported for the South Region. Climate

Table 12-12. Motorized snow projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.071	(12)	(21)	(17)	(69)	(73)	(60)
RPA South Region[a]	—	—	—	—	—	—	—
RPA Rocky Mountain Region	0.060	(28)	(37)	(32)	(33)	(43)	(35)
RPA Pacific Coast Region	0.034	4	(21)	(8)	(2)	(23)	(15)
Nation	0.040	(13)	(23)	(21)	(51)	(57)	(49)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	8	(14)	(8)	(13)	(12)	(9)	(14)
RPA South Region[a]	—	—	—	—	—	—	—
RPA Rocky Mountain Region	5	(15)	(18)	(11)	(14)	(19)	(11)
RPA Pacific Coast Region	9	(16)	(22)	(10)	(18)	(23)	(12)
Nation	7	(3)	(4)	(2)	(20)	(20)	(13)

RPA = Resources Planning Act.

[a] Winter activity models were not estimated for the South Region.

Table 12-13. Hunting projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.117	(19)	(28)	(18)	(38)	(45)	(27)
RPA South Region	0.137	(26)	(41)	(29)	(27)	(42)	(30)
RPA Rocky Mountain Region	0.162	(26)	(39)	(28)	(37)	(47)	(36)
RPA Pacific Coast Region	0.067	(32)	(41)	(29)	(25)	(33)	(27)
Nation	0.119	(22)	(31)	(23)	(25)	(34)	(25)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	19	(10)	(10)	(9)	(18)	(18)	(18)
RPA South Region	22	(1)	(1)	0	3	2	7
RPA Rocky Mountain Region	14	(5)	(10)	(8)	(6)	(11)	(9)
RPA Pacific Coast Region	20	(19)	(21)	(17)	(21)	(22)	(20)
Nation	19	(12)	(12)	(12)	(13)	(13)	(12)

RPA = Resources Planning Act.

Table 12-14. Fishing projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.296	(3)	(10)	(8)	17	6	5
RPA South Region	0.357	(12)	(20)	(15)	(17)	(24)	(18)
RPA Rocky Mountain Region	0.337	(4)	(13)	(8)	(21)	(27)	(21)
RPA Pacific Coast Region	0.264	(3)	(13)	(8)	(2)	(12)	(8)
Nation	0.309	(3)	(10)	(9)	(10)	(16)	(13)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	18	(5)	(5)	(5)	12	9	7
RPA South Region	21	(2)	(3)	(1)	(16)	(18)	(9)
RPA Rocky Mountain Region	14	(8)	(9)	(7)	(9)	(9)	(8)
RPA Pacific Coast Region	18	(8)	(9)	(7)	(8)	(9)	(8)
Nation	18	(5)	(7)	(4)	(6)	(7)	(4)

RPA = Resources Planning Act.

effects from higher summer and annual temperatures result in further decreases in the participation rate for the South and Rocky Mountain Regions. Warmer and drier summers in the North Region reverse the direction of change for projected participation rates and days per participant from a predicted decline to an increase in 2060. Climate changes most affected days per participant in the North and South Regions, albeit in different directions. The North Region has an increase in annual days per participant, but the South Region has the largest reduction in participant days across all scenarios because of climate effects from an increase in the number of days with high temperatures.

Nonmotorized Winter Activities

Downhill skiing and snowboarding, which comprise the aggregate activity of developed skiing, had adult participation rates between 10 and 14 percent (table 12-15). Projected participation rates show increases nationwide and for the three RPA regions across all scenarios. The growth in participation rate is highest under RPA A1B because of the higher levels of income. Although climate change has mixed effects across regions and scenarios, those effects, in general, are small. Developed skiing participant days show positive growth in the Rocky Mountain and Pacific Coast Regions. The income effect remains strong for those regions due to projected income growth. The North Region experiences the only significant projected downturn in days per participant. An insignificant contribution from income growth and an increase in the minority population negatively affects the rates of change. Climate variables are a major factor only in the 2060 projections for the North Region because winters with higher maximum temperatures reduce the available opportunities for developed skiing.

Undeveloped skiing includes cross-country skiing and snowshoeing. Participants engaged in undeveloped skiing about the same number of days annually as developed skiers, but the percentage of the population that participated was lower (table 12-16). Undeveloped skiing is another winter activity that shows many projected declines, although they are of a smaller magnitude than for motorized snow activities. The Pacific Coast Region shows the largest declines, influenced by an

Table 12-15. Developed skiing projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.116	32	6	8	29	7	8
RPA South Region[a]	—	—	—	—	—	—	—
RPA Rocky Mountain Region	0.131	40	13	14	42	12	15
RPA Pacific Coast Region	0.140	32	6	8	35	9	9
Nation	0.101	45	11	13	42	7	12
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	7	(16)	(15)	(16)	(32)	(32)	(22)
RPA South Region[a]	—	—	—	—	—	—	—
RPA Rocky Mountain Region	8	18	7	8	17	4	8
RPA Pacific Coast Region	9	19	5	6	19	5	6
Nation	7	10	1	2	9	(0)	1

RPA = Resources Planning Act.

[a] Winter activity models were not estimated for the South Region.

Table 12-16. Undeveloped skiing projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.048	2	(8)	(4)	(36)	(48)	(29)
RPA South Region[a]	—	—	—	—	—	—	—
RPA Rocky Mountain Region	0.045	6	(12)	(2)	(4)	(15)	(9)
RPA Pacific Coast Region	0.035	(27)	(29)	(22)	(20)	(21)	(21)
Nation	0.033	6	(8)	(6)	(39)	(47)	(36)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	7	3	2	4	(9)	(10)	(4)
RPA South Region[a]	—	—	—	—	—	—	—
RPA Rocky Mountain Region	7	(3)	(5)	(2)	(13)	(13)	(10)
RPA Pacific Coast Region	7	(4)	(7)	(2)	(10)	(10)	(10)
Nation	7	2	2	2	(5)	(5)	(2)

RPA = Resources Planning Act.

[a] Winter activity models were not estimated for the South Region.

increasing minority population, especially the Hispanic population. The North Region has the largest decline when climate effects are considered; the participation rate declines almost 50 percent under RPA A2. As with developed skiing, higher maximum winter temperatures drive those declines. By contrast, climate change ameliorates declines in the Pacific Coast Region in response to increasing precipitation. The projected days per participant vary across regions—slightly positive for the North Region and negative for the Rocky Mountain and Pacific Coast Regions. When factoring in climate change, all the projections for days per participant show declines for undeveloped skiing across all scenarios.

Nonmotorized Water Activities

Swimming and floating activities are included in a composite group of activities referred to as nonmotorized water activities. Swimming is a popular activity spanning all ages and comprises a variety of outdoor water activities accessible in pools, lakes, streams, and the ocean (table 12-17). Roughly 61 percent of adults participated in swimming nationwide in 2008, with significant regional variation. Moderate growth is anticipated for the participation rate under historical climate conditions. Swimming responds positively to rising education and income associated with RPA A1B. The outlook for positive growth holds when climate variables are included for all areas except the North Region, where the overall growth rate falls below zero for the RPA A2 and RPA B2 models. An unexpected negative correlation exists between warmer summer temperatures in the North Region and participation. The popularity of swimming in the Pacific Coast Region is also reflected by annual participation days, approaching 30. The projections of days per participant are quite variable across regions and scenarios. The highest growth occurs in the Pacific Coast Region with and without climate effects. Swimming days per person are highest under RPA scenario A1B due to a positive correlation with income and a negative correlation with a population that is aging and includes more minority residents. The North Region slips from positive growth rates without climate effects to moderate declines in response to more very warm days, declining water area per person, and an increase in population age. The South Region showed a similar decline due to climate effects.

The floating activities of canoeing, kayaking, and whitewater rafting are not nearly as popular as swimming. Except for RPA A1B, all the regional projections reflect moderate declines in participation rates by 2060 (table 12-18). Increasing population density, age, and the proportion of minorities all contribute to a reduction in the floating participation rate. The greatest declines result from a decrease in the floating opportunities per capita in the Rocky Mountain Region. Warmer and drier summer temperatures in the North Region and warmer summer temperatures in the South Region further reduce participation rates relative to the historical climate scenarios. Projections of days per participant are relatively flat across regions except for the Rocky Mountain Region, where moderate declines are projected. The inclusion of climate effects, however, creates notable shifts in projected 2060 days per participant for the North and South Regions. The RPA A1B and A2 scenarios for the North Region drop 20 percent after the inclusion of climate. The South Region benefits from climate change and actually shows increasing participant days across all scenarios. In both cases, warmer and drier spring conditions contribute to the change in participant floating days.

Summary

The number of Americans participating in outdoor recreation will continue to grow during the next five decades. The greatest growth in adult participation rates will come in developed skiing, challenge activities, day hiking, swimming, horseback riding on trails, and visiting interpretive sites. Activities with low or declining rates include hunting, snowmobiling, motorized off-roading, fishing, and floating. The largest increases in participants will be for already popular activities easily undertaken by most at a wide array of venues, including visiting developed and interpretive sites, nature viewing, swimming, and day hiking.

Table 12-17. Swimming projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.633	12	6	6	0	(6)	(4)
RPA South Region	0.590	11	6	5	7	1	2
RPA Rocky Mountain Region	0.522	8	3	2	13	8	6
RPA Pacific Coast Region	0.661	8	5	4	7	4	4
Nation	0.609	11	6	5	11	6	5
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	22	7	1	1	(5)	(12)	(5)
RPA South Region	24	2	(4)	(2)	(3)	(10)	(7)
RPA Rocky Mountain Region	20	1	(5)	(3)	2	(5)	(3)
RPA Pacific Coast Region	30	13	4	4	12	3	4
Nation	24	4	(1)	(1)	2	(4)	(3)

RPA = Resources Planning Act.

Table 12-18. Floating projected participation and use by RPA region, the Nation, scenario, and climate future, 2008 to 2060.

Nation or RPA region	2008	RPA scenario			RPA scenario		
		A1B	A2	B2	A1B	A2	B2
	per capita participation	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	0.187	6	(5)	(4)	(16)	(23)	(18)
RPA South Region	0.154	5	(5)	(4)	(6)	(13)	(12)
RPA Rocky Mountain Region	0.160	(5)	(15)	(12)	(5)	(15)	(13)
RPA Pacific Coast Region	0.165	2	(13)	(8)	1	(14)	(10)
Nation	0.169	3	(11)	(7)	(10)	(22)	(15)
	days per participant	Percentage increase (decrease) from 2008 initial value					
		without climate change			*with climate change*		
RPA North Region	7	(0)	(0)	0	(20)	(20)	(8)
RPA South Region	7	(2)	(3)	(2)	6	6	2
RPA Rocky Mountain Region	5	(8)	(10)	(6)	(11)	(11)	(8)
RPA Pacific Coast Region	6	(1)	(2)	(1)	(2)	(2)	(1)
Nation	7	(0)	(0)	0	(1)	(0)	(0)

RPA = Resources Planning Act.

Outdoor recreation participation growth will vary across regions. Growth, in general, is less in the North Region because population growth is lowest there. The fastest growing activities will be developed skiing, day hiking, and horseback riding on trails. For the South Region, the growth in participation will increase the most in hiking, birding, visiting developed sites, and motorboating. The Rocky Mountain Region has some of the highest growth rates for participants because the region has the highest projected population growth rate. Activities with the highest participant growth rates in this region are developed skiing, challenge activities, day hiking, and birding. In the Pacific Coast Region, the activities with the highest participant growth include developed skiing, motorboating, horseback riding on trails, and swimming.

Participation projections for total participants incorporating climate change reveal significant positive and negative effects on recreation participation growth for some activities (table 12-19). In general, where projected climate changes have an effect, the impact is more likely to affect participation adversely rather than enhance it. For many activities, however, climate has negligible impacts. The activities affected most positively

Table 12-19. Percentage change in recreation participants across all activities and scenarios by RPA region and the Nation, 2008 to 2060.[a]

Outdoor recreation activity group	Nation or RPA region	2008 total participants[b]	2060 average change in total participants[c]	2060 average change in total participants[d, e]
			without climate change	with climate change
		millions	*percentage change increase (decrease) from 2008*	
Developed site usage				
Visiting developed sites	RPA North Region	81	36	30
	RPA South Region	63	73	69
	RPA Rocky Mountain Region	17	94	94
	RPA Pacific Coast Region	31	68	67
	Nation	194	60	58
Visiting interpretative sites	RPA North Region	67	44	44
	RPA South Region	51	83	80
	RPA Rocky Mountain Region	15	108	107
	RPA Pacific Coast Region	26	72	71
	Nation	158	68	66
Observing nature				
Birding	RPA North Region	37	44	31
	RPA South Region	27	86	88
	RPA Rocky Mountain Region	7	104	103
	RPA Pacific Coast Region	13	69	71
	Nation	82	65	58
Nature viewing	RPA North Region	80	39	33
	RPA South Region	63	72	70
	RPA Rocky Mountain Region	18	97	96
	RPA Pacific Coast Region	31	66	65
	Nation	190	60	59
Backcountry activities				
Challenge activities	RPA North Region	9	25	22
	RPA South Region	7	92	74
	RPA Rocky Mountain Region	4	112	115
	RPA Pacific Coast Region	5	54	57
	Nation	25	74	73
Horseback riding on trails	RPA North Region	6	45	73
	RPA South Region	6	67	65
	RPA Rocky Mountain Region	2	73	57
	RPA Pacific Coast Region	3	78	75
	Nation	16	69	80
Day hiking	RPA North Region	33	43	31
	RPA South Region	20	94	82
	RPA Rocky Mountain Region	10	110	110
	RPA Pacific Coast Region	17	67	63
	Nation	79	70	64
Primitive area use	RPA North Region	36	30	6
	RPA South Region	28	61	60
	RPA Rocky Mountain Region	12	89	73
	RPA Pacific Coast Region	18	53	55
	Nation	91	52	48

Table 12-19. Percentage change in recreation participants across all activities and scenarios by RPA region and the Nation, 2008 to 2060.[a] (continued)

Outdoor recreation activity group	Nation or RPA region	2008 total participants[b]	2060 average change in total participants[c]	2060 average change in total participants[d, e]
			without climate change	with climate change
		millions	*percentage change increase (decrease) from 2008*	
Motorized activities				
Motorized off-roading	RPA North Region	17	28	19
	RPA South Region	17	40	37
	RPA Rocky Mountain Region	6	83	83
	RPA Pacific Coast Region	9	47	49
	Nation	48	43	43
Motorized water activities	RPA North Region	26	41	64
	RPA South Region	21	72	75
	RPA Rocky Mountain Region	5	103	81
	RPA Pacific Coast Region	10	80	78
	Nation	62	64	57
Motorized snow activities	RPA North Region	7	12	(57)
	RPA South Region[f]	1	—	—
	RPA Rocky Mountain Region	1	30	21
	RPA Pacific Coast Region	1	52	44
	Nation	9	28	(26)
Consumptive activities				
Hunting	RPA North Region	11	5	(15)
	RPA South Region	11	15	14
	RPA Rocky Mountain Region	3	32	15
	RPA Pacific Coast Region	3	9	19
	Nation	28	17	13
Fishing	RPA North Region	29	26	48
	RPA South Region	28	44	37
	RPA Rocky Mountain Region	7	76	48
	RPA Pacific Coast Region	10	52	54
	Nation	73	46	37
Nonmotorized winter activities				
Developed skiing	RPA North Region	12	56	55
	RPA South Region[f]	4	—	—
	RPA Rocky Mountain Region	3	135	136
	RPA Pacific Coast Region	5	91	96
	Nation	24	93	89
Undeveloped skiing	RPA North Region	5	30	(17)
	RPA South Region[f]	1	—	—
	RPA Rocky Mountain Region	1	86	74
	RPA Pacific Coast Region	1	22	32
	Nation	8	53	(7)
Nonmotorized water activities				
Swimming	RPA North Region	62	46	30
	RPA South Region	47	83	76
	RPA Rocky Mountain Region	11	100	110
	RPA Pacific Coast Region	25	75	74
	Nation	144	69	69
Floating	RPA North Region	18	33	9
	RPA South Region	12	69	52
	RPA Rocky Mountain Region	3	71	71
	RPA Pacific Coast Region	6	55	53
	Nation	40	49	32

RPA = Resources Planning Act.

[a] Activities are composites derived from the National Survey on Recreation and the Environment (NSRE). Participant estimates are the product of the average weighted activity participation frequency for NSRE data from 2005 to 2009 and the adult (> 16) population in the United States during 2008 (235.4 million).

[b] Because initial values for 2008 differ across RPA scenarios, an average is used for a starting value.

[c] Average percentage change in total participation across RPA scenarios A1B, A2, and B2, without climate considerations.

[d] Average percentage change in total participation across RPA scenarios A1B, A2, and B2 and across climate models.

[e] Percentage differences between without and with climate considerations exceeding 10 percent are highlighted: > 10-percent decrease > 10-percent increase

[f] Projection models were not estimated for winter activities in the South Region.

are horseback riding on trails, motorboating, and fishing in the North Region. The activities affected most negatively include snowmobiling in the North and Pacific Coast Regions, hunting in the North and Rocky Mountain Regions, undeveloped skiing in the North and Rocky Mountain Regions, and floating in the North and South Regions. Participation in activities such as developed skiing, motorized off-roading, nature viewing, visiting developed and interpretive sites, birding, and challenge activities appear largely unaffected by climate changes.

Annual days per participant appear somewhat more negatively influenced by expected future climate changes than do participation rates. This negative influence is also reflected in total participation days (table 12-20). Incorporating climate effects generally leads to lower increases in total participation days, particularly in the North Region. Exceptions include horseback riding on trails, motorized water activities, and fishing in the North Region and day hiking in the Rocky Mountain Region. In a number of cases, climate effects lead to projected decreases in total days for some activities versus their levels in 2008. The most notable cases are motorized snow activities, hunting, undeveloped skiing, and primitive area use in the North Region.

Table 12-20. Percentage change in recreation days across all activities and scenarios by RPA region and the Nation, 2008 to 2060.[a]

Outdoor recreation activity group	Nation or RPA region	2008 total days[b]	2060 average change in total participants[c]	2060 average change in total participants[d, e]
			without climate change	with climate change
		millions	*percentage change increase (decrease) from 2008*	
Developed site usage				
Visiting developed sites	RPA North Region	948	32	19
	RPA South Region	676	73	73
	RPA Rocky Mountain Region	234	92	86
	RPA Pacific Coast Region	389	82	78
	Nation	2,246	58	53
Visiting interpretative sites	RPA North Region	519	50	57
	RPA South Region	368	100	96
	RPA Rocky Mountain Region	134	116	113
	RPA Pacific Coast Region	228	103	95
	Nation	1,249	76	79
Observing nature				
Birding	RPA North Region	3,714	40	27
	RPA South Region	2,876	55	38
	RPA Rocky Mountain Region	555	116	107
	RPA Pacific Coast Region	1,110	57	56
	Nation	8,255	59	51
Nature viewing	RPA North Region	13,993	28	23
	RPA South Region	10,855	55	50
	RPA Rocky Mountain Region	2,762	79	78
	RPA Pacific Coast Region	4,851	48	44
	Nation	32,461	45	42
Backcountry activities				
Challenge activities	RPA North Region	38	24	21
	RPA South Region	26	110	122
	RPA Rocky Mountain Region	34	97	101
	RPA Pacific Coast Region	23	51	57
	Nation	120	71	74
Horseback riding on trails	RPA North Region	73	49	67
	RPA South Region	99	87	(2)
	RPA Rocky Mountain Region	69	69	54
	RPA Pacific Coast Region	22	138	133
	Nation	263	74	63
Day hiking	RPA North Region	727	39	28
	RPA South Region	465	86	73
	RPA Rocky Mountain Region	202	98	110
	RPA Pacific Coast Region	440	65	65
	Nation	1,834	80	75
Primitive area use	RPA North Region	417	16	(14)
	RPA South Region	414	62	50
	RPA Rocky Mountain Region	163	60	48
	RPA Pacific Coast Region	245	68	65
	Nation	1,239	50	42

Table 12-20. Percentage change in recreation days across all activities and scenarios by RPA region and the Nation, 2008 to 2060.[a] (continued)

Outdoor recreation activity group	Nation or RPA region	2008 total days[b]	2060 average change in total participants[c]	2060 average change in total participants[d, e]
			without climate change	with climate change
		millions	*percentage change increase (decrease) from 2008*	
Motorized activities				
Motorized off-roading	RPA North Region	284	14	6
	RPA South Region	564	37	5
	RPA Rocky Mountain Region	97	68	65
	RPA Pacific Coast Region	107	32	35
	Nation	1,053	34	37
Motorized water activities	RPA North Region	381	44	69
	RPA South Region	386	63	65
	RPA Rocky Mountain Region	72	109	86
	RPA Pacific Coast Region	119	90	88
	Nation	958	62	52
Motorized snow activities	RPA North Region	55	(1)	(62)
	RPA South Region[f]	4	—	—
	RPA Rocky Mountain Region	6	11	3
	RPA Pacific Coast Region	12	27	17
	Nation	69	24	(39)
Consumptive activities				
Hunting	RPA North Region	211	(5)	(30)
	RPA South Region	231	14	18
	RPA Rocky Mountain Region	47	22	5
	RPA Pacific Coast Region	49	(12)	(6)
	Nation	538	3	(2)
Fishing	RPA North Region	518	19	62
	RPA South Region	575	41	17
	RPA Rocky Mountain Region	97	62	35
	RPA Pacific Coast Region	178	40	41
	Nation	1,369	38	29
Nonmotorized winter activities				
Developed skiing	RPA North Region	82	32	10
	RPA South Region[f]	23	—	—
	RPA Rocky Mountain Region	23	162	161
	RPA Pacific Coast Region	47	112	116
	Nation	171	103	96
Undeveloped skiing	RPA North Region	32	34	(23)
	RPA South Region[f]	3	—	—
	RPA Rocky Mountain Region	7	80	53
	RPA Pacific Coast Region	10	17	19
	Nation	51	56	(11)
Nonmotorized water activities				
Swimming	RPA North Region	1,383	51	21
	RPA South Region	1,118	81	64
	RPA Rocky Mountain Region	223	95	105
	RPA Pacific Coast Region	752	88	86
	Nation	3,476	70	66
Floating	RPA North Region	125	33	(8)
	RPA South Region	80	65	60
	RPA Rocky Mountain Region	17	57	54
	RPA Pacific Coast Region	40	53	50
	Nation	262	49	32

RPA = Resources Planning Act.

[a] Activities are composites derived from the National Survey on Recreation and the Environment (NSRE). Participant estimates are the product of the average weighted activity participation frequency for NSRE data from 2005 to 2009 and the adult (> 16) population in the United States during 2008 (235.4 million).

[b] Because initial values for 2008 differ across RPA scenarios, an average is used for a starting value.

[c] Average percentage change in total participation across RPA scenarios A1B, A2, and B2, without climate considerations.

[d] Average percentage change in total participation across RPA scenarios A1B, A2, and B2 and across climate models.

[e] Percentage differences between without and with climate considerations exceeding 10 percent are highlighted: > 10-percent decrease > 10-percent increase

[f] Projection models were not estimated for winter activities in the South Region.

Overall growth in the number of recreation participants and total days of recreation is projected because the rate of growth of the population is expected to exceed the rate at which per capita participation declines. For most activities, however, population density is somewhat negatively correlated with participation. With projected increases in urbanization, population density will increase in many areas where people live. Unless recreation behavior changes, the increases in population density will be accompanied by decreases in participation rates for some activities, especially those most affected by crowding or access limits. With an assumed static public land base, and a declining private land base as a result of land use change and access limitations, some venues will likely see more crowding and, in many cases, a decreased quality of experience.

The magnitude and direction of outdoor recreation participation will change as the proportion of minority groups in the population grows, age levels increase, urbanization becomes more widespread, and economic conditions change. Non-Hispanic White visitors, particularly males, continue to dominate participation in most outdoor recreation activities. Some exceptions occur because American Indian populations have similar or higher participation rates for many backcountry activities in most regions, and Hispanic visitors are more likely than White visitors to participate in day hiking in the North, South, and Rocky Mountain Regions. For most activities and across most regions, African-American populations are the least likely to participate. Males are more likely to participate in most activity groups, except in visiting developed sites and nature viewing. Age is negatively correlated with most activities requiring stamina. Place of residence, as represented by population density, is also correlated negatively with participation in most activities across regions, especially with space-intensive activities like motorized off-roading, hunting, horseback riding on trails, and other backcountry use. Income is positively correlated with a number of activities across regions, including motorboating, horseback riding, downhill skiing, undeveloped skiing, hunting, fishing, and challenge activities. Higher education levels often have a negative effect on participation in activities like hunting, fishing, and motor sports. Thus, with income, age, education levels, urbanization, and the proportion of minority groups, especially Hispanic, rising in the population, participation rates can be expected to continue changing.

Recreation on National Forests and Grasslands

- ❖ National forests continue to provide outdoor recreation opportunities to large numbers of the American public.

- ❖ Disability access to national forests, in general, is acceptable.

- ❖ Minority groups, both racial and ethnic, continue to be underrepresented relative to the general population in their use of national forests for outdoor recreation.

- ❖ Overall, recreation visitors to national forests, nationwide and across the RPA regions, judged their experience as satisfactory.

The Forest Service's National Visitor Use Monitoring (NVUM) Program uses survey methodology to collect visitation data from national forests over time and space. In this section, we briefly describe NVUM and summarize regional and national results for estimates of visitation, activity participation, demographic characteristics, and perceptions of satisfaction and crowding among national forest visitors. More detailed analyses are available in Askew and Bowker (In press).

NVUM is an onsite survey of recreation visitors to all national forests. Recreation information is collected from each forest in 5-year intervals with 20 percent of national forests surveyed each year. The results compiled for this analysis are attributed to reporting year 2009 and represent the most recent complete NVUM interval, 2005 to 2009 (USDA Forest Service 2015a). These data provide a snapshot of national forest recreation spanning the latest National Survey of Recreation and the Environment (NSRE) data (1999 to 2008) used in other sections of this chapter and for recent RPA Assessment recreation reports (Bowker et al. 2012; Cordell 2012).

The surveys are conducted as recreation visitors exit four types of national forest recreation sites: day use developed sites, overnight use developed sites, general forest areas, and designated wilderness. The behaviors of recreationists differ by site type because activity opportunities, recreation intensities, and attributes of the setting vary across the four categories. Survey respondents report basic information about the current recreation visit, demographic characteristics of their group, spending in the immediate vicinity, and perceived satisfaction/importance for selected attributes of the recreation site or area visited (English et al. 2002). More than 230,000 visitors to national forests, about one-half of which were recreation visitors, were surveyed by NVUM during the 5-year period from 2005 to 2009.

Summaries of national forest recreation and visitor profiles are available at various scales, including single forests, multiple forests, regions, regional aggregates, and the Nation. The results displayed here are from an aggregation of nine National Forest System (NFS) regions into the RPA Assessment regions (see figure 12-1 in the first section of this chapter).

Visitation on National Forests and Grasslands

NVUM provides two measures of recreation visitation to national forests and grasslands: site visits and national forest visits. Site visits measure the number of recreation visits to individual sites or areas on a particular national forest. National forest visits represent the number of recreation visits to the entire national forest as a unit. A national forest visit occurs when an individual recreates on a national forest for any length of time, participates in one or more activities, and visits one or more sites on the forest (Zarnoch et al. 2011). If a person visits a national forest once and goes to three sites during that visit, one national forest visit and three site visits have been produced. National forest visits are an estimate of the number of visitors exiting the forest annually, not the number of unique individuals exiting the forest. An individual is counted multiple times for multiple visits. A visitor and a visit are used interchangeably in this document.

In 2009, an estimated 142.7 million national forest visits occurred (table 12-21). The Rocky Mountain Region had the greatest share of visits, at 65.7 million, and the North Region had the fewest visits, at 15.3 million. National forest visits, adjusted to a per-acre basis, were highest in the South Region (1.5 visits per acre), followed by the North (1.1), Rocky Mountain (0.56), and Pacific Coast (0.48) Regions. Special events and organized camps accounted for 2.6 million visits. Estimated national forest visits increased to 146.8 million in 2014, an increase of 3 percent (table 12-22). The South and Rocky Mountain Regions experienced visitation increases, and the North and Pacific Coast Regions saw decreased visitation.

The 2009 annual number of sites visited on national forests by all visitors was 184.4 million (table 12-21). The breakout of national site visits into individual site types shows the general forest area was the most visited site type, receiving 51 percent of total site visits. Wilderness reported the fewest number of visits, at 6.4 million visits, between 3 and 4 percent of the total. Several factors contribute to lower levels of visitation in wilderness areas, including limitations on the availability, access, and types of activity opportunities provided. For 2014, total site visits increased by from 184.4 to 191.8, or 4 percent. Although day use and general forest areas increased the most in total site visits, wilderness and overnight developed use increased the most relatively, at 28 and 7 percent, respectively.

Some of the variability in visits across regions can be explained by differences in the total NFS acreage in each RPA region (table 12-23). On an RPA regional basis, the North and South Regions had the fewest visits and least acreage overall and in wilderness, yet they supported the highest levels of visitation

Table 12-21. National forest visits and site visits by site type, RPA region, and the Nation, 2009.[a]

Visit or site type	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
			million visits		
Total national forest visits	15.3	21.3	65.7	40.3	142.7
Total site visits	19.3	27.8	83.6	53.7	184.4
Day use	4.6	6.5	33.8	24.9	69.8
Overnight developed	0.9	2.3	6.6	5.1	14.9
General forest area	13.2	18.3	39.7	22.1	93.3
Wilderness	0.6	0.7	3.5	1.6	6.4

RPA = Resources Planning Act.

[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

Table 12-22. National forest visits and site visits by site type, RPA region, and the Nation, 2014.[a]

Visit or site type	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
			million visits		
Total national forest visits	12.7	25.2	70.6	38.4	146.8
Total site visits	16.6	32.7	87.2	55.3	191.8
Day use	5.2	10.1	32.6	24.9	72.8
Overnight developed	0.9	2.4	5.9	6.7	15.9
General forest area	10.0	19.4	43.8	21.5	94.7
Wilderness	0.5	0.7	4.8	2.2	8.2

RPA = Resources Planning Act.

[a] Information for 2014 is compiled from surveys of all national forests during the interval from 2010 to 2014.

Table 12-23. Area of National Forest System (NFS) and wilderness[a] lands by RPA region and the Nation, 2009.

	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
			land area		
NFS	12,244	13,353	99,430	67,751	192,778
Wilderness	1,427	764	18,203	15,772	36,166

RPA = Resources Planning Act.

[a] Wilderness on NFS lands only.

Source: USDA Forest Service (2010).

on a per-acre basis. Nationwide and across the RPA regions, the visitation rate per acre for general forest areas is significantly higher than for wilderness.

Characteristics of Recreation Visits

Activity Participation

Recreation visitors to national forests reported participation in 28 recreation activities. Table 12-24 lists the top five activities by level of participation nationwide and for each RPA region in 2009. Viewing natural features, hiking/walking, viewing wildlife, and relaxing were all ranked in the top five in every region. Downhill skiing displaced driving for pleasure for the Pacific Coast Region as a top-five activity. Viewing natural features reported the highest participation, approaching 50 percent in most regions.

Visitors were also asked to provide the one activity that represented the main or primary activity for their visit. Viewing natural features and hiking/walking were ranked in the top five activities nationwide and across all regions for both participation and primary activity. Hunting and fishing were not included as top participation activities but ranked highly as main activities for a significant portion of recreation visitors. Conversely, wildlife viewing was an important ancillary activity for more than one-third of national forest visitors, yet it was not among the top primary activities. Downhill skiing was a top-five primary activity in all regions, excluding the South Region, and was selected by more than 20 percent of visitors in the Rocky Mountain and Pacific Coast Regions.

Frequency and Duration of Visits

National forest visitors reported the number of times they visited the same national forest in the past year. Nationwide, 48 percent of visitors reported between one and five visits annually; for the Pacific Coast Region, 56 percent of visitors reported between one and five visits per year. The frequency of annual visits dropped significantly beyond five visits and differed little across regions. About 7 percent of visitors returned to the same forest at least 100 times a year and 1 percent returned more than 300 times.

Understanding how many trips recreationists take provides insight into frequency, but to understand intensity requires an examination of the time spent on visits to national forests. Table 12-25 reports the average duration of visits to national

Table 12-24. Percentage of visitors in the top five recreation activities for participation and primary activity by RPA region and the Nation, 2009.[a]

Recreation activities	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
			percent		
Top five activities for participation					
Viewing natural features	52.6	45.4	47.3	49.1	48.0
Hiking/walking	32.4	42.0	39.3	44.7	40.6
Viewing wildlife	33.3	33.2	36.8	36.7	35.8
Relaxing	32.5	37.2	33.7	37.9	35.3
Driving for pleasure	18.8	26.6	22.6	—	22.3
Downhill skiing	—	—	—	23.4	—
Top five main/primary activities					
Hiking/walking	11.7	18.1	18.6	19.8	18.2
Downhill skiing	9.4	—	20.8	22.5	16.6
Viewing natural features	22.0	15.8	10.1	12.4	12.9
Fishing	8.1	13.8	6.3	5.4	7.5
Hunting	11.6	12.9	5.2	—	6.7
Relaxing	—	—	—	7.2	—
Driving for pleasure	—	5.9	—	—	—

RPA = Resources Planning Act.

[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

Table 12-25. Average duration of site and national forest visits by site type, RPA region, and the Nation, 2009.[a]

Visit or site type	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
			hours		
Duration of national forest visits	22.1	16.7	23.5	19.2	21.1
Duration of site visits	14.0	10.8	10.2	11.8	11.1
Day use	2.7	2.3	2.8	3.0	2.8
Overnight developed	48.3	49.4	38.3	54.0	46.0
General forest area	14.7	9.1	11.5	11.4	11.3
Wilderness	29.5	9.2	11.4	16.2	14.1

RPA = Resources Planning Act.

[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

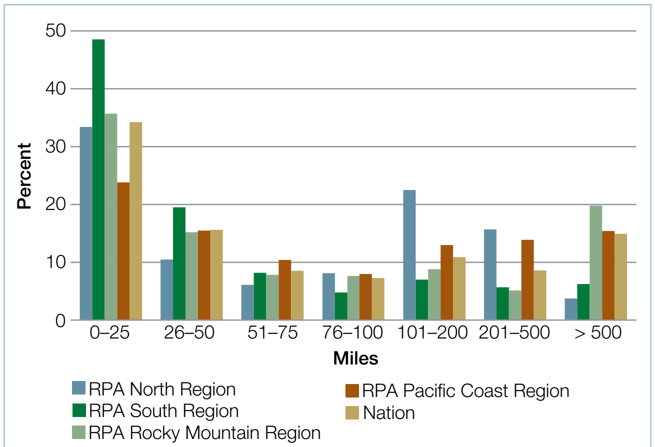
forests and the specific site types visited within forests. The average visit to a national forest nationwide was 21.2 hours, with the longest duration in the Rocky Mountain Region and shortest in the South Region. Nationwide and at the regional level, overnight developed sites reported the longest stays, about 2 days, and day use developed sites often restrict visits to daylight hours and reported an average duration of a little less than 3 hours. Wilderness sites had the largest variation in visit duration across regions.

Travel Distance

The distance traveled by visitors to national forests is an important element of recreation visitor behavior and is used to define market areas for forest recreation and individual activities. Activities not only vary in their geographical availabilities but also in the willingness of recreationists to travel for opportunities. For example, there may be abundant fishing opportunities within a short distance allowing visitors multiple choices among quality substitutes. Other activities like downhill skiing may require farther travel with fewer choices, especially if one lives in the South Region. Recreationists may curtail their driving if gas prices become too high, or they may be encouraged to travel farther or more often in the case of lower fuel costs.

Both nationwide and at the regional level, the largest share of national forest visitors traveled 25 miles or less to the forest (figure 12-2). These visitors live nearby, visit the forest often, and have a variety of recreation opportunities from which to choose. Nearly 50 percent of national forest visitors in the South Region traveled the shortest distances. Although the overall pattern reflects decreasing visitation as distance to the forest increases, unique variations appear in each region. The Rocky Mountain Region showed a second peak for travelers exceeding 500 miles, nearly 20 percent of reported national forest visits. This peak could be attributable to the popularity of skiing and other winter activities that were not as prevalent in other regions. The Pacific Coast Region showed the fewest fluctuations and changes across distance categories.

Figure 12-2. Percentage of national forest visits by distance traveled to forest, RPA region, and the Nation, 2009.[a]



RPA = Resources Planning Act.
[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

Demographic Profile of National Forest Visitors

The demographic characteristics of recreation visitors play an important role in informing recreation managers about the preferences and needs of visitors. Current visitors can be characterized demographically by gender, race/ethnicity, age, and household income (table 12-26). With the U.S. population anticipated to grow older and become more racially and ethnically diverse over time, it is important to understand how recreation participation of current users varies on these and other demographic traits across all national forests.

Table 12-26. Percentage of national forest visits by demographic characteristic, RPA region, and the Nation, 2009.[a]

Demographic characteristic	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
			percent		
Gender					
Female	28.5	28.6	36.7	39.2	35.4
Male	71.5	71.4	63.3	60.8	64.6
Race/ethnicity					
American Indian/ Alaska Native	2.0	2.8	2.2	2.5	2.4
Asian	0.9	0.7	1.1	8.1	3.2
Black/African-American	0.5	2.2	0.7	1.3	1.2
Hawaiian/Pacific Islander	0.1	0.2	0.4	0.8	0.5
White	97.4	96.6	96.8	89.6	94.6
Total across race groupings	**100.9**	**102.5**	**101.2**	**102.3**	**101.9**
Hispanic/Latino	1.3	4.3	6.3	7.9	6.0
Age					
Younger than 16	14.6	19.1	18.1	16.7	17.6
16 to 19	3.4	3.6	3.4	4.3	3.7
20 to 29	12.5	13.3	13.4	13.5	13.3
30 to 39	15.1	14.9	15.7	16.4	15.7
40 to 49	24.0	17.8	18.8	21.1	19.7
50 to 59	17.2	16.4	16.8	17.0	16.9
60 to 69	9.6	11.1	10.2	8.3	9.8
70 and older	3.5	3.8	3.6	2.7	3.4
Household income					
Less than $25,000	9.5	17.0	9.9	8.9	10.7
$25,000 to $49,999	29.4	31.5	20.9	19.8	23.1
$50,000 to $74,999	27.5	26.0	22.9	24.3	24.2
$75,000 to $99,999	13.1	11.5	17.6	20.3	16.9
$100,000 to $149,999	13.4	8.4	16.8	15.9	14.9
$150,000 and more	7.0	5.7	12.0	10.9	10.2

RPA = Resources Planning Act.
[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

Gender

National forest visitors were predominantly male, representing nearly 65 percent of national visits (table 12-26). This pattern did not vary substantially across regions. More variability was seen at the subregional or national forest level because gender distribution was sensitive to the availability of recreation activities and by proximity to population centers.

Race and Ethnicity

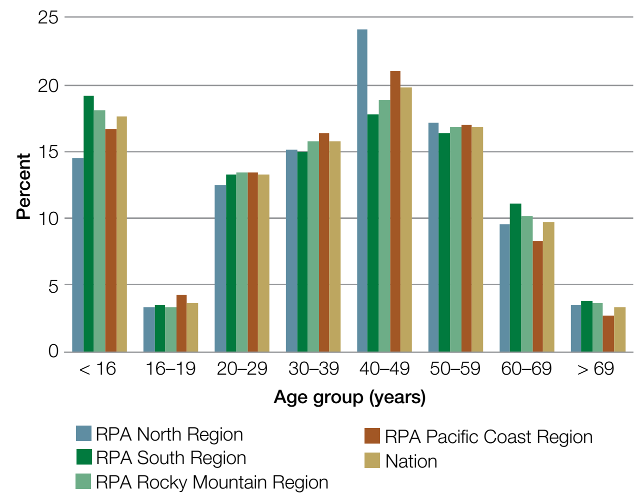
Visitors from different racial and ethnic groups vary in their recreation behaviors and preferences. These variations may also be influenced by the geographic distribution of minority populations. For example, the proportion of Black/African-American visitors is greatest in the South Region and of Asian visitors is greatest in the Pacific Coast Region. The proportion of Hispanic visitors is lower in the North Region than in the Rocky Mountain Region. A more thorough understanding of recreation user diversity can inform allocation of resources to encourage increased participation and to address the needs of all races and ethnicities. The percentage of national forest visits by race and Hispanic/Latino ethnicity is reported in table 12-26. The totals exceed 100 percent because multiracial visitors can select more than one race. Race and ethnicity are recorded separately to provide more accurate responses in each category.

Nearly 95 percent of national forest visits were from people who self-identify as being White. Of the minority racial populations, the American Indian/Alaska Native group had the lowest census percentage of the population but had the highest proportion of visits in most RPA regions. The Asian population had significantly more recreationists among minority participants in the Pacific Coast Region, likely because of the demographics of the region. The Hawaiian/Pacific Islander and Black/African-American groups provided the fewest recreation visitors, with the former corresponding to the lowest counts in all regions. Nationwide, Hispanic populations accounted for nearly 6 percent of national forest visits, with the greatest number in the Pacific Coast Region, at just under 8 percent. The North Region saw the lowest percentage of Hispanic visitation.

Age

Age is an important demographic variable for explaining recreation use across time (table 12-26). Understanding how recreation participation changes relative to age is important for the allocation of resources to encourage/maintain participation, improve accessibility, or restructure opportunities appropriate to specific age groups. Figure 12-3 shows that peak national forest visits for adults occurred in the 40-to-49-year age range. At the regional level, the peak was most pronounced for the North Region, where nearly one-fourth of national forest visits come from that age group. The smallest concentration of visitors was from

Figure 12-3. Percentage of national forest visits by age group, RPA region, and the Nation, 2009.[a]



RPA = Resources Planning Act.
[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

those identifying as 16 to 19 years of age and as 70 years old or older. The teenage group, however, was also the age interval with the fewest years. Those 70 years of age or older could have mobility or other restrictions and thus did not engage in the broad spectrum of activities that national forests provide.

Annual Household Income

Annual household income is another important demographic attribute explaining variation in participation among recreation visitors (table 12-26). The South Region had the greatest percentage of visitors with an annual household income of less than $25,000, almost double the percentages of other regions. Household incomes of more than $150,000 were reported most often in the Rocky Mountain and Pacific Coast Regions. For all regions except the Pacific Coast Region, the most common income categories were $25,000 to $49,999 and $50,000 to $74,999.

Visitor Perceptions of Recreation Setting Attributes

Satisfaction

Visitor satisfaction analysis is developed from NVUM to provide measures of performance to assess managerial effectiveness. Recreation visitors were asked to rate their perceptions of importance and satisfaction for 14 site attributes. The importance scale ranges from 1 (very unimportant) to 5 (very important) and the satisfaction scale ranges from 1 (very dissatisfied) to 5 (very satisfied). Of the 14 attributes, 11 were aggregated among the following 4 major categories for easier analysis and interpretation:

1. **Developed facilities—**restroom cleanliness and developed facilities.

2. **Access—**parking availability, parking lot condition, road condition, and trail condition.

3. **Services—**employee helpfulness, interpretative displays, recreation information availability, and signage accuracy.

4. **Feeling of safety—**feeling of safety.

Attributes not included in these groupings reflect qualities of the environment rather than characteristics or services directly related to management control. The percentages of satisfied visitors are given in table 12-27 by site type across RPA regions for the four aggregate quality categories. A management attainment goal for satisfaction was set at 85 percent (USDA Forest Service 2015b). Day use developed and overnight developed sites were grouped into a single category—developed sites—for this analysis.

For developed sites, general forest area, and wilderness, the attribute with the greatest percentage of satisfied users was feeling of safety with ratings between 92 and 97 percent for all regions and site types. The percentage of satisfied users was lowest for the services category when comparing site type scores across most regions and nationwide. Satisfaction with services in the general forest area and wilderness did not exceed 80 percent in any region and was only 68 percent for wilderness in the South Region. Recreationists were generally satisfied with access to recreation opportunities for wilderness in all regions and for developed sites in most regions. The Pacific Coast Region visitors were least satisfied, at 78 percent, significantly lower than the next lowest region. Satisfaction for developed facilities consistently was rated high for developed sites across all regions. Ratings were lower nationwide and across regions for the general forest area and wilderness sites—areas not known for developed facilities. Overall, national satisfaction ratings for the general forest area were lowest for three of the four attribute categories and exceeded the 85 percent satisfaction threshold only for the feeling of safety category.

Importance-Performance Analysis

The Forest Service uses mean satisfaction and importance scores to provide a two-dimensional insight into how users perceive recreation on national forests: whether important aspects are satisfactorily fulfilled or whether resources are dedicated to less-than-important areas. This Importance-Performance Analysis views recreationists as customers and is useful to managers in allocating limited resources to attributes of the recreation opportunity that need improving (Gill et al. 2010; Martilla and James 1977). The analysis involves classifying individual satisfaction and importance mean scores on the same attribute according to thresholds established beforehand. A threshold measure of 4 is used as a cutoff to assign the attributes by score into four importance/satisfaction categories:

1. **Keep up the good work—**Importance ≥ 4, satisfaction ≥ 4 (high importance, high satisfaction).

2. **Possible overkill—**Importance < 4, satisfaction ≥ 4 (low importance, high satisfaction).

3. **Low priority—**Importance < 4, satisfaction < 4 (low importance, low satisfaction).

4. **Concentrate here—**Importance ≥ 4, satisfaction < 4 (high importance, low satisfaction).

Table 12-27. Percentage of satisfied visitors for site attributes by site type, RPA region, and the Nation, 2009.[a]

Site type	RPA North Region	RPA South Region	RPA Rocky Mountain Region	RPA Pacific Coast Region	Nation
	percent				
Developed facilities					
Developed sites	86	86	87	82	85
General forest area	82	76	83	79	80
Wilderness	67	81	85	73	79
Access					
Developed sites	91	92	87	78	85
General forest area	84	84	83	84	84
Wilderness	86	86	89	88	88
Services					
Developed sites	84	82	83	84	83
General forest area	77	74	74	73	74
Wilderness	74	68	79	75	76
Feeling of safety					
Developed sites	97	95	95	95	95
General forest area	95	93	93	92	93
Wilderness	96	94	96	96	96

RPA = Resources Planning Act.

[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

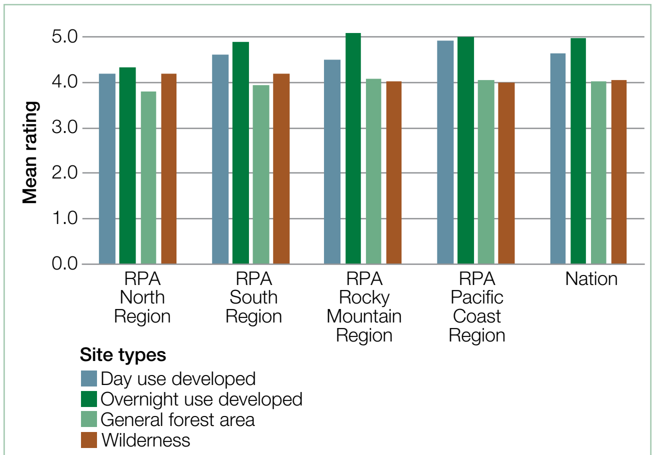
The results of this analysis (Askew and Bowker, in press) showed remarkably consistent and positive ratings for most of the recreation attributes across the 280 site type/region/quality combinations evaluated. Nearly 89 percent of the rankings were classified as "keep up the good work," in which both satisfaction and importance are rated highly. Only four combinations produced an outcome of "concentrate here," reflecting low satisfaction. These combinations included restroom cleanliness in day use developed sites for the Pacific Coast Region and the general forest area for the South Region, parking availability in Pacific Coast Region day use developed sites, and recreation information availability for wilderness in the South Region.

Crowding

Visitor perception of crowding is an important factor in user ratings of satisfaction from a recreation visit. Expectations of crowding vary by activity choice and also by site type selected for the visit. Visitors are likely to expect more solitude from visits to wilderness than to developed sites providing opportunities for interpretive services and picnicking. Consumptive activities like fishing may benefit from a lower level of crowding so that natural resources are not exhausted.

Crowding at national forest sites is evaluated on a 10-point scale, with visitor perception of crowding ranging from 1 (hardly anyone) to 10 (overcrowded). Average scores for crowding across all sites and regions varied between 3.8 and 5.1 (figure 12-4), a rating range reflecting slightly uncrowded conditions. Overnight use developed sites and, to a lesser extent, day use developed sites were a little more crowded than other sites across all regions. Within a site type, there was minimal variation (<0.3) from the national averages and between regions. The notable exception was the North Region, where overnight use developed and day use developed sites reported levels of crowding that were lower than national averages.

Figure 12-4. Mean crowding rating by site type, RPA region, and the Nation, 2009.[a]



RPA = Resources Planning Act.
[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009. The level of crowding is on a scale of 1 to 10, with 1 being "hardly anyone" to 10 being "overcrowded."

Accessibility

To facilitate access to recreation for all user groups, it is important to consider whether people with disabilities are able to participate. Overall, approximately 7 percent of visits involved a group with at least one member who had a disability; nearly 10 percent of the visitor groups in the South Region reported at least one member with a disability. For groups reporting a disability, the percentage of visitors rating facilities as accessible varied from 58 percent in the South Region to 85 percent in the Pacific Coast Region.

Summary

The national forests continue to provide outdoor recreation opportunities to large numbers of the American public, accommodating an average of 142.7 million annual national forest recreation visits. Agency estimates for 2014 indicate that forest visits rose to 146.8 million. A variety of recreation opportunities, from developed sites to wilderness areas, is available to provide venues for a wide range of outdoor recreation activities. The importance of public lands such as the national forests is expected to increase as access to private lands, either through land use change or restricted access, is expected to decrease over time.

The national forests continue to provide high-quality outdoor recreation opportunities and settings for the American public. Across nearly all regions and site types, national forest visitors expressed satisfaction with setting attributes they deemed important, including condition of the environment, natural scenery, signage adequacy, trail conditions, and value for any fees paid. Accessibility ratings by visitors, in general, were high but show room for improvement. With an aging population, led by a large segment of retiring baby boomers, and with a sizeable number of families having a disabled member, accessibility of outdoor recreation opportunities will continue to be important.

Minority populations, racial and ethnic, continue to recreate on national forests in smaller proportions than in the U.S. population at large. As the U.S. population is projected to become more racially and ethnically diverse, particularly in urban areas, it is likely that the number of minority groups recreating on national forests will increase in the future. Minority participation, however, will probably remain disproportionately lower than for the population at large, unless historical minority participation rates increase.

Future Work

The recreation trends and recreation projections parts of the 2010 RPA and this RPA Update drew primarily on data from the NSRE. The NSRE ended in 2010; thus, a significant need exists to identify and develop datasets for the 2020 RPA Assessment. We are exploring several datasets for the potential to do further work: the Forest Service NVUM project, the National Woodland Owner Survey (a periodic survey on nonindustrial private forest landowners), the Department of the Interior's Fishing Hunting and Wildlife-Associated Recreation survey, and the surveys conducted by the Outdoor Industry Association. We will be using the NVUM data for more detailed analyses of recreation on national forests.

A major limitation of previous RPA recreation projections is that they provide limited information regarding changes in recreation participation and drivers of these changes at smaller scales (climate patterns, regional economic differences, cultural change), which could be more relevant to resource managers. Moreover, the climate variables for projection modeling at the national and regional levels are strictly based on the participant's origin rather than destination. Thus, further analysis is needed that explores destination-based climate variables and levels of recreation participation and consumption.

Conclusions

The American public will continue to enjoy the benefits of outdoor recreation. The number of Americans participating in outdoor recreation will continue to grow during the next five decades. Differences in recreation opportunities and future resident populations will require recreation management strategies that respond to changing regional patterns. The fastest growing recreation activities vary across regions, influenced by a variety of socioeconomic factors and the availability of recreation opportunities. In addition, national, regional, and subregional levels of participation in certain activities may change by large amounts in response to climate change. Participation projections incorporating climate change reveal significant positive and negative effects on recreation participation growth for some activities.

Population growth results in increasing numbers of outdoor recreation participants. At the same time, projected increases in urbanization will increase population density in areas where most people live. For most activities, population density is negatively correlated with participation. Unless recreation behavior changes, the increased density will be accompanied by decreases in participation rates for some activities, especially those most affected by crowding or access constraints.

Managers of the Nation's recreation opportunities will be challenged to anticipate and adjust to the changing preferences and needs of the evolving population. Projected changes in the proportion of minorities and average age will affect patterns of participation and preferred activities. Increased and refocused recreation investments may be needed to address evolving recreation preferences and demand.

The national forests provide opportunities to large numbers of the American public. Most visitors have been satisfied with their recreation experiences on national forests to date. In the future, managers' responses to changes in activity preferences and climate change will affect both recreationists' activity choices and available recreation settings.

Chapter 13. Natural Resources, Human Settlement Patterns, and Economic Development: Contrasting Regions and Challenging Futures

The 2010 Resources Planning Act (RPA) Assessment (2010 RPA) highlighted resource implications for the four large RPA regions (figure 2-1 in chapter 2). Key findings identified areas of concern that affect renewable resources nationwide and also affect resource implications specific to the four RPA regions in the context of current and future conditions across the United States. Resource analyses in the 2010 RPA used a consistent set of drivers of change to explore 50 years into the future, including population growth, economic growth, land use change, bioenergy demand, and climate change. The key findings in the 2010 RPA, related technical supporting documents, and underlying data offer a rich data compilation that have been used to explore the effects of these scenarios on resources at finer scales within the RPA South Region (Wear and Greis 2012) and within the RPA North Region (http://www.nrs.fs.fed.us/futures/).

For this RPA Update, we explored our ability to use the 2010 RPA data and analyses to identify the status, trends, and projected future of renewable resources for two Forest Service NFS regions within the RPA Rocky Mountain Region: the Northern Region (Region 1) and the Southwestern Region (Region 3) (figure 13-1). We first describe the current patterns of human settlement in relation to NFS lands. We then explore the nature of economic development, with respect to timber and to grazing, and their relationships to human settlement and land use. We also assess recreation use and visitor satisfaction in national forests in both regions. We close the chapter by exploring future changes associated with population, economic development, and climate change in the context of environmental and social vulnerability. More detail about these analyses is available in Joyce (N.d.).

Highlights

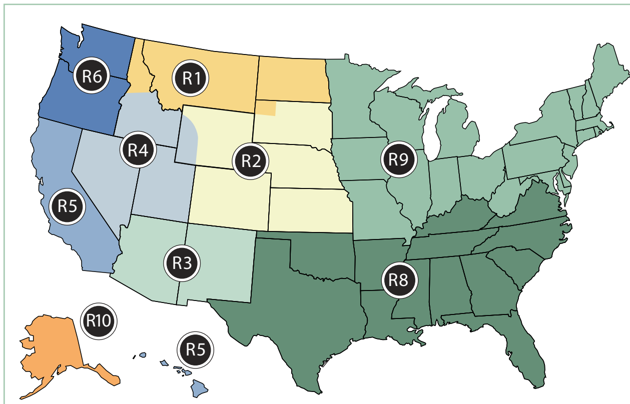
- Of National Forest System (NFS) lands in the southwestern-influence area, 25 percent occur in counties with both high population density and population growth rates greater than 20 percent from 1990 to 2010. By contrast, a smaller share of NFS lands occurs in northern-influence area counties with the highest population density and slower rates of population growth.
- Lightly populated counties in both influence areas saw no growth or they lost population in the past two decades; these counties have 26 percent of the NFS lands in the southwestern-influence area but 50 percent of the NFS lands in the northern-influence area.
- Rangeland, agriculture, and energy are increasingly interconnected in both regions, with incentives for energy development facilitating land use shifts within cropland and among rangeland, pastureland, and cropland uses and with increasing population density in rural counties, particularly in the northern-influence area.

Highlights (continued)

- Counties reliant on timber processing in both influence areas were impacted by the economic downturn from 2007 to 2009; recovery has been slow in the northern-influence area, whereas capacity for timber processing in the southwestern-influence area has increased 30 percent since 2012, primarily the result of new or reconfigured mills designed to generate electricity or produce energy products.
- National forest visits (NFVs) in Region 3 (NFS Southwestern Region) were about double those in Region 1 (NFS Northern Region), reflecting the greater population in Region 3.
- National forest visitors in Region 1 and Region 3 rated the quality of the natural environment very positively for all site types. Increased crowding over time was perceived at all site types, except at wilderness sites in Region 3.
- Range resources in the Southwestern Region will be highly vulnerable under climate change.
- The Southwestern Region is also more vulnerable to future water shortage than is the Northern Region.
- Timber-producing counties and counties heavily dependent on recreation in the northern-influence area may have lower social vulnerability than nontimber-producing counties; counties dependent on grazing are significantly more vulnerable overall.

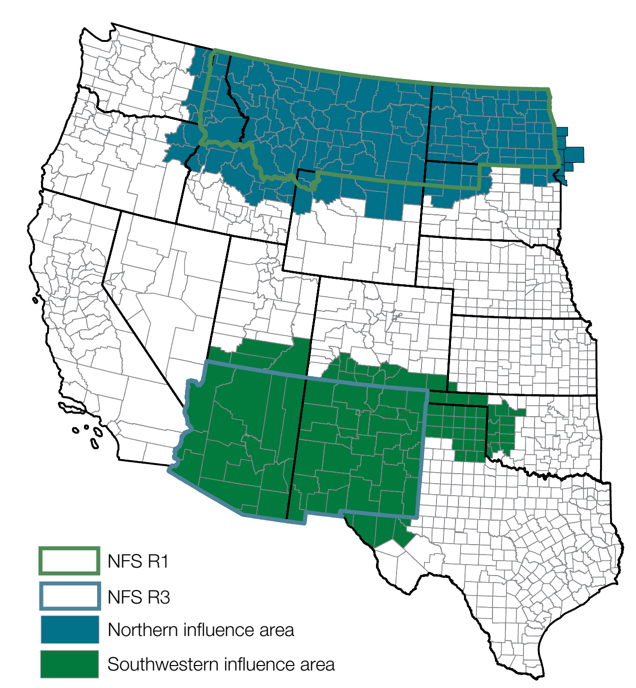
These two NFS regions offer considerable contrast in which to explore the future resource management challenges associated with natural resources and amenities, population growth, economic development, and climate change. The NFS regional boundaries are permeable to some of these drivers of change. For example, the timber-processing region for the Northern Region includes five counties outside the NFS regional boundary. Local visitors to national forests are defined as those traveling less than 50 miles to a national forest; two populous counties in Washington State are within 50 miles of Northern Region national forests. The influence of national forests adjacent to the regional boundary clearly extends beyond the regional boundary, and national forests are also influenced by the socioeconomic conditions of counties adjacent to the regional boundary. Therefore, we identified a regional influence area as all counties within the boundaries of the Northern Region and the Southwestern Region (figure 13-1) and any county within 50 miles of NFS lands within those regional boundaries (figure 13-2). These influence areas are the basis for analyses of population, economic dependency, and land use and are referred to as the northern-influence area and the southwestern-influence area. For situations in which the analysis focused inside NFS regional boundaries, we denoted the study areas as Region 1 and Region 3 (Northern Region and Southwestern Region).

Figure 13-1. National Forest System regions.



R1 = Region 1, Northern Region. R2 = Region 2, Rocky Mountain Region. R3 = Region 3, Southwestern Region. R4 = Region 4, Intermountain Region. R5 = Region 5, Pacific Southwest Region. R6 = Region 6, Pacific Northwest Region. R8 = Region 8, Southern Region. R9 = Region 9, Eastern Region. R10 = Region 10, Alaska Region.

Figure 13-2. The areas influenced by national forests in the National Forest System (NFS) Northern Region (NFS R1) (blue) and Southwestern Region (NFS R3) (green) are defined as any county within 50 miles of a national forest in the NFS region. The official boundaries for the Northern Region and Southwestern Region are shown in contrasting colors; State and county boundaries are in black.

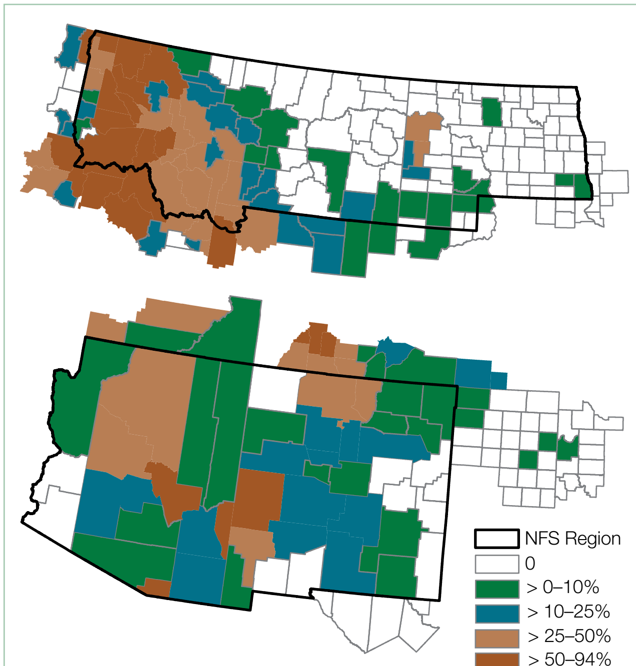


Human Settlement Patterns in Relation to NFS Lands

- Of the population in the southwestern-influence area, 81 percent lives in counties with NFS lands, and 46 percent of the population in the northern-influence area lives in counties with NFS lands; these percentages reflect the regional distribution of NFS lands.
- NFS lands in the southwestern-influence area are more evenly distributed and account for only 17 percent of county area where they occur; by contrast, NFS lands in the northern-influence areas account for 33 percent of the total county area where they occur.
- Population gains of more than 10 percent between 1990 and 2010 were concentrated in metropolitan areas in both influence areas.
- In the southwestern-influence area, counties with the highest population increase (22 percent) from 2000 to 2010 had 20 percent of NFS area; by contrast, only 6 percent of NFS area occurred in northern-influence area counties with the highest population growth rate (13 percent).
- Lightly populated counties had no growth or they lost population in the past two decades; these counties have 50 percent of all NFS area within the northern-influence area and 26 percent of the NFS area within the southwestern-influence area.

The location of NFS lands relative to population distributions affects the use of natural resources. Most counties in each influence area have NFS land; 118 of 165 counties in the northern-influence area and 59 of 105 counties in the southwestern-influence area. The northern-influence area has more counties that contain more than 50 percent NFS lands, and those counties are more concentrated in the western portion of the area (figure 13-3). As a result, the footprint of NFS land is more evenly distributed in the southwestern-influence area, accounting for only 17 percent of the total land area in counties with NFS lands in contrast with 33 percent of the total land area in the counties with NFS lands in the northern-influence area. Not only is the NFS footprint smaller in the southwestern-influence area, but also a larger proportion of the total population in that influence area (81 percent; 8.2 million people) lives in those counties. In the northern-influence area, 46 percent of the population, or 1.5 million people, lives in counties with NFS land. The combination of population size

Figure 13-3. Percent of National Forest System (NFS) land area, by county, for the northern-influence area (top) and southwestern-influence area (bottom).



Source: Data from http://www.unh.edu/demographic-indicators.

and NFS land distribution results in eight times as many people in the southwestern-influence area having access to NFS lands (198 people per square mile) than in the northern-influence area (23 people per square mile).

Developed land comprises a small percent of the total land area in most counties in both influence areas; however, the northern-influence area has a greater number of counties without developed land (figure 13-4). Several counties in the southwestern-influence area have more than 5 percent of county area in developed land, and all these counties except one have some NFS land within their boundaries and are adjacent to counties with NFS lands.

The average population density for the southwestern-influence area (31 people per square mile) is approximately three times the average for the northern-influence area; however, people in both areas are spread across the landscape in widely varying densities (figure 13-4). The most densely populated counties tend to be associated with the Rocky Mountains or toward the eastern and more mesic parts of North Dakota (figure 13-4). In contrast with the southwestern-influence area, no counties in the northern-influence area have a population density greater than 275 people per square mile. For both areas, substantial population is contained in these highest density counties.

County population density is lower in the northern-influence area than in the southwestern-influence area. Nearly 50 percent of the land area of the northern-influence area has a population density of less than 3.2 people per square mile (figure 13-5). By contrast, nearly one-half of the land area in the southwestern-influence area has a population density of 9 or more people per square mile. Counties with more than 18 people per square mile (the highest population density classes) in the southwestern-influence area include 83 percent of the population and encompass 24 percent of the total land area; by contrast, counties at this population density in the northern-influence area include 57 percent of the population and encompass 14 percent of the land area. Of the 17 counties in the northern-influence area that have more than 50 percent of their land area in national forests and grasslands, densities range from less than 1 to 5, with most being less than 9 people per square mile. For the 7 counties with more than 50 percent of their land area in national forests and grasslands in the southwestern-influence area, the densities range from less than 1 to 38, with most being less than 5 people per square mile (figure 13-4).

The populations of the States in the Northern and Southwestern Regions, except for Arizona, are more rural than the United States average of only 20 percent rural (https://www.census.gov/geo/reference/ua/uafacts.html) (figure 13-6). The rural

Figure 13-4. Percent developed land by county (left) and population density in number of people per square mile (right) for the northern-influence area and National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom), 2013. Developed land includes residential, industrial, commercial, and institutional land; it also includes transportation areas if surrounded by urban areas.

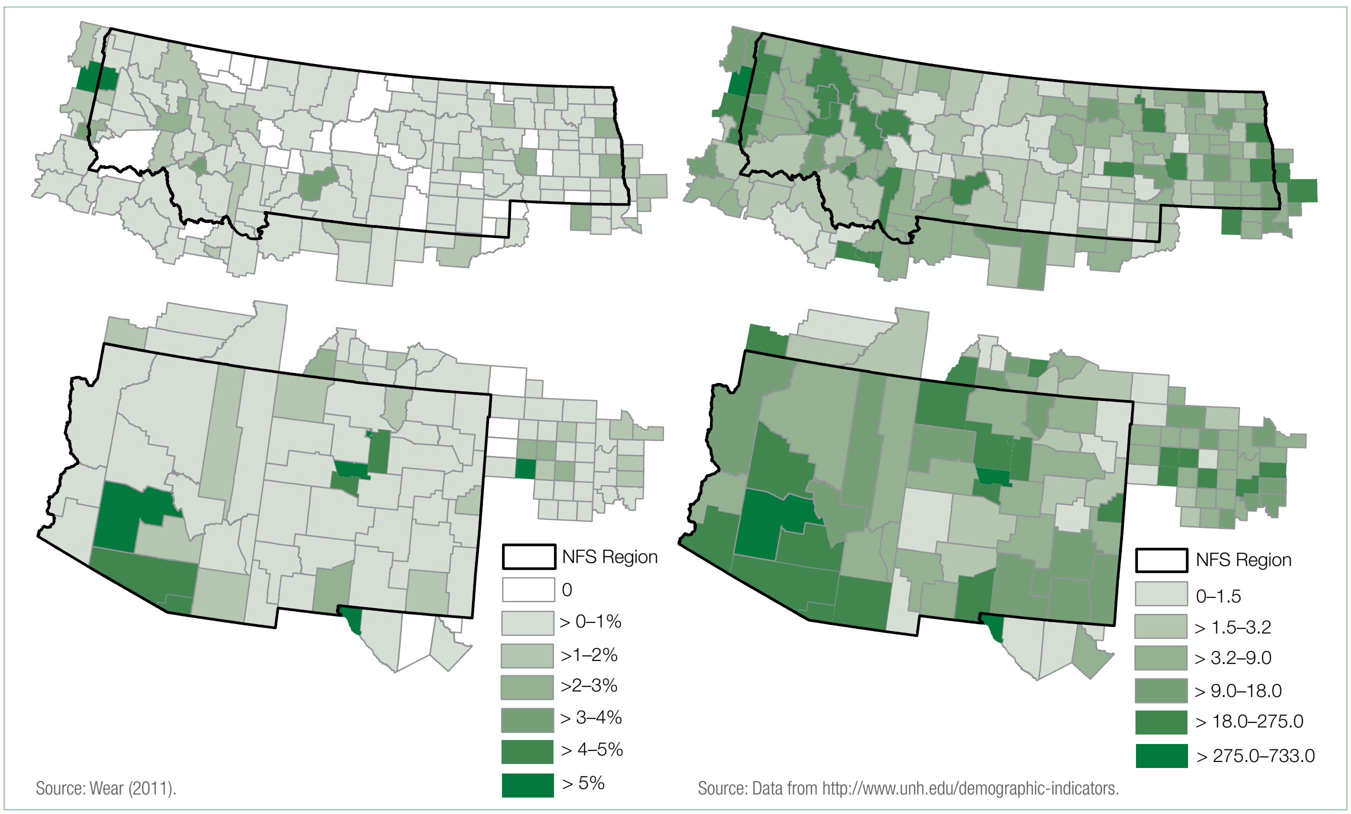
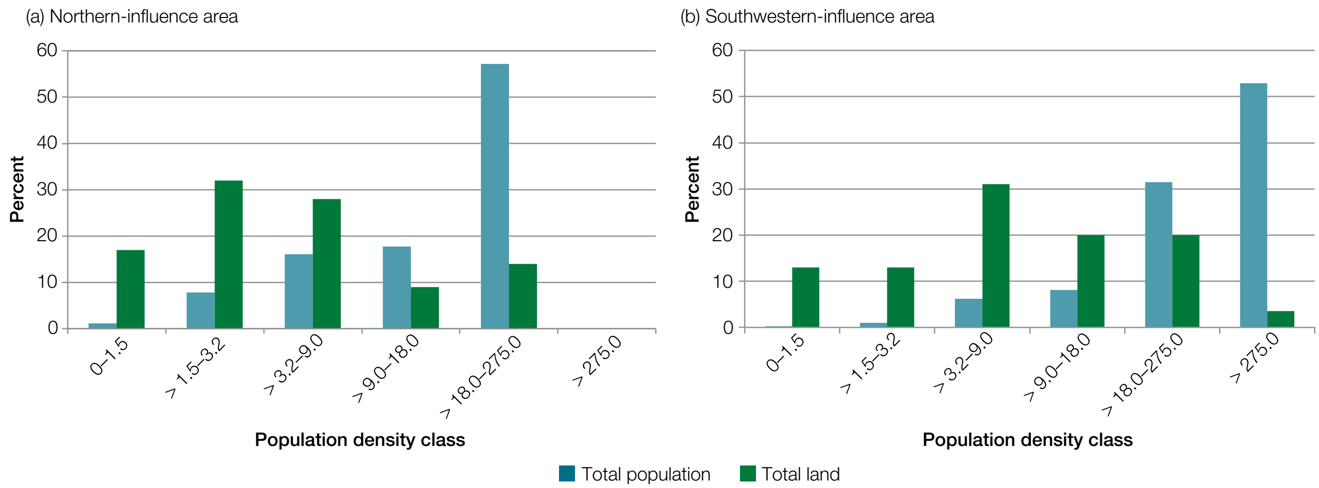


Figure 13-5. Percent of total population and total land area by population density class in (a) the northern-influence area and (b) the southwestern-influence area, 2013.

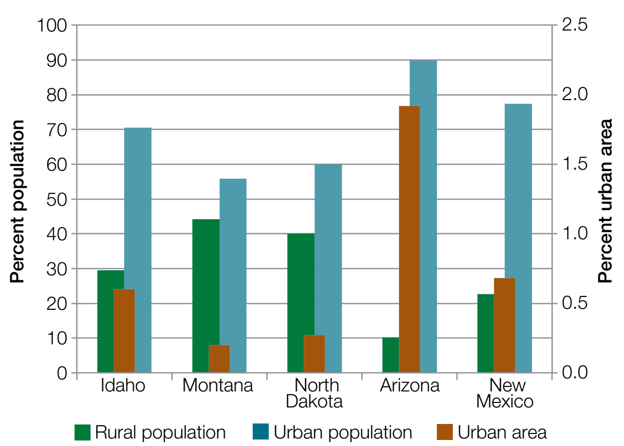


Source: Data from http://www.unh.edu/demographic-indicators.

population is higher in States in the Northern Region, where around 40 percent of the population in Montana and North Dakota live in rural areas; by contrast, as few as 10 percent of the total population of Arizona live in rural areas. Despite the low rural population, the vast majority of county lands remain rural. Arizona has only 2 percent of land area in urban areas, and Montana has only 0.2 percent urban land (figure 13-6).

Population growth during the past 20 years has remained consistently strong in parts of each influence area (figure 13-7). Between 1990 and 2000, 50 percent of the counties in the northern-influence area and 68 percent of the counties in the southwestern-influence area experienced positive growth, reflecting the positive economic conditions of that decade and decades of population expansion in the U.S. West. The greatest gains occurred in the southwestern-influence area, where nearly all counties in Arizona and most of the counties in New Mexico gained more than 10 percent in population. In the northern-influence area, counties with at least 10 percent of the county in NFS lands gained more than 10 percent in population. In both areas, the eastern counties, typically without NFS land, tended to decline in population. The economic downturn in the 2000s is seen in the smaller population growth overall between 2000 and 2010. Fewer counties gained 10 percent or more in population (figure 13-7). In both decades, population increases of greater than 10 percent were concentrated in metropolitan areas.

Figure 13-6. Percent of the population living in urban[a] and rural areas and percent of the land in urban land for States in the National Forest System (NFS) Northern Region (Idaho, Montana, North Dakota) and the NFS Southwestern Region (Arizona, New Mexico).

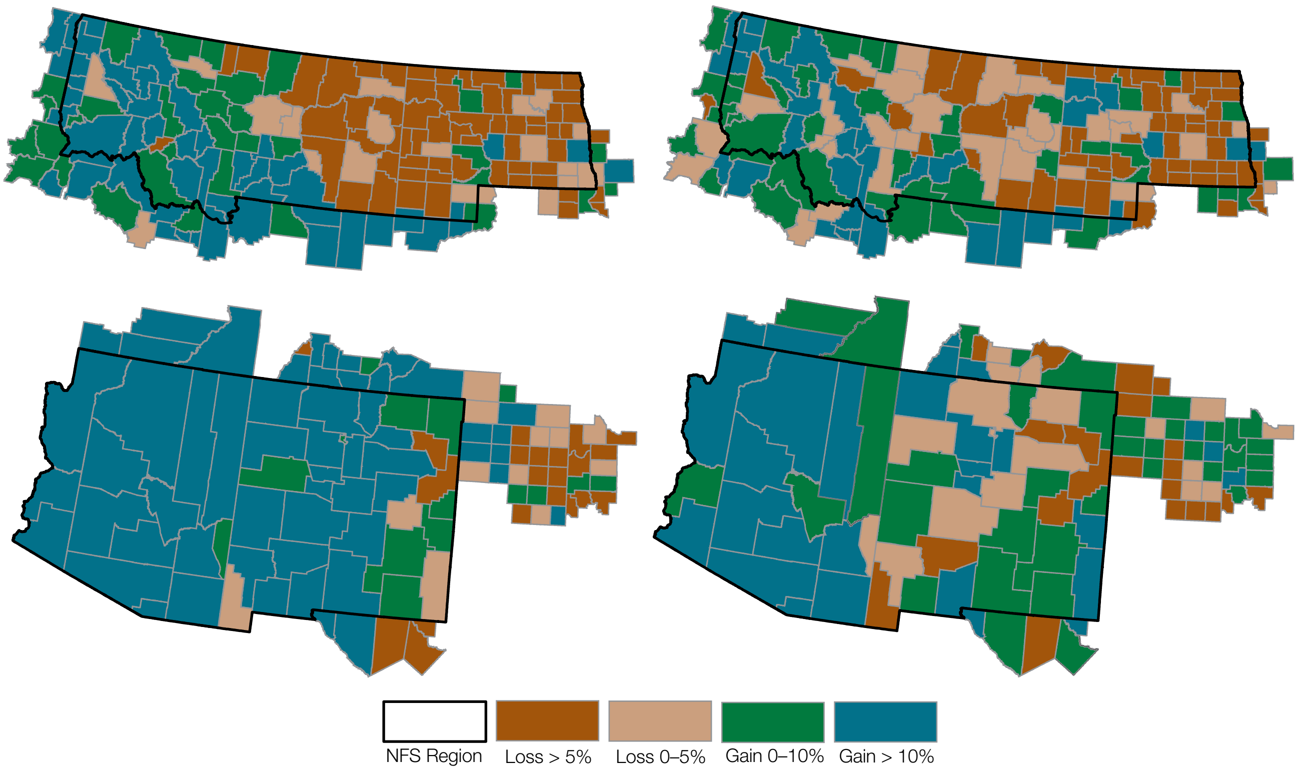


[a] Urban area is defined as the sum of urbanized areas and urban clusters. An urbanized area consists of densely developed territory that contains 50,000 or more people. An urban cluster consists of densely developed territory that has at least 2,500 people but fewer than 50,000 people.
Source: U.S. Census Bureau (2013).

Between 2000 and 2010, the greatest population change occurred in counties with the highest density classes (figure 13-8). In the southwestern-influence area, slightly less than 40 percent of NFS land is in counties experiencing a minimum of 10-percent growth in the past decade (top three density classes). By contrast, slightly less than 20 percent of the NFS land in the northern-influence area is in counties that experienced higher growth rates (figure 13-8).

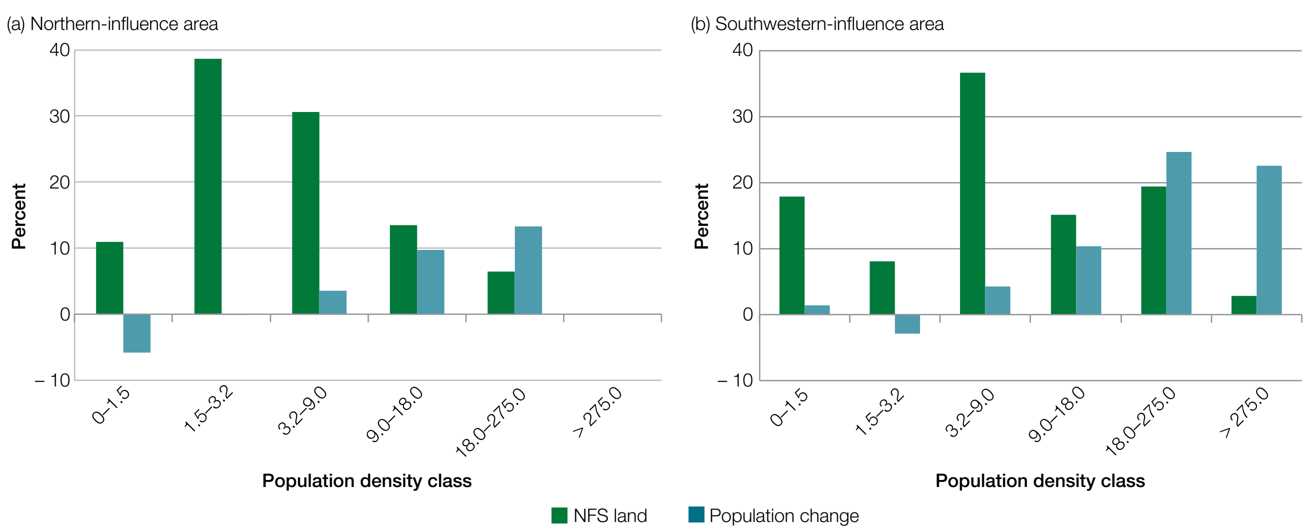
Lightly populated counties (0 to 3.2 people per square mile) remained the same or lost population in both areas (figure 13-8). A higher percentage of NFS lands are in these counties in the northern-influence area, where they contain nearly 50 percent of all NFS land. In the southwestern-influence area, approximately 25 percent of all NFS land occurs in the lightly populated counties. Overall, population change was relatively small or negative in counties where most NFS land occurs: around 80 percent in the northern-influence area and nearly 50 percent in the southwestern-influence area.

Figure 13-7. Population change for the northern-influence area and National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom), 1990 to 2000 (left) and 2000 to 2010 (right).



Source: Data from http://www.unh.edu/demographic-indicators.

Figure 13-8. Percent of land area in National Forest System (NFS) lands and percent change in population, by population density class (persons per square mile), in (a) the northern-influence area and (b) the southwestern-influence area, 2000 to 2010. Density class assignments were made using 2000 population data for each county.



Source: Data from http://www.unh.edu/demographic-indicators.

Natural Resources, Human Settlement Patterns, and Economic Development

- Rangeland, agriculture, and energy are increasingly interconnected in both the Northern and Southwestern Regions through agricultural markets, new technology for oil and gas extraction, and Federal policy.
- Ranching, timber, and oil and gas are seen as being economically important in the northern-influence area and, in some counties, shares of total income from grazing, timber, and oil and gas are above the national average.
- The availability of technology and markets for bioenergy have expanded cropland and initiated a series of cascading changes in which corn/soy replaced small grains, small grains replaced pasture, and pasture replaced rangeland, particularly in the northern-influence area.
- New technology has spurred an expansion of oil and gas development on rangelands, particularly in the northern-influence area, resulting in an increased share of county income from oil and gas development, large population increases, and competition among sectors for services in areas of expansion.
- Many counties in the northern-influence area are more reliant on timber processing than is the Nation as a whole; as a consequence, the impacts of the economic downturn and the U.S. housing decline were severe and recovery has been slow.
- In the southwestern-influence area, timber markets and employment dropped through the economic downturn; however, since 2012, capacity for timber processing has increased 30 percent, primarily the result of new or reconfigured mills designed to generate electricity or produce energy products.
- National forest visits to Region 3 were about double those to Region 1, reflecting the greater population in Region 3; the highest participation rates in both regions were associated with viewing natural features and hiking/walking.
- Visitors to both regions rated the quality of the natural environment very positively across all national forest site types but also perceived increased crowding in Region 3 over time in general forest areas, overnight use developed sites, and day use developed sites. In Region 1, decreased crowding was perceived in designated wilderness sites.

Past and current economic development and the terrestrial and aquatic productivity of these landscapes have influenced current land use patterns in each region. Human settlement patterns reflect use by Native Americans, Euro-American settlement, and, increasingly, the technology to work remotely from the office. Economies in both regions are sensitive to environmental factors that influence tourism, livestock, timber, and energy. Both regions have extensive Federal lands, including national parks, national forests, and designated wilderness areas. These Federal lands and the intermingled private lands have high amenity values and have played an important role in rural population growth during the past 60 years. Available technology influenced the nature of past economic development, particularly advances in agricultural equipment and crop genetics that resulted in cropland expansion and in extraction technology that has expanded where energy development could occur. The legacy of past human settlement and economic development influences future possibilities for natural resource production and for economic development.

Rural Land Use

Although total land area and Federal land are similar, the area of forests, rangeland, cropland, pastureland, and developed land varies across the two influence areas. The northern-influence area has nearly five times the amount of cropland and six times the amount of pastureland (table 13-1), and the southwestern-influence area has a greater area of rangeland and nearly two times the developed land.

The distribution of land covers varies across the influence areas (figure 13-9). Cropland and rangeland can comprise nearly 100 percent of non-Federal land cover in some counties in both influence areas. Reflecting higher moisture availability, cropland predominates in the eastern part of both regions. Pastureland never comprises more than 13 percent of a county land base. Rangeland dominates throughout the entire southwestern-influence area and can also be found in central and eastern parts of the northern-influence area. Forests are located in the western part of the northern-influence area, but, in the southwestern-influence area, forests grow primarily in the northern part, although isolated forested mountain ranges also occur in the southern part surrounded by landscapes of

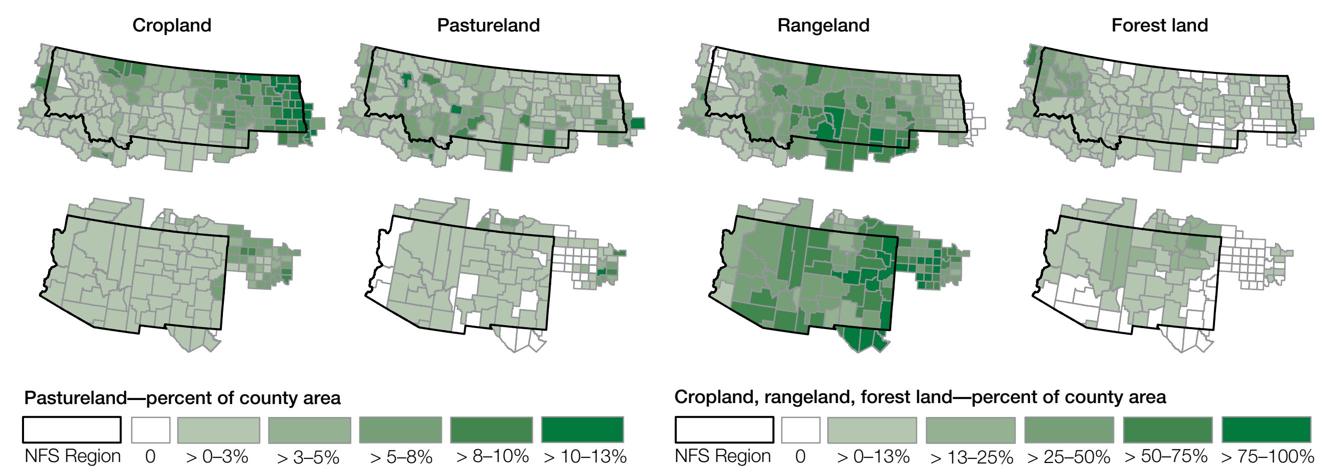
Table 13-1. Non-Federal land cover/use and total Federal land in the northern-influence area and the southwestern-influence area.

Land cover/use	Definition	Northern-influence area	Southwestern-influence area
		thousand acres	
Cropland	Land used for production of adapted crops for harvest; includes cultivated (row and close-grown crops) and noncultivated (permanent hayland and horticultural cropland)	50,017	11,345
Pastureland	Land managed primarily for production of introduced or native forage plants for livestock grazing	6,873	1,124
Rangeland	Land on which the climax or potential plant cover is composed principally of native grasses, grasslike plants, forbs, or shrubs suitable for grazing and browsing and introduced forage species that are managed like rangeland.	67,116	99,743
Forest land	Land that is at least 10 percent stocked by single-stemmed forest trees of any size that will be at least 13 feet tall at maturity	12,374	11,207
Developed land	Land consisting of residential, industrial, commercial, and institutional land and also transportation areas (roads, railroads) if surrounded by urban areas	1,208	2,242
Other	Federal[a]	76,155	81,331
Total area		**213,743**	**206,991**

[a] Land cover/use on Federal lands is not sampled in the National Resources Inventory.

Source: Wear (2011).

Figure 13-9. Percent of non-Federal cropland, pastureland, rangeland, and forest land cover, by county, in the northern-influence area and National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom), 2006. (Note: The scale for pastureland differs from other land types.)



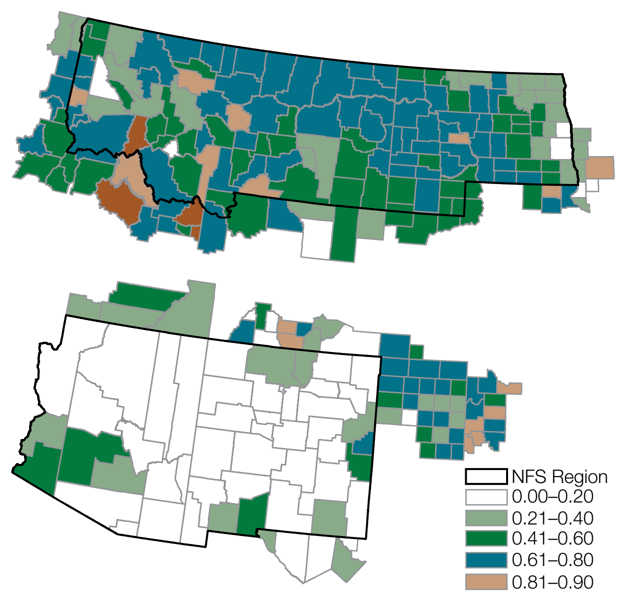
Source: Wear (2011).

grasslands and deserts. Forest land cover never reaches more than 62 percent of any county in the northern-influence area or more than 50 percent of any county in the southwestern-influence area.

Economic opportunities capitalize on the availability of natural resources and on the availability of undeveloped rural land. Although both influence areas have Federal and State lands, the availability of undeveloped rural non-Federal land influences current and, consequently, future land use and land cover change. Wear (2011) developed a rural land use complexity index that has two important elements: (1) the proportion of non-Federal land within a county that is rural and (2) the diversity of rural land uses (figure 13-10). The index incorporates three land use aggregates: (1) undeveloped rural uses, equal to the sum of forest and range uses; (2) cropland; and (3) pastureland.

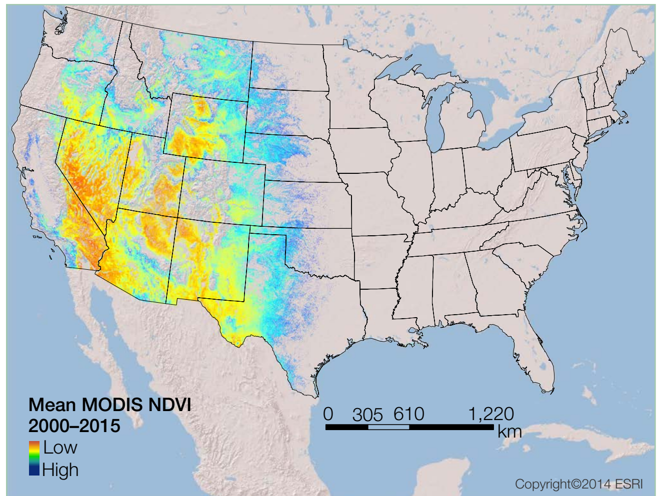
The complexity of land use in the northern-influence area is greater than in the southwestern-influence area (figure 13-10). Land once converted from natural cover to pastureland or cropland can and has shifted among land uses; these shifts reflect the potential diversity of rural land use. Counties with increasing human populations and expanding urban and developed areas, however, have less rural land and, as a consequence, fewer options for land use development. These patterns also suggest that the potential for future land use change is greater in the northern-influence area than in the southwestern-influence area.

Figure 13-10. Rural land use complexity index for the northern-influence area and National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom). The index ranges between 0 and 1 and reaches its maximum when the entire county is rural (forest and rangeland) and there is an equal split among the three use classes—cropland, pastureland, and native land (forest and rangeland). Minimum values occur when counties have no rural land or when only one land use dominates the rural area.



Source: Wear (2011).

Figure 13-11. Vegetation productivity across conterminous U.S. rangelands, using mean annual maximum Normalized Difference Vegetation Index (NDVI) from the MODIS satellite platform, 2000 to 2015.



Source: Reeves and Baggett (2014).

Rangelands, Agriculture, and Energy

Human settlement in both areas has capitalized on the productivity of rangelands with conversions to cropland, pastureland, and urban land use. Reeves and Mitchell (2012) concluded that, across the Western United States, historic rangeland losses were the result of agricultural development (17 percent), resource extraction (7.4 percent), and residential development (5.8 percent), with smaller losses resulting from mixed use, recreation, and transportation. They estimated the loss of historic rangeland in States in the northern-influence area to be as high as 71 percent in North Dakota and as low as 24 percent in Montana. In States in the southwestern-influence area, the loss estimates for both Arizona and New Mexico historic rangeland were less than 10 percent.

Rangelands in eastern Montana, western North Dakota, and western South Dakota are some of the most productive rangeland systems in the United States (figure 13-11). Livestock grazing makes an important economic contribution in the northern-influence area (see the sidebar Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Ranching Sector). Advances in agricultural technology, access to water, short-term mesic climate conditions, improved transportation systems to move crops and livestock to urban centers, and economic incentives through Federal and State programs, however, have facilitated the conversion of rangeland to agricultural land. Conversion of rangeland to cropland has also occurred in parts of the southwestern-influence area, where rangeland productivity is high (figure 13-11). Cropland can be found in New Mexico and, to a lesser extent, in Arizona (figure 13-9); however, cropland conversion is greatest in the eastern part of the southwestern-influence area, where productivity can be as high as parts of the northern-influence area (figure 13-11).

These economic driving forces continue to shape land cover and use in these two influence areas, as seen in the net change in non-Federal rangelands between 1982 and 2012. Rangeland area declined nearly 1.2 million acres in Montana, and New Mexico lost more than 1.6 million acres of rangeland to other land uses. At the national level, the loss of non-Federal rangelands between 1982 and 2012 was slightly more than 3 percent of the current non-Federal rangeland base (USDA 2015).

Land use changes are dynamic, particularly between cropland and pastureland, indirectly influencing rangeland. Agricultural markets, new technology, and Federal policy influence the direction of land use change among these three land uses and also influence a mix of uses, including energy development. Recent policy and economic incentives to produce ethanol have expanded corn production, and new technology has facilitated the expansion of oil and gas development on rural land. Between 1945 and 2007, cropland area first increased and then decreased in nearly all States in the northern-influence

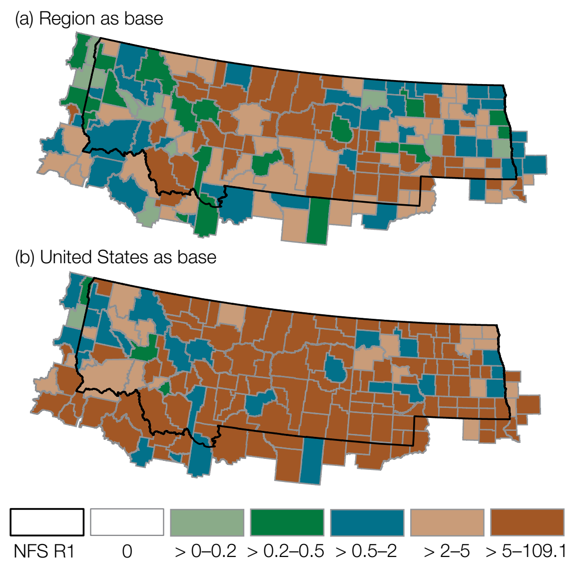
Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Ranching Sector

We examined the economic dependence of communities on grazing, energy, timber, and forest-based recreation. Our approach examined economic activity in all counties in the northern-influence area using economic development clusters. Clusters are groups of geographically concentrated, interconnected firms, institutions, and service providers that share similar traits (Porter 1990, 2000) and form the basis of a region's competitive advantage. The strength of, or economic dependence on, a county's cluster is measured by its location quotient (LQ). LQs are the ratio of that cluster's share of total economic output within the county relative to that cluster's share of total output within some base geography. For each natural resource sector, we consider two bases: (1) the share of total output within the United States and (2) the share of total output within the northern-influence area. Using the U.S. values as a base gives a sense of the cluster's strength at the national level; using the influence area's values as a base provides more definition at the local level and highlights which counties are most important to the regional sector. LQs larger than 1 indicate that the sector plays a larger role in the county's economy than in the baseline economy; LQs smaller than 1 indicate that the sector plays a smaller role in the county's economy than in the baseline economy.

The Ranching Sector

Although a variety of economic uses for rangeland exist in the northern-influence area, grazing cattle is by far the largest use, with at least some grazing in all counties. According to Reeves and Mitchell (2012), stocking rates throughout this area remained at or below the land's current capacity to support livestock, with very few counties experiencing forage demand above current forage supply. Nearly all counties had shares of total income from grazing above the national average, with some counties in Montana and South Dakota having more than 100 times the national average (figure 13-12). With the regional comparison, most of the counties had LQs greater than 1. A smaller set of counties, however, had LQs at the regional level that are greater than 5, indicating this industry plays an important regional role in these counties. Most of these counties had less than 25 percent of county land in NFS lands; in some cases, no NFS land occurred in the county (figure 13-3). Instead, the counties tended to be associated with the largest percentages of both rangeland and pastureland (figure 13-9). These counties tended to be where population density is the lowest (less than 3.2 people per square mile; figure 13-4), and many of these counties lost population during the 1990-to-2010 period (figure 13-7).

Figure 13-12. Location quotients for ranching cluster for the northern-influence area and National Forest System (NFS) Northern Region (R1), where (a) the base is the entire influence area and (b) the base for comparison is the entire United States.

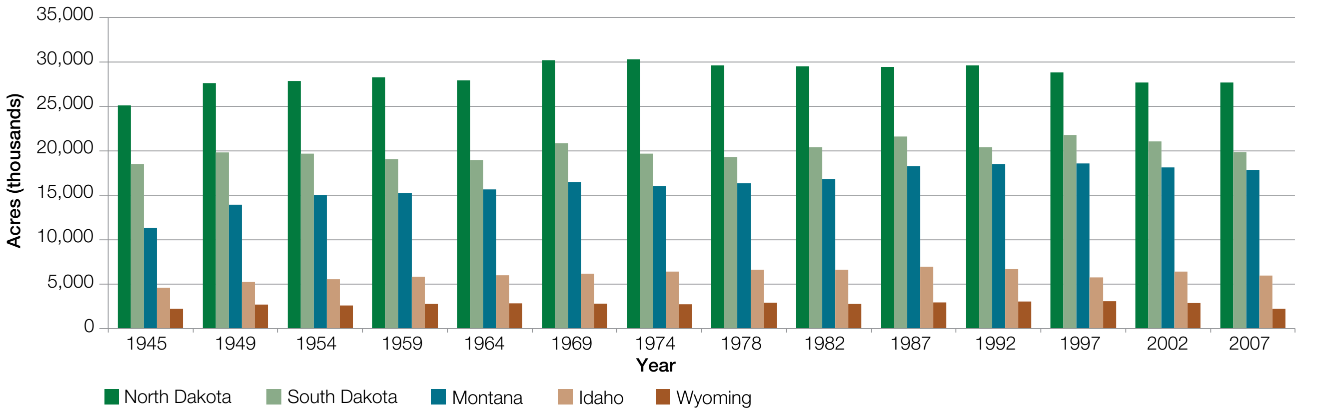


Note: Location quotients are calculated using IMPLAN (2012) data.

area (figure 13-13). Montana had the greatest increase from 11 million acres in 1945 to slightly more than 17 million acres in 2007. By contrast, cropland area in Wyoming has remained nearly the same. Cropland area peaked at 1.7 million acres in 1969 in Arizona and at 2.8 million acres in 1948 in New Mexico during this 60-year period (data not shown).

One contributor to the ebb and flow of cropland is the U.S. Department of Agriculture's Conservation Reserve Program (CRP). The CRP has offered farmers a financial compensation for removing private land from crop production for a period of years. At the national level, the 36.8 million acres in CRP in 2007 dropped to 25.6 million in 2014. This decline in participation in CRP likely reflects rising commodity prices, low CRP land rental rates, developing bioenergy interests, and declining interest in retiring land from crop production (Clark et al. 2013; Stubbs 2014). Montana and North Dakota each saw more than 3 million acres leave the CRP, representing 50 percent of the total acreage that was in CRP in each State in 2007 (table 13-2). Across States in the southwestern-influence area, 15 to 30 percent of the CRP acres left the program. Overall, fewer acres were in the CRP in the southwestern-influence area, and Arizona had no acres in CRP between 2007 and 2014. We show Colorado, Oklahoma, and Texas, even though only a small number of counties from these States are in our study area. The changes in these States are similar to States within the influence area, and these changes in a larger region reflect national drivers of change, such as crop prices, in addition to regional drivers, such as bioenergy expansion (table 13-2).

Figure 13-13. Cropland area in States in the northern-influence area, 1945 to 2007.



Note: All States, including Idaho and Wyoming, show the area of cropland for the entire State.
Source: Data from http://www.ers.usda.gov/data-products/major-land-uses.aspx.

Table 13-2. Change in Conservation Reserve Program (CRP) acres for States within the northern-influence area and southwestern-influence area, 2007 to 2014.

States	Change in CRP area 2007 to 2014[a]	Change relative to 2007
	acres	*percent*
Northern-influence area		
Montana	– 1,725,887	50
North Dakota	– 1,769,236	52
Idaho	– 220,038	27
South Dakota	– 626.777	40
Wyoming	– 87,406	31
Southwestern-influence area		
Arizona	0	0
New Mexico	– 155,664	26
Colorado	– 483,998	20
Oklahoma	– 317,102	30
Texas	– 897,457	22

[a] Arizona had no CRP acreage in 2007 or 2014.

Source: USDA Farm Service Agency CRP statistics (http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=rns-css).

Recent and potential shifts in conversion and use of rangeland, pastureland, and cropland to intensive cropland and/or bioenergy crop production have raised concerns about sustainability of current ecosystem services and potential environmental effects (Clark et al. 2013; Fargione et al. 2009; Fore et al. 2013; Johnston 2014). When CRP was initially authorized, the program was seen as a supply management tool for removing land from crop production and for providing environmental benefits (Stubbs 2014). Since initiation, CRP land has also provided forage harvesting and grazing for livestock owners during drought. The recent declines in CRP land have raised a number of questions about the role of CRP, particularly as revenue from cropping is currently greater than CRP payments. Several studies suggest that, if environmental benefits were to remain an important component of CRP, analysis of program incentives would be important to keep enrollment rates on land where environmental benefits could be attained (Feng et al. 2013; Keeney and Hertel 2009; Stubbs 2014).

Understanding how these shifts play themselves out on the landscape that produces a diversity of ecosystem services is important. Energy development is occurring across many parts of these two regions, affecting shifts in cropping practices and also the use of rangeland. In both situations the changes are likely to be long term.

Recent incentives for bioenergy production have added an additional component to this pattern, particularly in the northern-influence area. Native grasses and their cultivars have characteristics that are appealing from a bioenergy perspective; they are native, with little potential for becoming invasive; are adapted to climates ranging from humid to semiarid; have consistently high yields, with minimal inputs; and are established from seed (U.S. DOE 2011). Although switchgrass has been field tested and found potentially profitable given the establishment of a viable cellulosic biofuels market (U.S. DOE 2011), increased planting of corn for ethanol has been documented. Johnston (2014) noted that, between 2011 and 2012, the gains in corn and soy land came from lands that have never been planted to corn and soy during the previous 6 years. Part of this increased cropping of corn is a simplification of crop rotations as improved genetics and pesticides to control pests have reduced the incentive for the rotation to abate weed, disease, and insect organisms (Johnston 2014). In addition, genetics and technology are expanding the geographic area so that corn and soy can be planted into areas previously seen as climatically intolerant for those species.

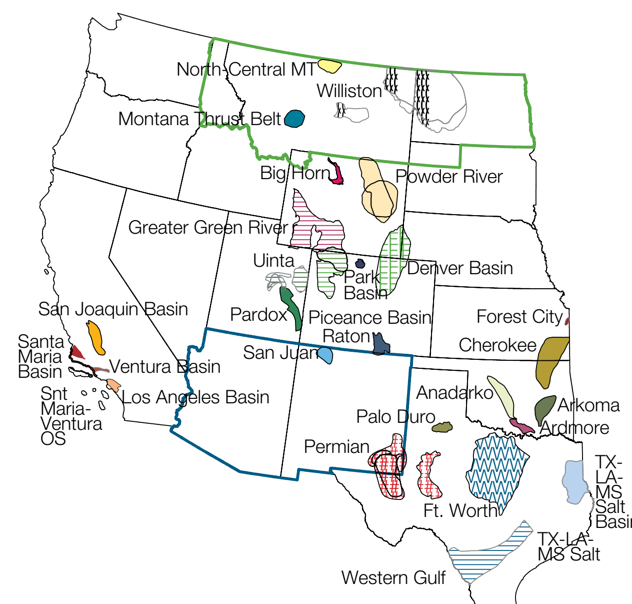
These changes in land use can occur quite rapidly, particularly in the northern-influence area. Corn and soybean acreages increased by 27 percent between 2010 and 2012, drawing from cropland planted to small grains and from grasslands. This increase in corn and soy acreage also affected grasslands indirectly, because grasslands were then planted to small grains. Three States in this influence area saw a shift of more than 40 percent of CRP land taken out of CRP in the space of 5 years—this represents more than 6 million acres that potentially returned to cropland use (table 13-2). Clark et al. (2013) concluded that the large-scale conversion of CRP lands to row crops would likely incur a significant environmental cost, without a concomitant benefit in terms of biofuel production. Fargione et al. (2009) suggested that biofuels could avoid negative impacts on wildlife only if crop production practices are compatible with wildlife or the biomass sources do not require additional land (e.g., wastes, residues, cover crops, algae). Some studies suggest that this expansion of corn plantings associated with ethanol plants may create disincentives for the use of permanent cover crops for bioenergy.

Many energy technologies are seen as compatible with other uses of the rangeland, such as grazing. Reeves and Mitchell (2012) noted that western rangelands have potential for providing future energy production, such as developing an unconventional, domestic fuels industry due to substantial oil and gas reserves, renewable biofuel opportunities, and significant wind energy sources. All energy sources, both renewable and nonrenewable, are subject to environmental and economic constraints. Choices of energy options will depend on both economic and political influences (Chow et al. 2003). Oil and gas well heads, windmills, and harvest areas (in the case of biofuels) have negative effects that can sometimes be mitigated to minimize impacts. Oil and gas production can be developed in such a fashion that allows other land uses to occur, although permanent infrastructure reduces cover and production of rangeland vegetation (Allred et al. 2015).

Rangelands in the Northern and Southwestern Regions encompass hydrocarbon-rich shale formations (plays) from which relatively clean fuel—natural gas—can be developed (figure 13-14). Many of these formations have been mined for several years; however, new technology to identify and drill for oil has resulted in nearly a fourfold increase from 2008 to 2012 in tight oil production (oil produced from very low permeability shale, sandstone, and carbonate formations). Tight oil production accounted for 12 percent of total U.S. crude oil production in 2008 and 35 percent in 2012 (U.S. DOE EIA 2014). The energy outlook forecasted a positive economic outlook for these oil resources, even with the recent decline in energy prices (see the sidebar Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Energy Sector—Oil and Gas).

Rapid increases in oil and gas development also resulted in rapid socioeconomic change. Based on 2013 population estimates, large population increases occurred in counties in

Figure 13-14. Potential oil and gas energy resources in the Western United States.



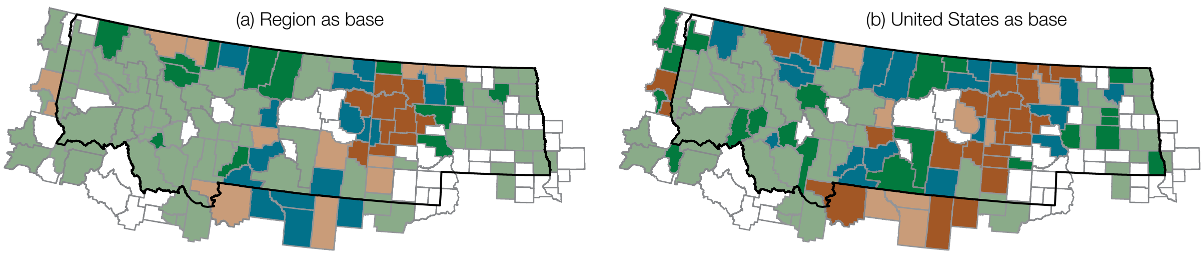
Source: Reeves and Mitchell (2012).

Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Energy Sector—Oil and Gas

Oil and gas have provided a large boom to areas in the northern-influence area, where development is occurring. In that area, 17 counties had shares of income from oil and gas that were more than 9 percent; 7 counties had shares of more than 20 percent. By comparison, the top two shares of county income in grazing were about 8.8 percent. These areas also changed from having declining populations in the 1990-to-2000 decade to having population gains that exceeded 10 percent in the 2000-to-2010 decade (figure 13-7). Of income earned in these counties, more than 1 out of every 5 dollars came from oil and gas. Counties with location quotients (LQs) greater than 2 were located in the Bakken Formation within the Williston Basin in western North Dakota and eastern Montana and in the Powder River Basin in southeastern Montana and northeastern Wyoming (compare figure 13-14 with figure 13-15). Oil and gas LQs based on the entire United States have values as high as 2 to 35 in various parts of the influence area, indicating the national importance of this sector.

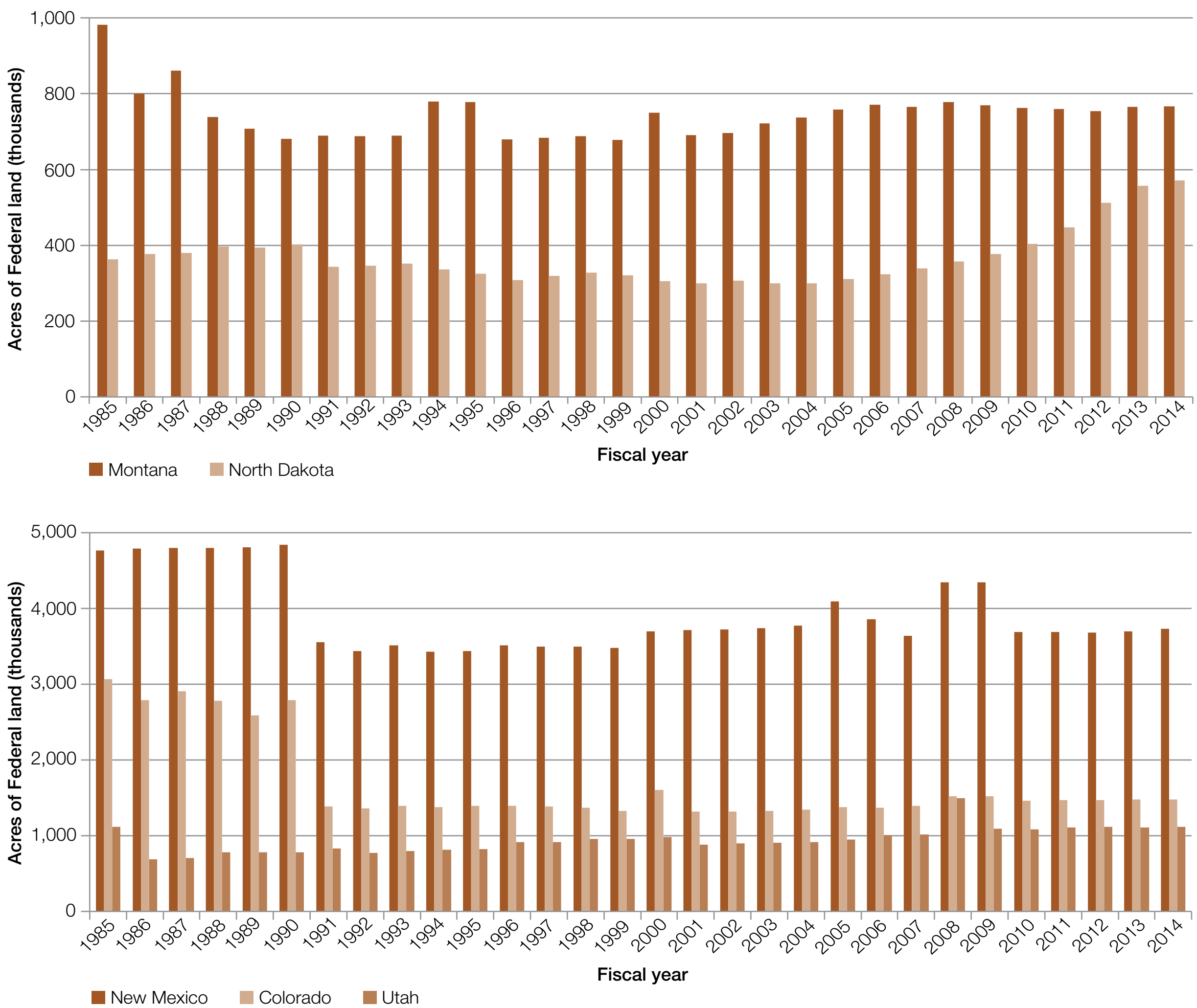
Since 1985, the number of acres on Federal land covered by producing oil and gas leases has increased and, in some States, the increase has been rapid. The acres of producing leases in North Dakota have increased by 50 percent in the past 7 years (figure 13-16). Much of the oil and gas development in North Dakota is on private lands. Federal lands in Wyoming had producing leases on more than 2 million acres in 1985, rising to more than 4 million in 2014; much of this development is in the southern part of Wyoming.

Figure 13-15. Location quotients for oil and gas in the northern-influence area counties and the National Forest System (NSF) Northern Region (R1), where (a) the base is the entire influence area and (b) the base for comparison is the entire United States.



Note: Location quotients are calculated using IMPLAN (2012) data.

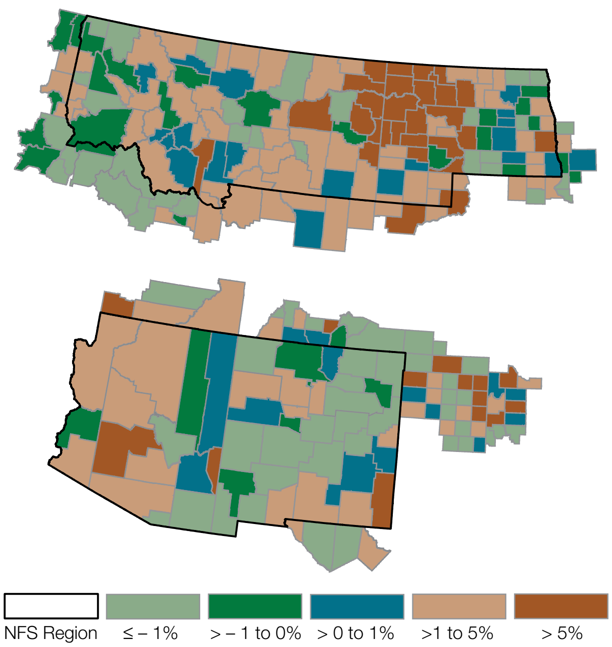
Figure 13-16. Acres of Federal land covered by producing oil and gas leases as of the last day of the fiscal year (FY), by State, in the National Forest System (NFS) Northern Region (top) and NFS Southwestern Region (bottom), FY 1985 to FY 2014.[a]



[a] Data are provided on a Federal fiscal year basis that begins on October 1st and ends on September 30th.
Note: Arizona had no producing acres on Federal lands.
Source: Data from http://www.blm.gov/wo/st/en/prog/energy/oil_and_gas/statistics.html.

the Williston Basin (compare figure 13-17 with figure 13-14). For example, Williston County saw a 31-percent increase in population between 2010 and 2013. Some of these growing counties in western North Dakota saw declining populations in the 1990-to-2000 decade. Services previously used by other components of the economy are now competing with the oil sector, such as lodging for oil and gas workers. Counties in the eastern parts of the southwestern-influence area also had large increases in population; these counties also had increases in oil and gas production.

Figure 13-17. Percent change in population for the northern-influence area and National Forest System (NFS) Northern Region (top) and southwestern-influence area and NFS Southwestern Region (bottom), 2010 to 2013.



Source: Data from http://www.unh.edu/demographic-indicators.

Forest Land and Wood Products

During the past 50 years, the use of forests in both influence areas has been influenced by the growth of the forest industry, housing development in the wildland-urban interface, demand for places to recreate, and the need for clean drinking water. Forest products continue to contribute to the economic development of both areas through jobs in the forest industry, timber revenues to forest owners, and benefits to consumers. At the national level, the forest products economic sector was hard hit by the 2007-to-2009 recession, and the U.S. timber harvest declined by slightly more than one-third from 1998 to 2010, with most of that decline occurring after 2005 (USDA Forest Service 2012a). The impacts to these areas demonstrate how national and global economic factors can potentially alter regional infrastructure and use of land.

The amount of forest land ranges from 27 percent of the total land base in Montana to less than 2 percent of the total land base in North Dakota (table 13-3). Forest land area in Arizona and New Mexico amounts to 15 and 21 percent, respectively, of total State area. Timberland, the component of forest land capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands, mostly regenerates naturally, although a small acreage is planted in all States in the two influence areas, except Arizona. Woodland, a class of land that consists mostly of stands of sparse woodland species (Oswalt et al. 2014), predominates in the southwestern-influence area.

Table 13-3. Forest and woodland area by major class and State for the northern-influence and southwestern-influence areas, 2012.

Area and State	Total land area	Forest land						Woodland[a]
		Total forest land	Timberland			Reserved	Other	
			Total	Planted	Natural origin			
	thousand acres							
Northern-influence area								
Montana	93,149	25,169	19,629	146	19,483	3,903	1,637	404
Idaho	52,892	21,247	16,772	204	16,568	3,422	1,054	200
Wyoming	62,140	10,807	6,002	48	5,954	3,780	1,025	641
Southwestern-influence area								
Arizona	72,700	10,795	3,001	0	3,001	1,096	6,699	7,848
New Mexico	77,631	16,615	4,278	8	4,270	1,328	11,009	8,225
Colorado	66,331	19,995	10,937	13	10,924	2,519	6,538	2,842
Utah	52,589	11,866	3,809	7	3,802	897	7,159	6,269

[a] Woodland is a class of land that consists predominantly of stands of sparse woodland species, such as juniper, pinyon juniper, mesquite, and small-stature hardwood species. Woodland is found in the arid to semiarid regions of the interior Western United States. See Oswalt et al. (2014) regarding the inventory for these lands. For some local analyses, these lands might be called scrub forest, but the preferred terminology is "forest and woodland" when referring to these combined areas. The values in this column do not currently include qualifying areas that are predominantly shrub species only and large areas of chaparral.

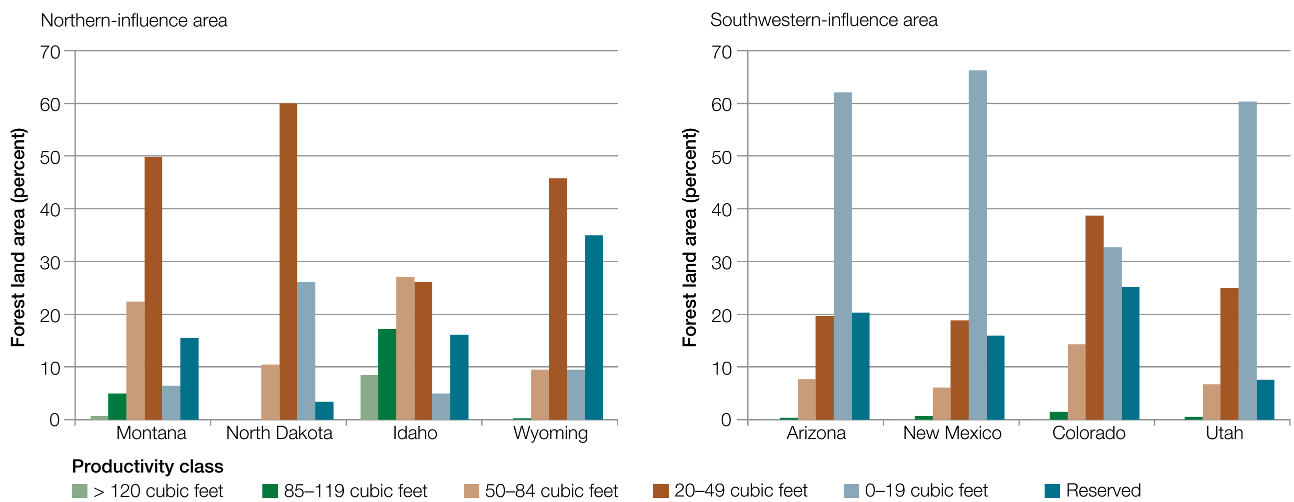
Note: Only States with most of their forest land area in the northern-influence and southwestern-influence areas are included here.

Sources: Oswalt et al. (2014); U.S. Census Bureau (2010).

Forest productivity is higher in States in the northern-influence area than in States in the southwestern-influence area, a function of increased moisture availability (figure 13-18). As a consequence, a larger percentage of the total forest land is classified as timberland in the northern-influence area (figure 13-18). Although forests in the northern-influence area are more productive, little area falls into the highest productivity classes (Oswalt et al. 2014). In Arizona and New Mexico, most of the forest area is in the lowest productivity class, 0 to 19 cubic feet per year. Reserved forest land (i.e., land withdrawn from timber utilization) ranges from 34 percent of forest land in Wyoming to less than 10 percent in Arizona and New Mexico (figure 13-18).

Ownership patterns also vary by influence area (table 13-4). More than 70 percent of the forest land in Montana and Idaho is public forest, mostly NFS lands, whereas public forest land in Arizona and New Mexico is slightly more than 60 percent of total forest land. Private forest land is predominately noncorporate in Idaho, Montana, North Dakota, South Dakota, and Wyoming.

Figure 13-18. Forest area by productivity class and reserved land (land withdrawn from timber utilization) by State, 2012.



Notes: Woodland is not included in these figures. Kansas, Oklahoma, Oregon, Texas, and Washington have very little area in the study area.
Source: Oswalt et al. (2014).

Table 13-4. Forest land area by ownership and State in the northern-influence area and southwestern-influence area, 2012.

Area and State	Forest area on all ownerships	Public		Private[a]		
		Total public	National forest	Total private	Private corporate	Private noncorporate
	thousand acres	*percentage of total forest land*				
Northern-influence area						
Montana	25,169	73	61	27	8	19
North Dakota	734	29	8	71	0	71
Idaho[b]	21,247	86	76	14	6	8
Wyoming[b]	10,807	84	56	16	0	16
Southwestern-influence area						
Arizona	10,795	65	54	35	1	34
New Mexico	16,615	62	45	38	3	35
Colorado[b]	19,995	77	54	23	2	21
Utah[b]	11,866	81	48	19	4	16

[a] It is no longer possible to classify private forest as *forest industry* and *nonindustrial private* because of disclosure issues. The new classes are *private corporate* and *private noncorporate.* Private corporate includes forest land that is administered by entities that are legally incorporated; private noncorporate includes land that is not owned by corporate interests, such as individual, Native American lands, unincorporated partnerships, clubs, and lands leased by corporate interests.

[b] Not all of this State area is included in the influence area.

Source: Oswalt et al. (2014).

Timber harvest reflects ownership patterns and the availability of timber for harvest. Over time, timber harvest has shifted from predominately public land to public and private land in the northern-influence area (table 13-5). In Idaho and Montana, public lands—primarily national forests—made up slightly more than one-half of the harvest until 1990; thereafter, private ownerships increased their harvest share. The contribution of private noncorporate harvest in Idaho declined from 31 percent to 12 percent by 2011 as private corporate owners increased their share of the harvest (Simmons et al. 2014). Public lands in Idaho contributed 42 percent of the 2011 harvest, with State lands and Bureau of Land Management (BLM)-managed lands contributing a larger share than national forests. Arizona and New Mexico show no clear trend in harvest by ownership.

The forest products industry in the northern-influence area, particularly in Montana and Idaho, was severely impacted by the 2007-to-2009 recession and U.S. housing decline. Montana's timber harvest declined from 785 million board feet (MBF) in 2004 to 374 MBF in 2009 (McIver et al. 2013). Log home sales in Idaho declined 80 percent between 2006 and 2011 (Simmons et al. 2014). Employment directly related to forestry and logging declined 37 percent in Montana and 33 percent in Idaho from 2005 to 2009 (Keegan et al. 2011). Forest products employment between 2005 and 2009 declined 24 percent in Montana and 29 percent in Idaho. Recovery is assessed as slow in both Montana and Idaho (Cook et al. 2015; McIver et al. 2013). See the sidebar Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Timber Sector.

In a similar way, the forest products sector in the southwestern-influence area was impacted by the recession. Forest products industry employment between 2005 and 2009 declined 50 percent in Arizona and 29 percent in New Mexico (Keegan et al. 2011). Employment directly related to forestry and logging declined 2 percent in Arizona (data unavailable for New Mexico). According to Sorenson et al. (2014), the capacity for timber processing in the Four Corners States (Arizona, Colorado, New Mexico, and Utah) in 2012 has increased 30 percent since 2007, primarily the result of new or reconfigured mills designed to generate electricity or produce energy products such as fuel pellets. In 2012, the Four Corners States were net exporters of timber products.

Table 13-5. Trend in timber harvest ownership[a] by National Forest System (NFS) Region and State, 1979 to 2012.

NFS Region, State, and ownership class	Year							
	1979	1985	1990	1995	1998	2001	2006	2011
NFS Northern Region								
Idaho[b]								
Private (%)	43.7	48.9	44.6	60.5	—	74.5	74.4	58.0
Public (%)	56.3	51.1	55.4	39.4	—	25.5	25.6	42.0
		1981	1988	1993			2004	2009
Montana								
Private (%)	—	56.4	55.8	69.3	—	—	77.0	56.5
Public (%)	—	43.6	44.2	30.7	—	—	23.0	43.5
		1984		1997	1998	2002	2007	2012
NFS Southwestern Region								
Arizona								
Private (%)		33.5		—	63.0	84.4	59.0	3.8
Public (%)		66.5		—	37.0	15.6	41.0	96.2
New Mexico								
Private (%)		—		88.0	—	86.3	82.9	50.2
Public (%)		—		12.0	—	13.7	17.0	49.7

[a] Public includes ownership by Federal, State, and other public entities and is primarily NFS lands in both regions. Private includes private and noncorporate private (see table 13-4 for definitions).

[b] Data for Idaho includes the entire State, not just the portion of Idaho in the NFS Northern Region.

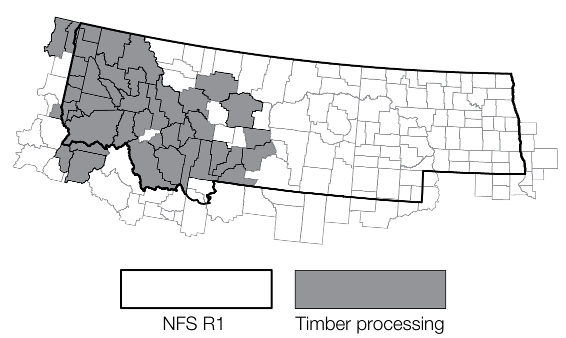
Sources: McIver et al. (2013); Simmons et al. (2014); Sorenson et al. (2014).

Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Timber Sector

McIver et al. (2013) defined a timber-processing region as those counties with processing facilities that receive timber from counties containing nonreserved timberland. This region encompasses 12 Idaho counties, 26 Montana counties, and 4 Washington counties; 5 of these counties are outside the Region 1 boundaries (figure 13-19). This definition focuses on sectors in which the value-added component of the sold good was deemed to originate from the forest itself, rather than from human or machine processing.

Forest products (defined by North American Industry Classification System sectors 113, 1153, 321, 322) make up more than 23 percent of direct manufacturing employment in Montana (McIver et al. 2013). In the northern-influence area, seven counties have more than 10 percent of their income originating from the timber industry (figure 13-20). Counties that have large shares of national forest land within their boundaries tend to have the larger location quotients. Many of these counties have at least 25 percent, if not more than 50 percent, of their land in National Forest System land. Counties where forest ecosystems intermingle with grasslands in central Montana can have both timber and livestock as industries of importance. Many counties are more reliant on timber processing than is the Nation as a whole.

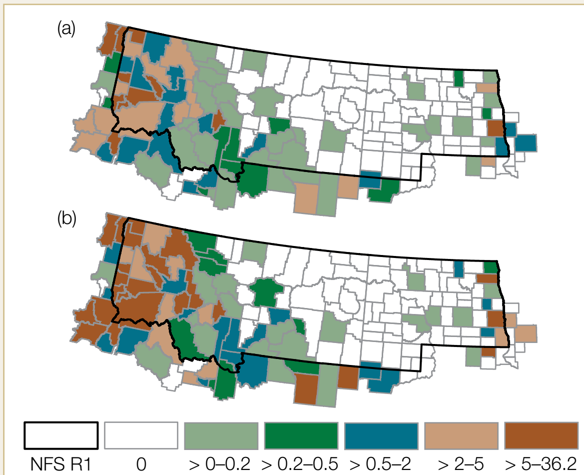
Figure 13-19. Counties in the timber-processing region in the northern-influence area and National Forest System (NFS) Northern Region (R1).



Note: Timber-processing region defined by McIver et al. (2013).

Timber processing depends on the availability of timber for harvest. Harvests in Montana from all lands peaked in the 1970s, with more than 1,800 million board feet (MBF) and, in 2014, harvests were at about 1,000 MBF (Cook et al. 2015). Montana's annual sawtimber-processing capacity utilization declined during periods longer than the recent economic downturn, partially a function of timber availability. In 1976, 75 percent of sawtimber-processing capacity was utilized and, in 2009, capacity utilization dropped to 50 percent, the lowest level on record. McIver et al. (2013) identified this drop as being related more to the economic downturn than to timber availability. In Idaho, the utilization of sawtimber-processing capacity dropped from 81 percent in 1979 to 71 percent in 2011 (Simmons et al. 2014). Although the Great Recession impacted the forest sector in Idaho and Montana, longer trends show declining harvests and underutilized capacity in Idaho and Montana mills.

Figure 13-20. Location quotients for timber for counties in the northern-influence area and National Forest System (NFS) Northern Region (R1), where (a) the base is the entire influence area and (b) the base for comparison is the entire United States.



Note: Location quotients are calculated using IMPLAN (2012) data.

Outdoor Recreation

NFS Regions 1 (Northern Region) and 3 (Southwestern Region) provide abundant recreation opportunities. The variable elevations in both regions provide conditions conducive to an assortment of recreation, from skiing to hiking and backpacking. Also popular are activities not dependent on mountainous terrain or winter conditions, such as picnicking, visiting interpretative sites, and camping. In this section, we used National Visitor Use Monitoring Program (NVUM) data, described in chapter 12 at the RPA region level, to assess recreation use and visitor satisfaction on the national forests and grasslands of Regions 1 and 3. More detailed regional and national forest-level information is available at the NVUM website (http://www.fs.fed.us/recreation/programs/nvum/).

Recreation Use on National Forests and Grasslands

Region 1 contains 12 national forests and Region 3 contains 11 national forests and 3 national grasslands. As described in chapter 12, the NVUM data presented in this section were collected from 2005 to 2009. Recreation visits were summed across four site types: day use developed sites, overnight use developed sites, general forest areas, and designated wilderness. A national forest visit is defined as a visit by one person to a national forest for the purpose of recreation within the past 12 months, for any length of time. Because any national forest has multiple sites for recreation, a single NFV may include multiple site visits (SVs).

Table 13-6 describes the estimated annual recreation SVs and NFVs to both regions based on NVUM data from 2005 to 2009, which represent the most recent complete NVUM interval (USDA Forest Service 2015a). Visitation to Region 3 was about double the level of Region 1, likely reflecting the population difference between the regions. In both regions, general forest areas were the most common site type visited. Visitation to day use developed sites, however, was proportionately more popular in Region 3.

NVUM respondents can report participation in up to 28 different activities during their visit. The five activities with the highest participation rates are listed in table 13-7. These activities are broadly accessible, with many opportunities and low demand for resources. The activities had slightly higher participation rates in Region 3. The five activities with the lowest participation rates varied slightly across regions, with horseback riding, resort use, and other motorized activity being common to both.

Travel distances for recreation may vary by activity. If recreationists are required to travel longer distances, then their frequencies and willingness to travel may be impacted by factors such as fuel prices, suitability of conditions on site, and climate. Those who traveled 50 miles or less were considered local recreationists and comprised a majority of NFVs (figure 13-21). Among nonlocal recreationists, the highest visit frequencies in both Regions 1 and 3 occurred for those traveling more than 500 miles, reflecting a willingness to travel long distances to participate in recreation.

The NVUM data also provide information about visitor characteristics and preferences. Males dominated national forest visitation. Females constituted slightly more than one-third of NFVs in both regions, accounting for 35 percent of NFVs in Region 1 and 39 percent in Region 3. Most people who undertook NFVs identified as White, with nearly 98 percent in Region 1 and 95 percent in Region 3. Hispanic/Latino visitors accounted for almost five times as many NFVs in Region 3 as in Region 1, reflecting the difference in regional populations.

Recreation opportunities appeal to different age ranges; as people age, their preferences for activities may shift. The proportion of NFVs by age group is shown in figure 13-22. The distribution was similar across regions with minor differences. Visitors in the 40-to-49- and 50-to-59-year-old groups accounted for the largest percentage of NFVs in Region 1, and

Table 13-6. Annual national forest visits and site visits by site type in National Forest System (NFS) Regions 1 and 3, 2009.[a]

Visit type	NFS Region 1	NFS Region 3
	visits (thousands)	
Total national forest visits	9,921	17,747
Total site visits	11,207	21,836
Day use developed site visits	2,440	7,251
Overnight use developed site visits	736	2,512
General forest area visits	7,638	10,756
Designated wilderness visits	392	1,317

[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

Table 13-7. Percentage of visitors participating in the top five and bottom five recreation activities in National Forest System (NFS) Regions 1 and 3, 2009.[a]

Recreation activities	NFS Region 1	NFS Region 3
	percent	
Top five activities for participation		
Viewing natural features[b]	49.5	56.6
Hiking or walking	47.0	54.9
Viewing wildlife[c]	39.0	45.2
Relaxing[d]	38.5	44.2
Driving for pleasure on roads	24.9	28.3
Bottom five activities for participation		
Horseback riding	2.0	0.9
Backpacking[e]	1.6	—
Resort use[f]	1.4	0.9
Other motorized activity[g]	0.3	0.6
Snowmobiling	—	0.2
Off-highway use	2.2	—
Cross-country skiing	—	1.2

[a] Information for 2009 is compiled from surveys of all national forests during the interval from 2005 to 2009.

[b] Viewing/photographing natural features, scenery, flowers, etc.

[c] Viewing/photographing wildlife, birds, fish, etc.

[d] Relaxing, hanging out, escaping heat, noise, etc.

[e] Backpacking, camping in unroaded areas.

[f] Resorts, cabins, or other accommodations on Forest Service-managed lands (private or Forest Service).

[g] Motorized activities other than snowmobiling and off-highway use.

Figure 13-21. Percent of national forest visits, by distance traveled, for National Forest System (NFS) Regions 1 and 3, 2009.

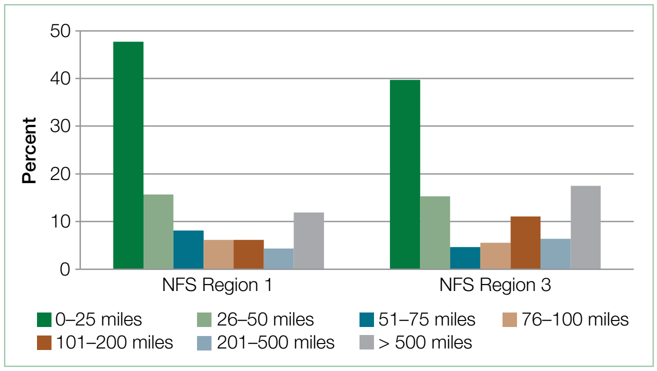
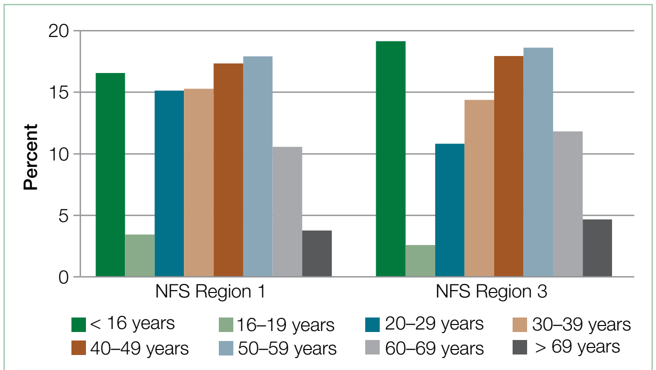


Figure 13-22. Percent of national forest visits by age group and National Forest System (NFS) region, 2009.



those less than 16 years old accounted for the largest group in Region 3. The group contributing the fewest NFVs in both regions was 16-to-19 year olds.

Recreation Visitor Satisfaction

We assessed recreation visitor satisfaction in Regions 1 and 3 by examining NVUM information on Importance-Performance Analysis metrics related to visitor satisfaction with their recreation experiences during two rounds of NVUM data collection: round 2 (2005 to 2009) and round 3 (2010 to 2012). As described in chapter 12, recreation visitors were asked to rate their perceptions of importance and satisfaction for 14 different site attributes. The importance scale ranges from 1 “very unimportant” to 5 “very important,” and the satisfaction scale ranges from 1 “very dissatisfied” to 5 “very satisfied.”

These attributes cover onsite facilities or availability of information, perception of safety and/or value, or other factors relevant to the recreation experience. Five site/area-specific qualities were assessed for all four site types: (1) condition of natural environment, (2) feeling of safety, (3) scenery, (4) condition of trails, and (5) value for fees paid. Three additional qualities were examined for three site types (day use developed sites, general forest area sites, and overnight use developed sites): (1) availability of parking, (2) condition of roads, and (3) adequacy of signage, where the latter two attributes pertain to the forest as a whole. As a last step, we computed site/area-specific rankings for cleanliness of restrooms, condition of developed facility, and condition of parking lot only for day use developed and overnight use developed sites.

When viewed across different setting types on national forests in a region and across periods of time, changes in importance and condition metrics could signal important trends in recreation resource condition. This analysis examined various attributes associated with setting types within each region (also allowing interregional comparisons) through time.

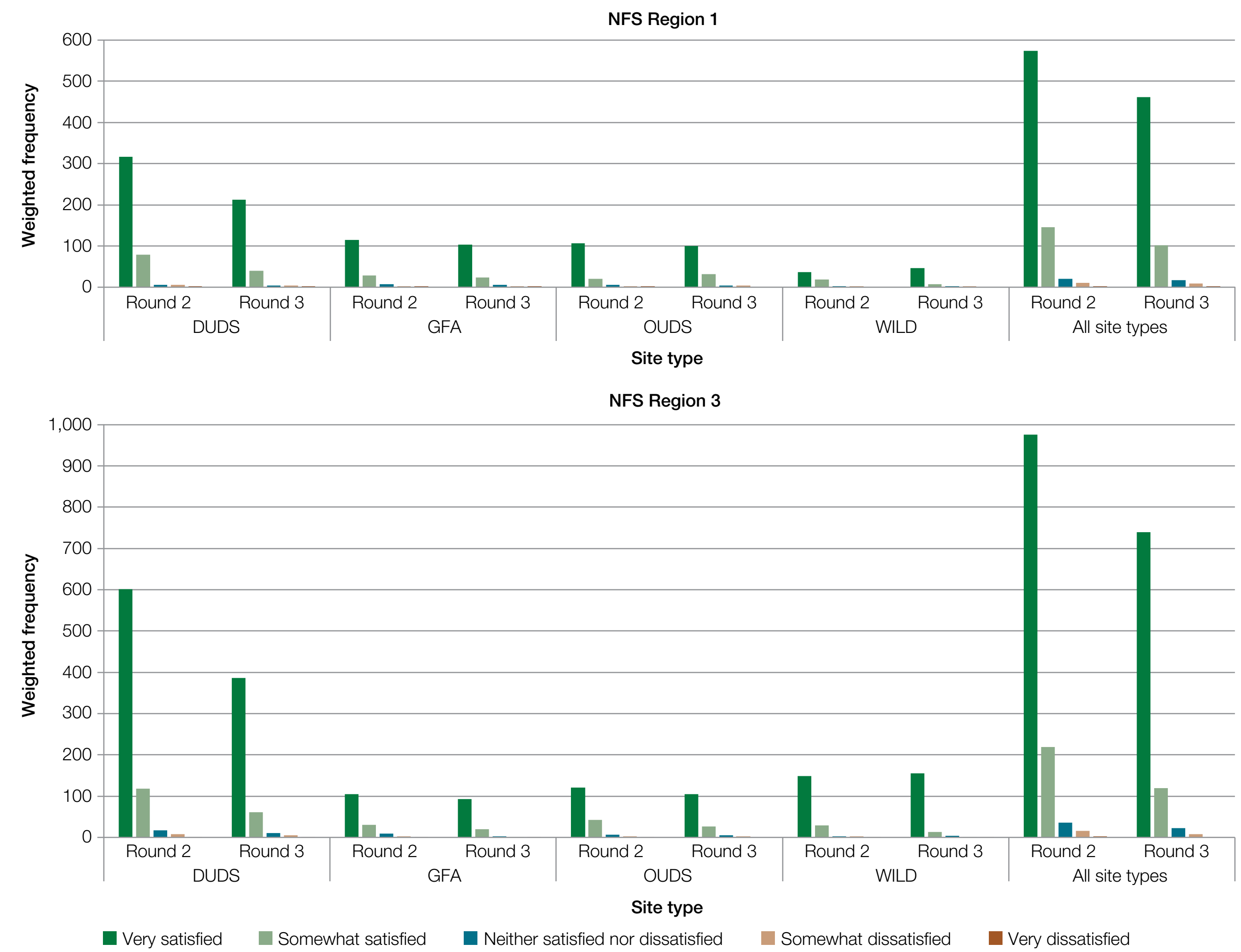
User satisfaction is likely to influence future national forest visitation. If users experience unsatisfactory trips to national forests, then they may adjust their behaviors in ways that negatively impact recreation demand. For example, a person seeking solitude in designated wilderness may take fewer trips if he or she experiences an undesirable level of crowding. In a similar way, a person who perceives that information or signage is lacking may find the recreation experience inconvenient or unfulfilling if he or she cannot navigate efficiently. Overall, national forest visitors in Regions 1 and 3 judged the condition of the natural environment in a very positive light across all site types, with satisfaction ratings clustered in two categories: “somewhat satisfied” and “very satisfied” (figure 13-23).

To gain a better understanding of whether the attributes were important to visitors, satisfaction (performance) ratings can be charted against the importance rating. Plotting the importance against satisfaction (performance) results provides a snapshot of the overall satisfaction and potential areas of improvement. A threshold (e.g., a performance target) can be used to create four quadrants:

1. High importance, high satisfaction: The desired outcome—a quality that is deemed highly important and performing well means to “keep up the good work.”
2. High importance, low satisfaction: A highly important quality that is not performing well means that we should “concentrate here.” Items falling into this quadrant over time suggest a decline in need of attention.
3. Low importance, high satisfaction: This is a potential indicator of “possible overkill,” using resources on an area of low importance for customers to be satisfied. In a limited budget, the areas of overkill may be a start for shifting resources.
4. Low importance, low satisfaction: Although customers may not be as satisfied, the low importance attached to this quality indicates that this is an item of “low priority.”

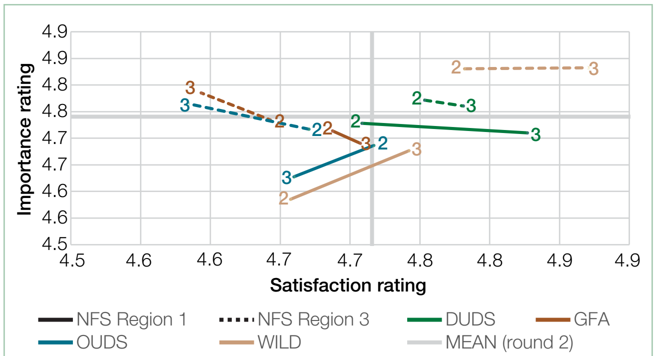
Figure 13-24 shows the results of this approach for the attribute “conditions of the natural environment,” combining the satisfaction results seen in figure 13-23 with importance ranking. The rankings from rounds 2 and 3 are shown to indicate how rankings have changed during the two time periods. The threshold delineating the quadrants in figure 13-24 is the cross-section of the mean rating from the two measures in round 2. The means are quite high, so interpreting results should be done cautiously, given the clustering of high scores for both importance and satisfaction across all site types. The designated wilderness site type from Region 3 performed best, although the scale of the graphic magnifies the differences. By contrast, the designated wilderness site from Region 1 was in the “low priority” quadrant for round 2 but shifted to “possible overkill” in round 3. The day use developed sites in Region 3 showed a

Figure 13-23. Distribution of visitor satisfaction ratings for conditions of the natural environment in National Forest System (NFS) Region 1 (top) and NFS Region 3 (bottom) in two time periods (round 2 = 2005 to 2009 and round 3 = 2010 to 2012).



DUDS = day use developed site. GFA = general forest area. OUDS = overnight use developed site. WILD = designated wilderness.

Figure 13-24. Importance-Performance Analysis for conditions of the natural environment in National Forest System (NFS) Regions 1 and 3 in two time periods (round 2 = 2005 to 2009 and round 3 = 2010 to 2012).



DUDs = day use developed site. GFA = general forest area. OUDS = overnight use developed site. WILD = designated wilderness. MEAN (round 2) = grand mean computed from ratings of the specific attribute (i.e., conditions of natural environment for NFS Regions 1 and 3 in round 2 only as baseline for temporal comparisons with round 3).

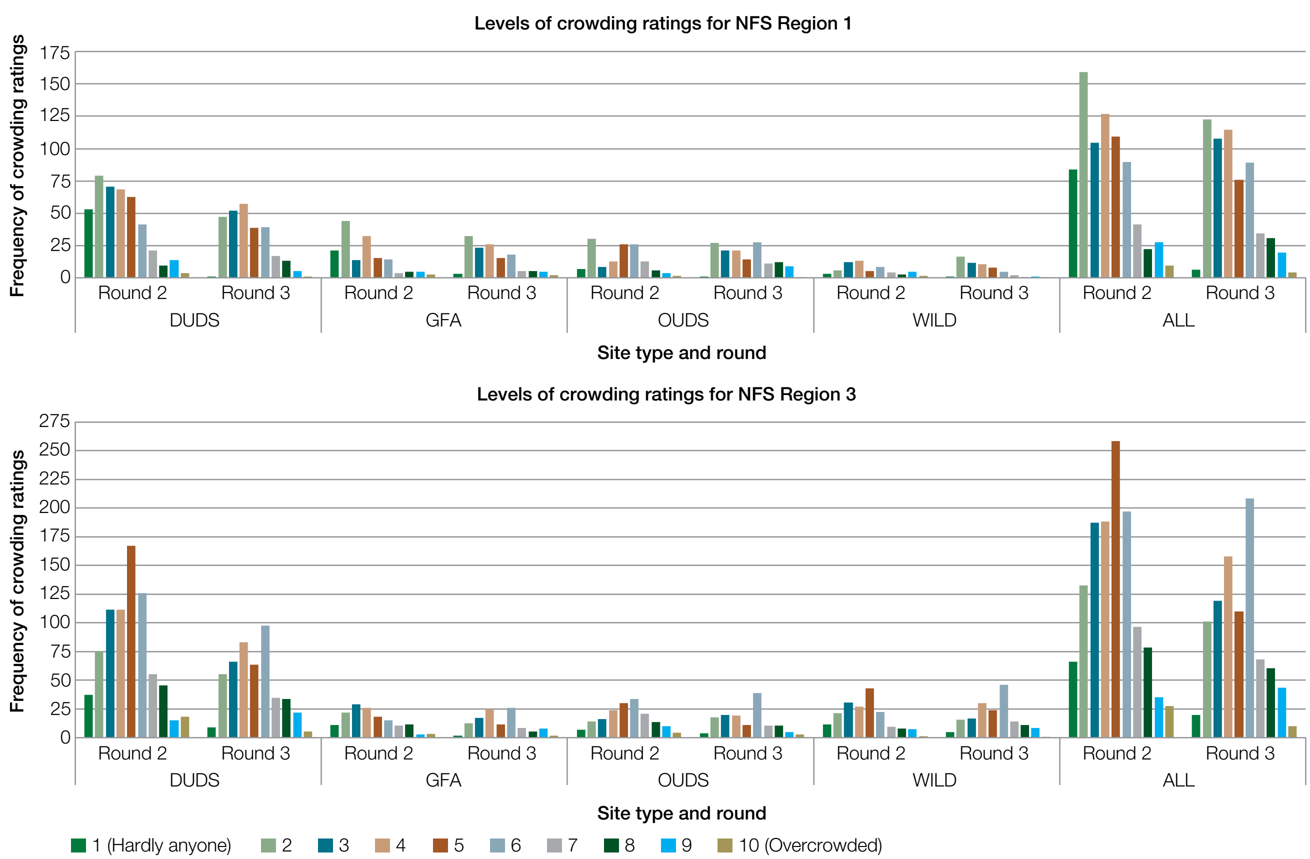
slight decline from round 2 to round 3, but they remained high in both importance and performance. In Region 3, the attribute could be performing under expectations in general forest areas and overnight use developed sites compared with the high levels of satisfaction in developed day use sites and designated wilderness. In Region 1, natural scenery conditions were "low priority" or "possible overkill."

The same analyses were conducted for the other site qualities and attributes. Overall, visitors in Regions 1 and 3 during rounds 2 to 3 found the experiences fulfilling, according to the qualities we evaluated. Using more stringent thresholds to assess relative performance, the attributes falling in the "needs work" quadrant could warrant closer monitoring if trends persist through the next round. On the conditions of scenery and perception of safety, even with the stricter threshold, no regional site type appeared in the "needs work" area. Aside from some points close to the crosshairs of the quadrant, the attribute "condition of trails" did not exhibit a need for improvement. The perception of value for fees paid, overall, showed a need for improvement or a lack of priority; none of the regional site types qualified as "keep up the good work." Recreationists rated conditions of developed facilities and parking lots as being of lower importance. The other attributes did not show a systematic trend but rather a variation, perhaps due to the factors of site type, region, and round, described above.

NVUM provides further insight into recreationists' experiences through a one-dimensional rating for crowding. Respondents were asked to rate their perception of crowding at the site where surveyed on a scale of 1 to 10, with 1 being "hardly anyone" to 10 being "overcrowded." Figure 13-25 shows the distributions of crowding ratings for Regions 1 and 3, subdivided into round and site type. Although bar heights differ because of sample size, the bar charts tend to trail off as the ratings increase, especially after a rating of 8. The peaks within each site type and round for the regions vary between the ratings of 2 and 7, with a peak of 2 (mostly uncrowded) most recurrent for Region 1 and a peak of 6 (somewhat crowded) for Region 3. Although the crowding means are on the lower end of the scale, the distribution of responses reveals the presence of some who perceive overcrowding and also those who encountered "hardly anyone." From rounds 2 to 3, the only declines in crowding appear for designated wilderness in Region 1 and overnight use developed sites in Region 3. The largest perceived increase takes place in general forest area sites in both regions. Collapsing over site type, the general tendency is that the Region 1 national forests could see larger increases in crowding than Region 3, although Region 3 has the larger levels of crowding in magnitude. Following the completion of round 3 and subsequent sampling rounds, more time points will facilitate a better understanding of crowding trends across and within site types in these two regions.

Treating the recreationists' responses as those of consumers, we could ascertain which qualities may need improvement for maintenance of high satisfaction levels. If expectations are not being met, then recreationists—like customers in an economy—may adjust their number of trips and/or activity mixes, potentially affecting demand on national forests. The spatial-temporal data permitted evaluations of short-term trends across two survey rounds, with methodology in place to extend

Figure 13-25. Distribution of responses to crowding by site type and survey round in National Forest System (NFS) Region 1 (top) and NFS Region 3 (bottom) in two time periods (round 2 = 2005 to 2009 and round 3 = 2010 to 2012).



DUDs = day use developed site. GFA = general forest area. OUDS = overnight use developed site. WILD = designated wilderness.

to longer time intervals. Projections are not possible because more time points are not available, so, instead, we looked at a snapshot for potentially problematic spots or high performers on which limited resources may be invested. The current results indicate that, overall, recreation visitors to national forests in Regions 1 and 3 were very satisfied with most of the attributes evaluated.

Recreation in the northern- and southwestern-influence areas is important to both the quality of life of residents and the strength of the economy. The sidebar, Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Recreation Sector, examines the importance of recreation to counties in the northern-influence area.

Economic Dependency of Counties in the Northern-Influence Area on Natural Resource Sectors: Recreation Sector

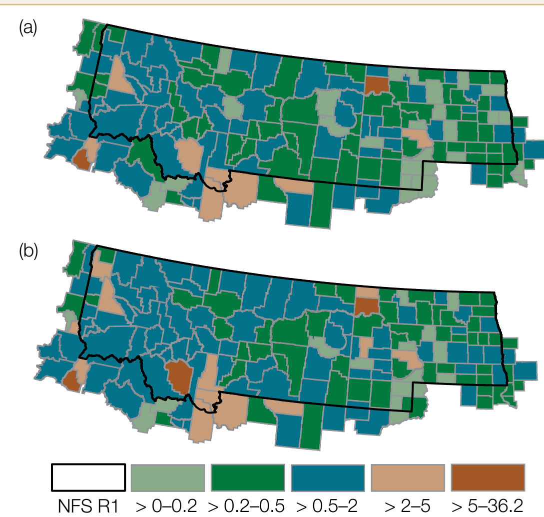
The definitions of tourism and recreation-related sectors have been described as evading simple characterization (Marcoullier and Xia 2008). We follow an approach that characterizes the travel and tourism industry as an aggregation of sectors that are, in total, reliant on tourists as a demand source, defined by U.S. Department of Commerce tourism industry ratios (Zemanek 2013). This approach focuses on a supply-side characterization of the travel and tourism industry and does not distinguish the important demand elements of each sector necessary for a strict tourism- and/or travel-based definition. With a demand-based approach (assessment of expenditures), the amount of out-of-region demand (the tourism component) for each sector may vary from low (clothing retailers) to high (accommodation). As a result, we must further refine this aggregation to employment and income attributable to recreation demand.

Tourism ratios express the proportion of sector output that is consumed by travelers more than 50 to 100 miles from home. Industry ratios were matched with IMPLAN sectors following Creason (2000) and Warziniack and Creason (2001). The industry ratios were then multiplied by employment and labor income in the corresponding IMPLAN sectors to estimate total tourism employment and labor income by sector.

Figure 13-26 shows location quotients for the northern-influence area. Although all counties have some share of recreation in their economy, in general, recreation is not a strong economic force in the region; however, recreation is very important in some counties. Nearly one-fourth of all income in Washington County, Idaho, and 20 percent of all income in Williams County, North Dakota, originate from the recreation sector. Washington County has 13 percent of its total land area in national forests and 23 percent in Bureau of Land Management land, and it is a gateway to counties with more than 50 percent of their land in national forests. Population growth in Washington County was greater than 16 percent in the 1990-to-2000 decade and then grew only 2 percent in the 2000-to-2010 decade. Ranching and forestry, which are important components of the economy in this county, also depend on the natural resources of the area. Recreational opportunities in Williams County, North Dakota, include access to the Yellowstone and Missouri Rivers and to State parks. Oil production is increasingly becoming a major component of the economy because the county lies within the Williston Basin (figure 13-14). The population declined in the 1990-to-2000 decade but increased 13 percent in the next decade; the estimated increase in population since 2010 is 31 percent. As oil and gas development increases, this sector is competing for some of the resources that recreationists use, such as lodging.

The counties in the south-central part of the northern-influence area sit in or provide access to the Greater Yellowstone Ecosystem, one of the largest nearly intact temperate zone ecosystems on Earth. The recreation clusters in these counties are based strongly on the natural amenities in these counties. Regional attractions include Yellowstone National Park, the fourth most visited national park in the country, despite its remote location, and Montana's highest peak, located in the Custer Gallatin National Forest.

Figure 13-26. Location quotients for recreation in counties in the northern-influence area and National Forest System (NFS) Northern Region (R1), where (a) the base is the entire influence area and (b) the base for comparison is the entire United States.



Note: Location quotients are calculated using IMPLAN (2012) data.

Drivers of Future Change: Population, Land Use, and Climate Change

- In both influence areas, nearly all counties with NFS lands or counties surrounding NFS land are projected to have increases in population density; counties with no NFS land are projected to have declines in population density.
- Population density increases could be substantial in major metropolitan areas in the Southwestern Region, which will affect demands on national forests in close proximity.
- The attraction and location of natural amenities in the forested areas of both areas, coupled with increased population densities, suggest the potential for increased housing growth surrounding national forests, potentially impacting wildlife species composition and diversity within national forests.
- Within the larger RPA Rocky Mountain Region, the greatest change in climate will be in the NFS Southwestern Region; temperatures are projected to warm and precipitation is projected to decrease.
- Wildlife habitat under climate change is influenced not only by the changes in temperature and precipitation but also by wildfire dynamics and fire management. Within the northern-influence area, vegetation production declines under fire suppression, with small changes in vegetation types. Without fire suppression, the changes in vegetation types are greater, particularly in the central Idaho and western Montana national forests. The southwestern-influence area sees greater changes in climate than the northern-influence area, but fewer vegetation type shifts, and smaller relative changes in biomass production.
- Range resources in the Southwestern Region will be highly vulnerable to climate change.
- The vulnerability to future water shortages, when adaptation is not considered, is also highest in the Southwestern Region.
- Timber-producing counties of the northern-influence area and counties heavily dependent on recreation in both areas may have lower social vulnerability than nontimber-producing counties and counties dependent on grazing.

As described earlier, factors such as population dynamics and economic growth have influenced past and current use of renewable resources in the northern-influence and southwestern-influence areas. Climate influences natural resource production, and changes in climate are likely to influence future natural resource production. Scenarios describing future population dynamics, economic growth, and climate change enable us to explore how these drivers may affect future renewable resource production and how natural amenities may affect population growth and economic development. The 2010 RPA constructed a consistent set of scenarios for the United States (USDA Forest Service 2012b) (see chapter 2) to develop projections that were used to analyze renewable resource conditions 50 years into the future.

We use these scenarios to explore how population growth and changes in developed land use will alter the nearby settings of national forests. We explore how climate change will affect wildlife habitat, rangeland productivity, and the availability of domestic water 50 years into the future. Given these potential changes, we look at the current social vulnerability of these counties and how they may be able to respond in the future. We close this section with suggestions for future work.

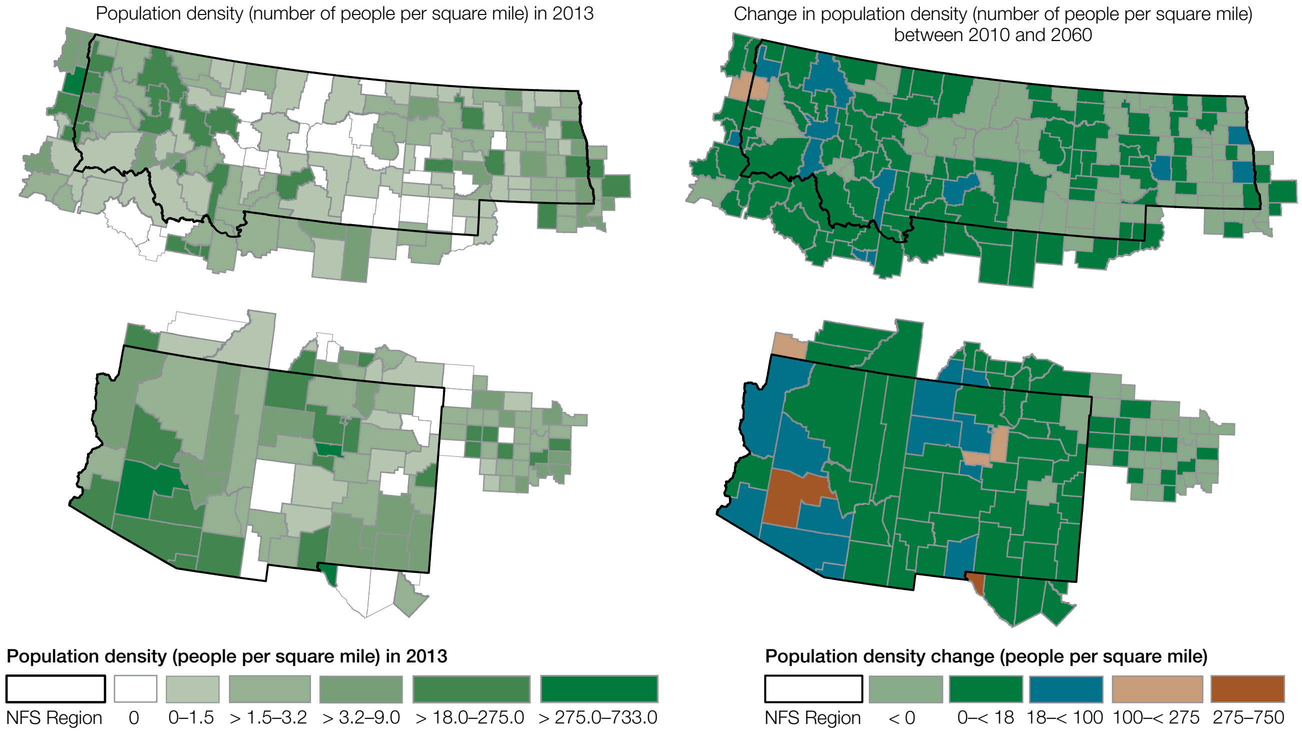
Future Human Population and Land Use

Increases in county-level population density are projected across both influence areas, particularly in areas associated with major metropolitan counties (figure 13-27). Projected increases are largest in the southwestern-influence area. Numerous counties in both influence areas are projected to decline in population density, primarily in the eastern portions of both areas. These counties tend to be in the grassland regions of both areas (figure 13-9) and, for the most part, do not have NFS lands within their boundaries. Some of these counties also saw declines in the past two decades (figure 13-3).

Nearly all counties with NFS lands or counties surrounding NFS lands will see an increase in population during the next 50 years. In the southwestern-influence area, five counties will see density changes greater than 100 people per square mile in the next 50 years. In the northern-influence area, two counties will see density increases of 100 people or more per square mile (figure 13-27). This increasing density surrounding NFS lands will decrease the connectivity of national forests with rural lands.

Population growth rates historically have been less than rates of land conversion; thus, increasing populations and densities suggest high rates of land conversion in the future. At the national level, between 1945 and 1992, one additional person led to

Figure 13-27. Population density in 2013 (left) and projected population density change (right) for the northern-influence area and National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom), 2010 to 2060, based on the RPA A1B scenario.



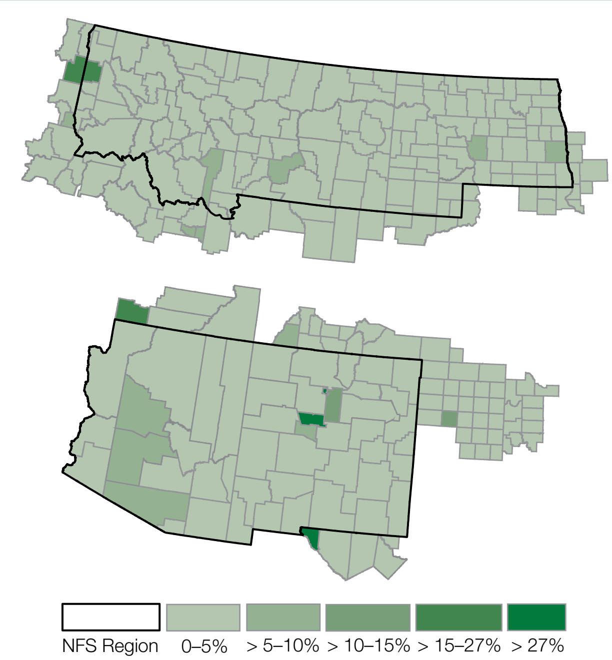
RPA = Resources Planning Act.
Source: Data from http://www.unh.edu/demographic-indicators.

about one-half acre converted to urban use; between 1992 and 1997, the rate reached 1.2 acres per additional person (Sampson and DeCoster 2000). Urban and developed areas currently constitute a very small percentage of area in most counties (figure 13-4). By 2060, most counties will still have less than 5 percent of their area in developed area. In the northern-influence area, the number of counties with more than 5 percent developed land area will increase from 2 to 9 (6 with NFS lands) and, in the southwestern-influence area, the number will increase from 5 to 11 (9 with NFS lands) (figures 13-4 and 13-28).

This projected expansion of human populations and developed area occurs across landscapes where species formally listed as threatened or endangered under the Endangered Species Act are found (figure 13-29). The number of listed species is higher in the western parts of Montana, where NFS lands are found and developed land expansion is projected as low relative to the expansion of developed areas across the State. Listed species are found throughout many counties in the southwestern-influence area, some of which will see high growth in populations and developed areas. Listed species' habitat on NFS lands or other protected lands may be particularly important where they surround counties with projected high population growth.

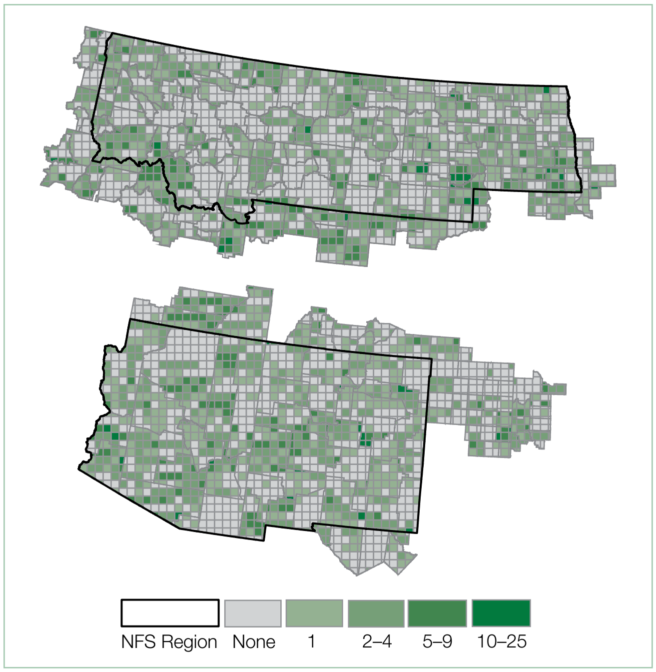
One indicator of the attraction and location of the natural amenities in both influence areas is past trends in housing

Figure 13-28. Percent of developed area, by county, projected for 2060 in the northern-influence area and National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom) under the RPA A1B scenario.



RPA = Resources Planning Act.
Sources: USDA Forest Service (2012b); Wear (2011).

Figure 13-29. Current geographic distribution within the northern-influence area and National Forest System (NFS) Northern Region (top) and southwestern-influence area and NFS Southwestern Region (bottom) of federally listed threatened or endangered species. Data are derived from the National Heritage Programs as maintained by NatureServe (2014) and mapped onto a systematic equal-area grid (250 square miles [647.5 square kilometers]) of the United States.



growth adjacent to or within (on private inholdings) protected areas (see figure 11-1 in chapter 11). In the 1990s, the housing growth rate within 1 kilometer of protected areas (20 percent per decade in the 1990s) exceeded the national housing growth rate (13 percent) (Radeloff et al. 2010). Housing growth rates were higher around protected lands in the southwestern-influence area than in the northern-influence area (see figure 11-1). If trends continue, the number of houses built adjacent to or within protected areas is likely to continue to increase. Density of housing outside protected areas has been shown to influence bird diversity outside protected areas and also within protected areas (see chapter 11). For species of greatest conservation need as identified in State Wildlife Action Plans (Association of Fish and Wildlife Agencies 2011), proportional abundance was higher inside the protected area when housing density outside the protected area was less than one house per 40 acres (figure 11-4 in chapter 11). In addition, synanthropes (species that tolerate and benefit from human activity and are often non-native species) tended to have higher proportional abundance within the protected area when housing density was greater than one house per 40 acres outside the protected areas in the Desert and Great Basin, Western Mountains, and Prairie Badlands—all biomes of interest to these two influence areas (figures 11-3 and 11-4). If the projected increasing population densities are matched with increased housing density as historical trends indicate, then bird communities within and at the boundary of protected areas could be characterized by lower representation of species of greatest conservation need and higher representation of synanthropes.

Population projections explored in this chapter do not reflect the effects of the potential for future oil and gas development on county populations in counties underlain with oil shale in North Dakota and Montana. These counties have seen population increases of 10 percent in the past 10 years (figure 13-7) and more than 5 percent in just the past 3 years (figure 13-17). Depending on future energy prices, these counties with increasing densities would be likely to continue to increase in population numbers and densities.

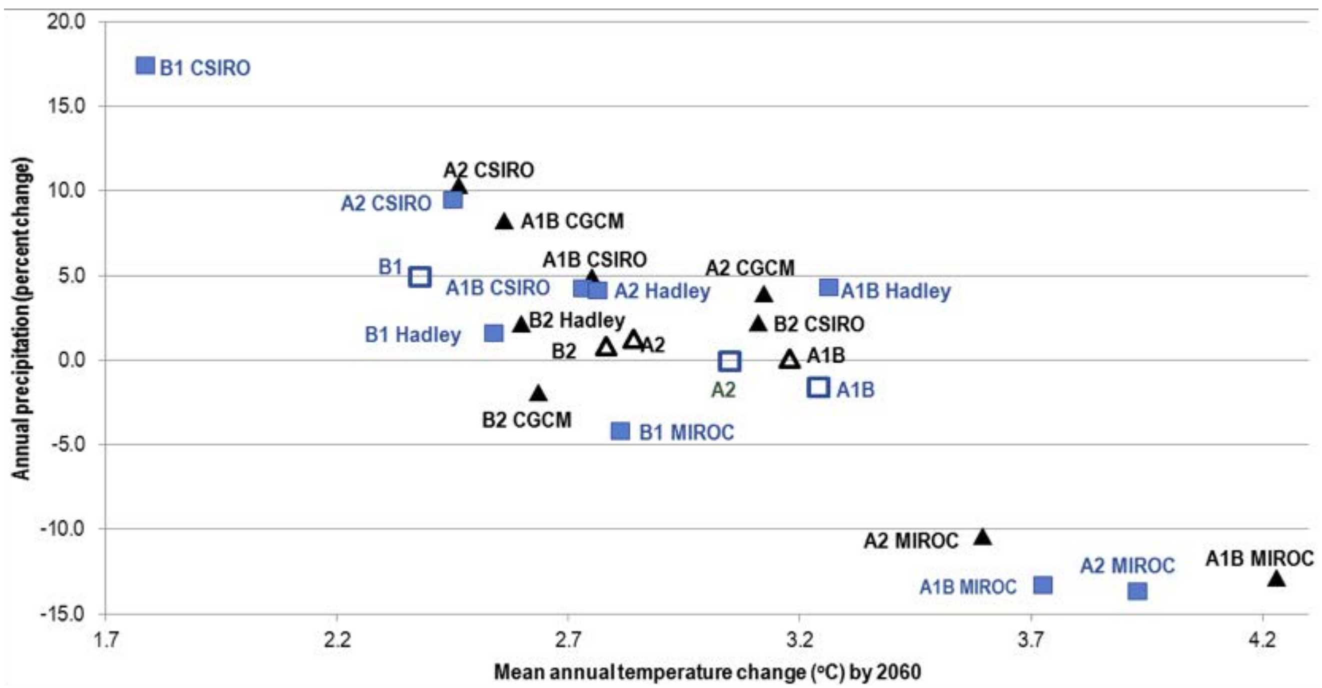
Climate Change

The 2010 RPA included the analysis of potential climate change effects on several natural resources. We present those results for the northern-influence and southwestern-influence areas for rangeland and water and also present wildlife results discussed earlier in this RPA Update for the RPA Rocky Mountain region, but we are focused here on the two influence areas.

Comparisons of the changes in temperature and precipitation allow for a visual summary of the similarity or differences in various climate projections. Figure 13-30 shows differences in the projections used in the 2010 RPA and in projections used in the wildlife habitat analyses in this RPA Update. In this Update's wildlife habitat analyses, the B1 scenario with models from the Fourth IPCC Assessment replaces the B2 scenario (with models from the Third Assessment) used in the 2010 RPA. The projections for the B1 scenario suggest a smaller change in mean annual temperature than do the B2 projections (figure 13-30). For the A1B and the A2 scenarios, the individual climate models and the mean changes for the scenario are similar between the 2010 RPA and the models used here.

Global emissions are more closely tracking the projected emissions from the IPCC A2 scenario, so we focus here on the results from the A2 scenario on potential changes in climate for the northern-influence area and the southwestern-influence area. Many comparisons focus only on temperature or summarize temperature and precipitation, but it is the interaction of these changes in temperature and precipitation that plants, animals, and ecosystems will experience. To explore the potential changes in future climate, we used an index that summarizes changes in both temperature and precipitation between the historical and projected periods. Differences in temperature and in precipitation between the historical period (1960 to 1999) and the future period (2050 to 2099) are computed using Euclidean distance for each grid and each climate model projection. We averaged the results for the three climate model projections for A2 and displayed this metric using a hot-spot

Figure 13-30. U.S. temperature and precipitation changes from the historical period (1961 to 1990) to the decade surrounding year 2060 (2055 to 2064). Mean changes for each scenario (A1B, A2, B1, B2) are shown as outlined squares and triangles; mean changes for each climate model are shown as solid squares and triangles. Solid black triangles and black outlined triangles are based on climate models used in the 2010 RPA. Solid blue squares and blue outlined squares represent climate models used in the wildlife habitat analyses in this RPA Update.

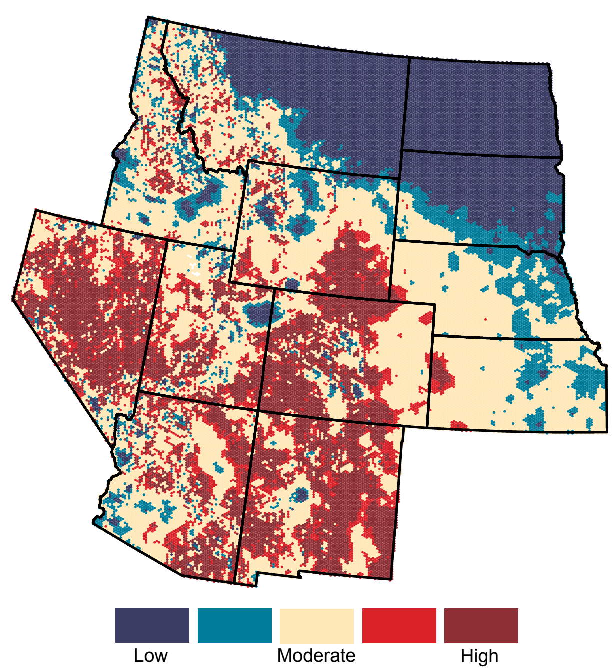


scale in which the largest relative changes in the RPA Rocky Mountain Region are shown in shades of red and the smallest relative changes are in shades of blue (figure 13-31).

Found within the RPA Rocky Mountain Region are the driest areas (Great Basin and Southwest) and some of the coldest areas (high-elevation Rocky Mountains) of the United States. Within this larger region, the most change in climate is projected to occur in the NFS Southwestern Region and the least change in climate in eastern Montana, North Dakota, and South Dakota. Changes are still occurring in the NFS Northern Region, but across this entire RPA Rocky Mountain Region, the greatest changes will occur in the Southwestern Region. Temperatures are projected to rise and precipitation is projected to decline in the Southwestern Region; by contrast, the projections for precipitation indicate no change or a slight increase in the Northern Region.

We drew from the wildlife habitat stress analysis in chapter 11 to look at the percent of high-stress area within the NFS Northern and Southwestern Regions in the larger RPA Rocky Mountain Region (see figure 11-5 in chapter 11). The assignment of hot spots is done at the regional scale, not within each national forest. We found that 10 percent of the area in Northern Region national forests and 13 percent of the area in Southwestern Region national forests are in high stress under fire suppression (table 13-8), where high stress is defined as

Figure 13-31. Changes in climate (mean annual temperature and total annual precipitation) for the A2 scenario based on three climate models (MIROC2medres, UKMO HadCM3, and CSIRO-MK3.0) for the RPA Rocky Mountain Region. High implies the largest relative changes from historical climate; low implies the smallest relative changes from historical climate within this region.



RPA = Resources Planning Act.

Table 13-8. Percent of National Forest System (NFS) lands within Regions 1 and 3 in high stress (top 20 percent) and low stress (bottom 20 percent) under the A2 scenario and two different fire scenarios.

Region	Fire suppression	No fire suppression	Fire suppression	No fire suppression
	high stress (percent)		*low stress (percent)*	
NFS Region 1	10	27	38	24
NFS Region 3	13	11	8	18
All lands in RPA Rocky Mountain Region	18	28	19	17

RPA = Resources Planning Act.

those grid cells with Terrestrial Climate Stress Index scores in the top 20 percent at the RPA Rocky Mountain regional scale. That less than 20 percent of national forest area is considered high stress under the fire suppression scenario was not surprising, given that the greatest changes under fire suppression in the RPA Rocky Mountain Region occurred in southern Idaho, eastern Wyoming, eastern South Dakota, and Nebraska, areas mostly outside NFS regional boundaries. Within the Northern Region, vegetation production declines under fire suppression, with small changes in vegetation types. Without fire suppression, wildfire is a larger component of the landscape dynamics and the changes in vegetation types are greater than with fire suppression, particularly in the central Idaho and western Montana national forests in the Northern Region. The Southwestern Region sees only a small percentage of area in high stress under no fire suppression. Changes are still occurring in this part of the RPA Rocky Mountain Region, but, in this relative scale, the changes are less than elsewhere in the RPA region. The Southwestern Region sees the greatest changes in climate within the RPA Rocky Mountain Region but sees fewer vegetation type shifts and smaller relative changes in biomass production. Even though woody encroachment occurs in the Southwestern Region, Barger et al. (2011) noted that changes in ecosystem carbon under woody encroachment tend to be less in arid environments than in semiarid to subhumid environments.

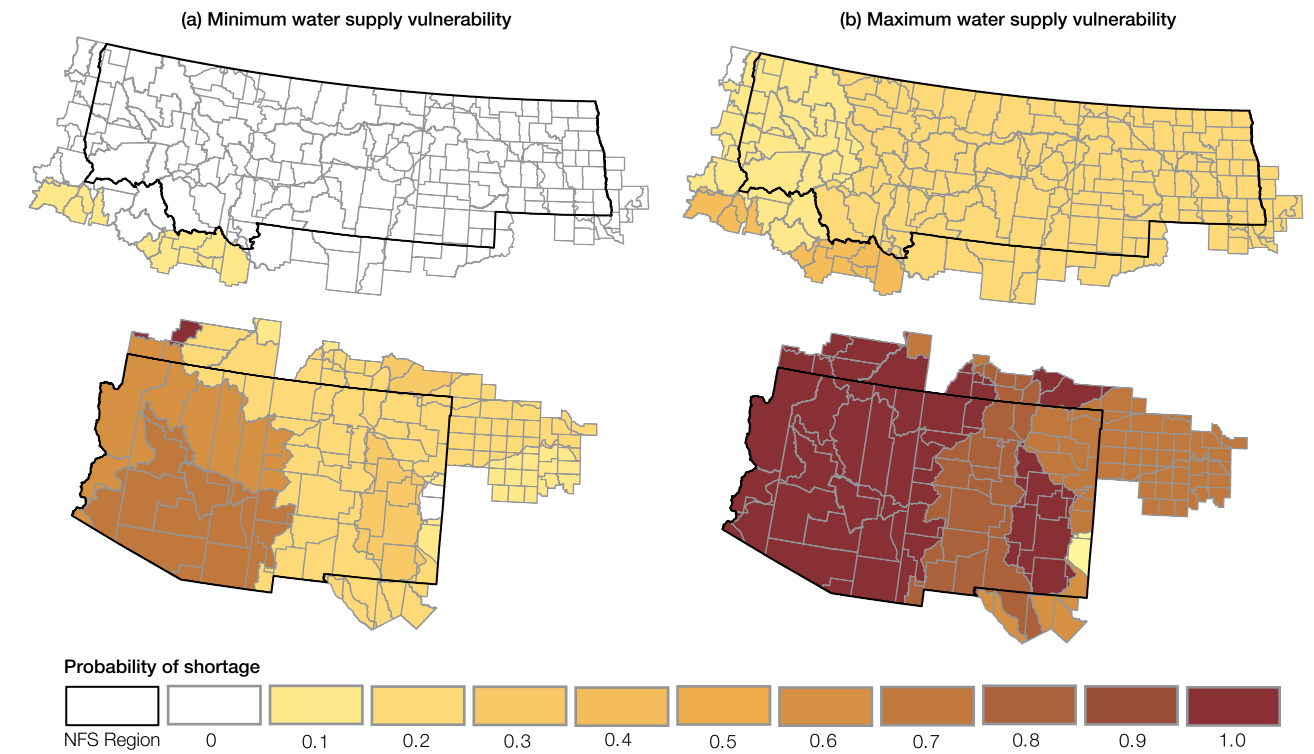
These results suggest that the influence of fire on vegetation types is important to consider in projecting the future effects of climate change on wildlife habitat. Where a particular fire regime has been a major influence in sustaining a vegetation type, such as surface fires and grasslands, the effect of a changing climate and a changing fire regime on wildlife habitat stress will differ, depending on the management of wildfire. Suppression of wildfire under a changing climate could facilitate more woody encroachment in some areas.

The potential impacts of climate change on range resources in the NFS Northern and Southwestern Regions are described in detail in chapter 9. Overall, the conclusion is that conditions in the Northern Region will be less impacted by climate change than in the Southwestern Region. Vegetation productivity in the arid Southwestern Region was most correlated to precipitation and water relations; with future changes in precipitation, in particular, range productivity is likely to decline. By contrast, the eastern grass-dominated areas of the Northern Region were more correlated to temperature, suggesting a positive response to future temperature warming and the projection of no change or a slight increase in precipitation (see figure 9-3).

Ranching is an important economic sector (figure 13-12) in both regions. Forage supplies are sensitive to vegetation productivity and potential changes from grass types to woody vegetation types. Most cattle raised in these two regions have low tolerance to high temperature as they were developed from European breeds (Joyce et al. 2013). Increasing temperatures will stress cattle. Using the elements of forage quantity, vegetation type trajectory, heat stress on livestock and forage variability and a wide range of future scenarios, overall vulnerability in cattle production was seen as increasing in the Southwestern Region in contrast with the Northern Region (see figures 9-13 through 9-15). The greatest vulnerability was found in the Desert Southwest and Southwest rangeland ecoregions (Nevada, New Mexico) and the least vulnerability in the northern Great Plains rangeland ecoregion (the grassland parts of Montana, North Dakota, and South Dakota) (figure 9-14). Although adaptation options to cope with these stresses are available (e.g., drought management, heat-stress coping strategies), implementation of these strategies, particularly drought management, remains limited (Joyce et al. 2013). The capacity to assess risk and respond with management strategies or enterprise restructuring varies greatly across landowners. The landscapes in both regions are mosaics of private, State, and Federal ownership and, in some cases, are interdependent in terms of the ecosystem services produced. Adaptation strategies that reflect ecological and socioeconomic vulnerabilities will be needed to address climate change in both regions (Briske et al. 2015).

The potential impacts of climate change on water resources projected in the 2010 RPA were particularly severe in the southwestern-influence area as a result of both temperature increases and precipitation decreases (figure 13-32), with potential for associated decreases in the future supply of water. Water is already scarce in many parts of the Western United States, and, as population growth occurs, the demand for and consumptive use of water will increase. Water vulnerability was evaluated in the 2010 RPA (Foti et al. 2012) by totaling all the reservoir storage, water supply, and water demand within assessment subregions under nine RPA scenario-climate combinations. The minimum and maximum probabilities of

Figure 13-32. (a) Minimum and (b) maximum water supply vulnerability (probability of shortage) in 2060 for the northern-influence area and National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom) across nine alternative futures.



Source: Foti et al. (2012).

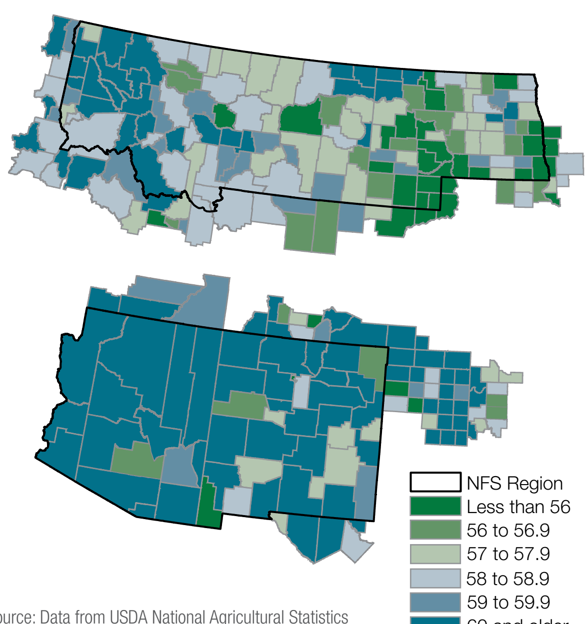
shortage by subregions (defined by rivers and watersheds) are shown in figure 13-32 for the northern-influence and southwestern-influence areas. Many counties in the northern-influence area have low or no probability of shortage. Water vulnerability is highest for the southwestern-influence area. This analysis represents a future in which no adaptation is enacted. Adaptation options are presented in chapter 10 to evaluate likely outcomes for addressing water scarcity. Such adaptations bring all aspects of society together: urban water users, farmers who irrigate, industries, and lands protecting habitat for wildlife and fish. The challenges for land managers and communities will be daunting (see chapter 10).

Managing for a Resilient Future With Increasing Populations, Economic Growth, and Climate Change

Future interactions of population dynamics, economic growth, and climate change across the landscapes of these two regions depict future challenges, not only for natural resource land managers but also for rural and urban communities. Human modification of forests and rangelands, along with the fragmentation that results, is motivated by opportunities for economic growth, as land is converted to higher dollar value uses. Where oil and gas development in the Northern Region has been occurring, it has provided a large economic boom. Some economists describe jobs in the oil and gas sector as rural America's route to higher incomes, replacing the role that high-paying manufacturing jobs used to play in America (Kinnaman 2011; Munasib and Rickman 2015; Paredes et al. 2015). The Northern Region's natural amenities are also often touted as the region's greatest economic asset (e.g., Power 1998; Rasker 1993). The conversion and fragmentation of forests and rangelands to residential and developed land have brought new populations, higher incomes, and higher tax bases to many rural communities throughout the U.S. West, creating what has been called the "New West" (Riebsame et al. 1997). In the RPA Rocky Mountain Region, 67 percent of counties grew faster than the national average during the 1990s (Beyers and Nelson 2000). This development has occurred at the same time that Federal environmental programs targeting private lands have promoted protection of ecosystem services like clean water and habitat for wildlife, including habitat for threatened and endangered species.

The availability and condition of natural resources will influence future options for economic growth. For example, the economies of counties that depend heavily on grazing but lack large oil and gas reserves or have not seen strong residential growth (or other economic growth opportunities) may be especially vulnerable to changes in climate that reduce forage or increase the variability of vegetation production. Cultural assets may also be vulnerable due to a loss of rural lifestyle and character in which large declines in ranching employment or the breakup of large ranches or family forest lands are coupled with above-average rates of New West population growth. Opportunities on private lands will be influenced by near-term decisions made about land use and succession planning. Overall, the average age of principal farm operators is more than 60 years for more counties in the southwestern-influence area than in the northern-influence area (figure 13-33). Legacy planning for farmers and ranchers is one focus of several State extension agencies (https://www.ag.ndsu.edu/ndestateplanning; http://store.msuextension.org/publications/FamilyFinancialManagement/EB0149.pdf). Counties where the average operator age is more than 60 in the northern-influence area tend to coincide with the western counties that provide habitat for threatened and endangered species and are also expected to see increased population growth associated with attraction to high-valued natural amenities. Family forest owners manage 38 percent of forest land across the United States; their primary objectives are maintaining aesthetics, maintaining the privacy the land provides, and preserving the land as part of their family legacy (Butler 2008). Changes in ownership can bring change in landowner objectives.

Figure 13-33. Average age of principal farm operators in the northern-influence area and the National Forest System (NFS) Northern Region (top) and the southwestern-influence area and NFS Southwestern Region (bottom), 2012.



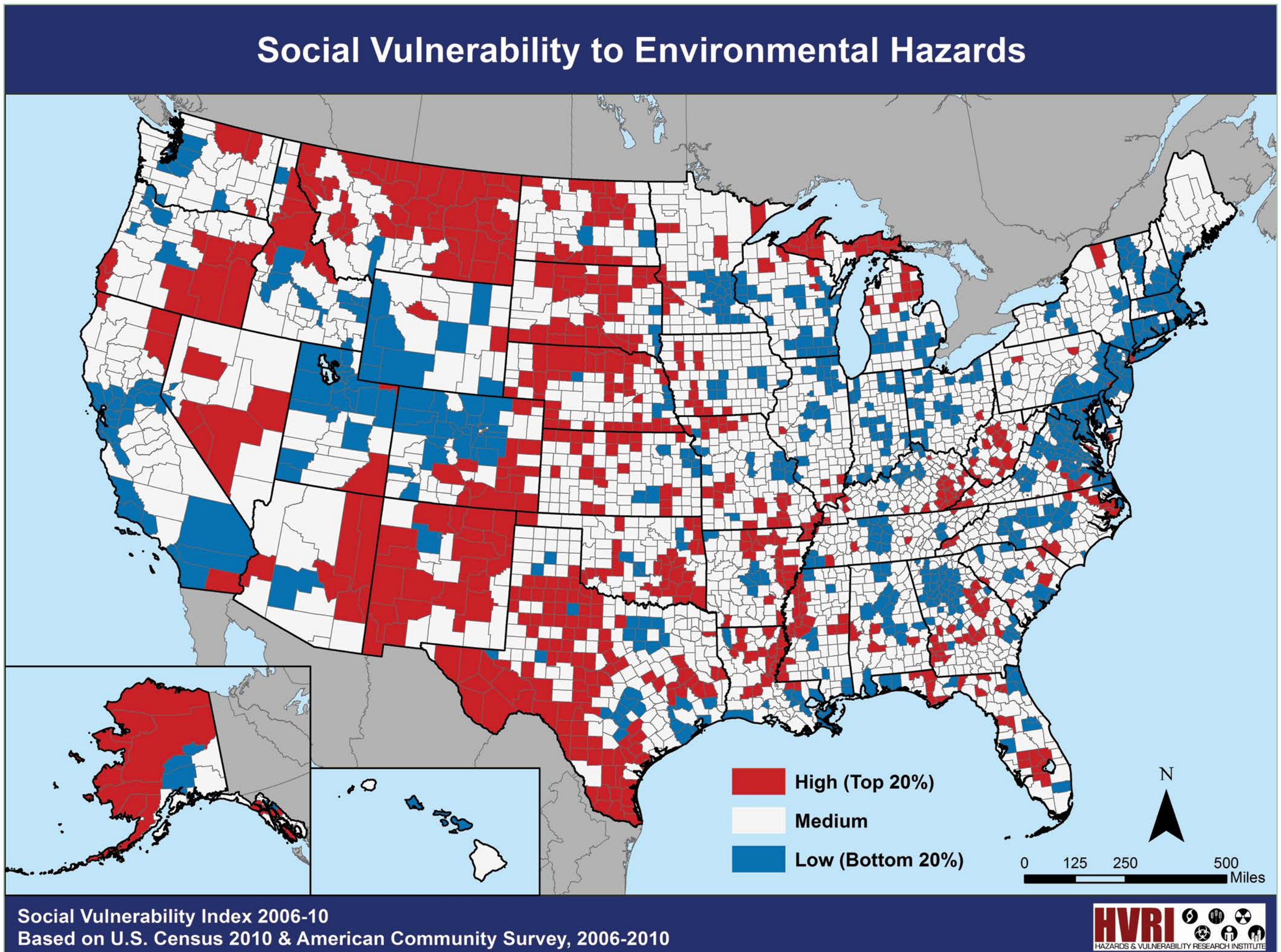
Source: Data from USDA National Agricultural Statistics Service (www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Atlas_Maps/Operators/Characteristics/12-M124.php).

The adaptive capacity of the ecosystems and the urban and rural communities will strongly influence how these driving forces of change affect the landscapes in both regions. The capacity of particular ecosystems to respond to stresses, such as extreme weather events and potential climate change, has been assessed in chapters in this RPA Update and also in the Third National Climate Assessment (Melillo et al. 2014). Adaptation management strategies are being developed for many of the ecosystems and the economic enterprises (such as ranches) associated with these ecosystems (see chapter 9). The challenges will occur on forests and rangelands where population growth and economic development interact with climate change. For example, the potential impacts of climate change on wildlife are multiple and interacting, across scale and time. Spatially explicit information on habitat stress attributed to climate change can be integrated with the location of current stressors (e.g., concentrations of intensive land uses that could affect wildlife movements) to evaluate the coincidence of future climate change threats with existing threats to wildlife resources. Linking changes in habitat to changes in climate provides a template for decisionmakers to evaluate potential risks to wildlife resources that are attributable to climate change across landscapes.

Humans and communities are also vulnerable to specific stresses. This social vulnerability or the adaptive capacity of human communities is a widely applied concept with often varying definitions. Definitions generally suggest that vulnerability is a property of a population that influences how the population experiences stress (i.e., stress associated with environmental hazards or the effects of climate change) (Brooks 2003; O'Brien et al. 2004a). Definitions of vulnerability can typically be grouped within three more generalized theoretical frameworks: (1) a risk/hazard framework, (2) a political ecology/political economy framework, or (3) a socioecological resilience framework (Polasky N.d.). Just as the capacity of ecosystems to respond to stress is not easily captured by one method, no single assessment framework for social vulnerability is entirely comprehensive.

The Social Vulnerability Index (SoVI), first published in 2003, is designed to measure the vulnerability of U.S. counties to environmental hazards, using variables that are selected to characterize broader dimensions of social vulnerability (Cutter et al. 2003). The aspects of vulnerability included in the index were compiled through a literature review and are primarily related to demographic or socioeconomic features of each county's population. Each variable within the index is considered to contribute to vulnerability by increasing the risk of exposure to an environmental hazard (figure 13-34). Many counties in the eastern part of Montana, central North Dakota, and central South Dakota fall into the highly vulnerable category; counties at the eastern edge of Arizona and east-central portion of New Mexico are similarly ranked as highly vulnerable.

Figure 13-34. Social vulnerability to environmental hazards. The Social Vulnerability Index scores at the national level are mapped using quantiles. Scores in the top 20 percent of the United States are more vulnerable counties (red) and scores in the bottom 20 percent of the United States indicate the less vulnerable counties (blue).



Source: Cutter et al. (2003).

When economic dependence on resource sectors is compared with the SoVI, we find that timber-producing counties have lower SoVI scores (less vulnerable) than nontimber-producing counties and that counties heavily dependent on recreation have lower SoVI scores than those with little recreation. Counties dependent on grazing are significantly more vulnerable according to the SoVI, which could be a reflection of aging populations, low regional incomes, reliance on a single economic sector, and a large proportion of minorities. For the Southwestern Region, the high social vulnerability overlaps with the high-stress pattern associated with climate change, perhaps portending a lower adaptive capacity to climate change.

We explored the relationship between short-term changes in per capita income over the 2007-to-2009 recession with the county's dependency on timber, oil and gas, ranching, or recreation. The worst year, on average, for the Northern Region was 2009, when inflation-adjusted per capita income fell by 9 percent. The impact was spread unevenly among counties (table 13-9). A few counties, mainly those dependent on oil and gas, saw extreme booms and busts. Regardless of how we defined dependency, counties dependent on grazing saw significantly larger drops in per capita income than did nongrazing counties, echoing the SoVI results for eastern Montana. Timber and recreation counties saw significantly smaller drops in per capita income. Note that these analyses do not account for spurious relationships and correlations between resources. Many recreation-dependent counties, for example, are also dependent on timber; a fuller analysis is needed to tease out these effects. We are more confident in the results for grazing—grazing was rarely correlated with other resources and was the only resource to see larger decreases in incomes.

Table 13-9. Change in per capita personal incomes for counties in the National Forest System Northern Region.

Counties with largest losses	Percent change in per capita income	Years	Counties with smallest losses	Percent change in per capita income	Years
Cavalier, ND	– 37	2008–2009	McKenzie, ND	8	2008–2009
Slope, ND	– 35	2007–2008	Stark, ND	4	2008–2009
Teton, WY	– 28	2008–2009	Morton, ND	3	2008–2009
Garfield, MT	– 28	2008–2009	Musselshell, MT	2	2010–2011
Ziebach, SD	– 26	2005–2006	Oliver, ND	1	2009–2010
Towner, ND	– 25	2008–2009	Powell, MT	1	2008–2009
Emmons, ND	– 23	2005–2006	McLean, ND	1	2010–2011
Steele, ND	– 22	2008–2009	Pend Oreille, WA	0	2008–2009
Sargent, ND	– 22	2008–2009	Deer Lodge, MT	0	2008–2009
Chouteau, MT	– 22	2008–2009	Clearwater, ID	0	2008–2009

Future Work

This chapter drew connections between the ecological information and the socioeconomic information from the 2010 RPA but did so at the scale of two NFS regions. Although many connections were drawn in this chapter, additional analyses would be possible from the rich information base developed as part of the 2010 RPA and this RPA Update. We linked some RPA data to social vulnerability metrics; this work reflects only a start at the many ways in which the RPA Assessment and analyses like it can be useful in social vulnerability analysis. These types of reports may also be useful in addressing critiques levied against existing social vulnerability models and in improving assessment methods in general. Such a report offers the ability to bring together multiple perspectives in one place. When coupled with social vulnerability analysis, these perspectives have the potential to generate new and exciting research questions that expand on our existing understanding of social vulnerability—within the United States and beyond.

Conclusions

This chapter uses the extensive information and data from the 2010 RPA to draw out connections among natural resources, climate change, and social and economic drivers of change at the scale of two National Forest System regions—the Northern Region (Region1) and the Southwestern Region (Region 3). In addition, we brought in additional socioeconomic information, such as the location quotients and the Social Vulnerability Index to provide additional perspectives. Information from recent studies associated with this RPA Update enhanced our findings on the challenging futures these regions face in light of the wealth of their natural amenities, population dynamics, and economic opportunities.

We chose these two NFS regions to explore the use of the RPA Assessment data because they offer obvious differences in the current climate, available natural resources, and population. Yet, they have some similarities as well; NFS lands in both regions are spread across counties with widely varying population densities, although the southwestern-influence area has a higher population density and a more urbanized population. Projected population growth will create areas where national forests increasingly are surrounded by urban areas, with increased visitor use, and future visitor use perception of crowding. These challenges will arrive sooner in the southwestern-influence area.

These two NFS regions differ in terms of natural resources and amenities, primarily because of the differences in climate. Reflecting greater precipitation, the northern-influence area is more productive in terms of vegetation and timber production and in the availability of domestic water than is the southwestern-influence area. Changes in climate are projected to be more severe in the southwestern-influence area, with warmer temperature, a decrease in precipitation, and likely increases in drought. These changes, coupled with the existing greater numbers of federally listed threatened or endangered species, suggest that resource managers will be challenged to find ways to maintain the resilience of the ecosystems in the southwestern-influence area.

While the future may at first seem less challenging for the northern-influence area, the nature of the amenities here will draw increasing numbers of people and economic development. Already, rangeland, agriculture, and energy are increasingly interconnected in both regions through agricultural markets, new technology for oil and gas extraction, and Federal policy. In the eastern part of the northern-influence area and to a lesser extent in the eastern part of the southwestern-influence area, new technology has spurred an expansion of oil and gas development, resulting in increased shares of county income from oil and gas development, large population increases, and competition among sectors for services in areas of expansion. Across the eastern part of the northern-influence area, land use shifts among cropland, pastureland, and rangeland have been promoted by availability of technology and markets for bioenergy. Warming temperatures in this region have already encouraged corn planting in areas previously seen as inhospitable, and the trend in warming temperatures suggests likely further extensions of corn plantings. The combination of these agricultural land use changes, coupled with energy development, has already raised concerns about wildlife conservation.

These dynamic land shifts will have consequences for NFS lands. The increasing urbanization in counties with national forest land will likely increase the value of national forest lands for watershed protection and wildlife habitat, just as climate change is potentially altering that habitat for resident plants and animals, particularly in the Southwestern United States. Increased population growth, along with the warmer temperatures associated with climate change, is likely to shift the recreation interest of local and long-distance visitors to higher elevations in both influence areas, where temperatures may be relatively cooler. In the northern-influence area, natural amenities are likely to continue to draw populations into the wildland-urban interface at a time when climate change may be increasing fire dynamics in these areas. Increasing development in the wildland-urban interface in the northern-influence area will also likely increase the importance of national forest lands for wildlife habitat and listed species. Recognizing and incorporating the interaction of population growth, economic development, and climate change impacts on natural resources could be a valuable contribution to natural resource planning.

References

Abt, K.L.; Abt, R.C.; Galik, C. [et al.]. 2014. Effect of policies on pellet production and forests in the US South: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-202. Asheville, NC: U.S. Department of Agriculture, Forest Service. 33 p.

Abt, R.C.; Cubbage, F.W.; Abt, K.L. 2009. Projecting southern timber supply for multiple products by subregion. Forest Products Journal. 59: 7–16.

Ackrill, R.; Kay, A. 2011. EU biofuels sustainability standards and certification systems: how to seek WTO-compatibility. Journal of Agricultural Economics. 62: 551–564.

Adger, W.N.; Arnell, N.W.; Tompkins, E.L. 2005. Successful adaptation to climate change across scales. Global Environmental Change. 15: 77–86.

Aguilar, F.X.; Goerndt, M.E.; Song, N.; Shifley, S. 2012. Internal, external and location factors influencing cofiring of biomass with coal in the U.S. Northern Region. Energy Economics. 34(6): 1790–1798.

Allred, B.W.; Smith, W.K.; Twidwell, D. [et al.]. 2015. Ecosystem services lost to oil and gas in North America. Science. 348: 401–402.

Anderson, M.G.; Ferree, C.E. 2010. Conserving the stage: climate change and the geophysical underpinnings of species diversity. PLOS ONE 5(7): e11554, doi:10.1371/journal.pone.0011554.

Andreadis, K.M.; Clark, E.A.; Wood, A.W. [et al.]. 2005. Twentieth-century drought in the conterminous United States. Journal of Hydrometeorology. 6: 985–1001.

Andreadis, K.M.; Letternmaier, D.P. 2006. Trends in 20th century drought over the continental United States. Geophysical Research Letters. 33: L10403, doi:10.1029/2006GL025711.

APA—The Engineered Wood Association. 2015. Engineered wood statistics, fourth quarter 2014. Tacoma, WA: APA—The Engineered Wood Association. 9 p.

Archer, S.; Predick, K.I. 2008. Climate change and ecosystems of the Southwestern United States. Rangelands. 30(3): 23–28.

Ash, A.; Thornton, P.; Stokes, C.; Togtohyn, C. 2012. Is proactive adaptation to climate change necessary in grazed rangelands? Rangeland Ecology and Management. 65: 563–568.

Askew, A.; Bowker, J.M. [N.d.]. Visitation, demographics, and preferences on national forests 2005–2009: a technical document supporting the Forest Service 2015 RPA Assessment Update. Gen. Tech. Rep. SRS-GTR. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. In progress.

Association of Fish and Wildlife Agencies. 2011. State wildlife action plans: shaping national fish and wildlife conservation. Washington, DC: Association of Fish and Wildlife Agencies. 28 p.

Bachelet, D.; Lenihan, J.; Daly, C. [et al.]. 2001. MC1: A dynamic vegetation model for estimating the distribution of vegetation and associated ecosystem fluxes of carbon, nutrients, and water. Gen. Tech. Rep. PNW-GTR-508. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 95 p.

Bachelet, D.; Sheehan, T.; Ferschweiler, K. 2014. MC2 dynamics at the 10 km (0.083 degree) spatial scale using AR4 climate projections. Final report 12-JV-11221636-151. Corvallis, OR: Conservation Biology Institute. 34 p.

Bagne, K.E.; Friggens, M.M.; Finch, D.M. 2011. A system for assessing vulnerability of species (SAVS) to climate change. Gen. Tech. Rep. RMRS-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 28 p.

Bagne, K.E.; Reeves, M.C. 2016. Vulnerability of cattle production to climate changes on U.S. rangelands. Gen. Tech. Rep. RMRS-GTR-343. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 37 p.

Bailey, R.G. 1995. Description of the ecoregions of the United States [Separate map at 1:7,500,000]. 2nd ed., rev. Miscellaneous publication no. 1391 (rev). Washington, DC: U.S. Department of Agriculture, Forest Service. 108 p.

Bailey, R.G.; Hogg, H.C. 1986. A world ecoregions map for resource reporting. Environmental Conservation. 13: 195–202.

Baker, B.B.; Hanson, J.D.; Bourdon, R.M.; Eckert, J.B. 1993. The potential effects of climate change on ecosystem processes and cattle production on U.S. rangelands. Climatic Change. 25: 97–117.

Barger, N.N.; Archer, S.R.; Campbell, J.L. [et al.]. 2011. Woody plant proliferation in Northern American drylands: a synthesis of impacts on ecosystem carbon balance. Journal of Geophysical Research. 116: G00K07, doi:10.1029/2010JG001506.

Bates, B.; Kundzewicz, Z.W.; Wu, S. [et al.]. 2008. Technical paper on climate change and water. Geneva, Switzerland: Intergovernmental Panel on Climate Change. 210 p.

Batima, P. 2006. Climate change vulnerability and adaptation in the livestock sector of Mongolia: a final report submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC). Project No. AS 06. Washington, DC: International START Secretariat. 105 p.

Beier, P.; Brost, B. 2010. Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology. 24: 701–710.

Bell, C.; Devarajan, S. 1987. Intertemporally consistent shadow prices in an open economy: estimates for Cyprus. Journal of Public Economics. 32(3): 263–285.

Bentley, J.W.; Cooper, J.A. 2015. Southern pulpwood production, 2012. e-Resource Bulletin SRS-206. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 39 p.

Beurskens, L.W.M.; Hekkenberg, M.; Vethman, P. 2011. Renewable energy projections as published in the national renewable energy action plans of the European Member States. Petten, Netherlands: Energy Research Centre of the Netherlands and European Environment Agency. Report Number ECN-E—10-069. 244 p. http://www.ecn.nl/docs/library/report/2010/e10069.pdf. (2014 November 7).

Beyers, W.B.; Nelson, P.B. 2000. Contemporary development forces in the nonmetropolitan West: new insights from rapidly growing communities. Journal of Rural Studies. 16(4): 459–474.

Binder, L.C.W.; Barcelos, J.K.; Booth, D.B. [et al.]. 2010. Preparing for climate change in Washington State. Climatic Change. 102: 351–376.

Bock, C.E.; Jones, Z.F.; Bock, J.H. 2008. The oasis effect: response of birds to exurban development in a southwestern savanna. Ecological Applications. 18: 1093–1106.

Bonsma, J.C.; Scholtz, G.D.J.; Badenhorst, F.J.G. 1940. The influence of climate on cattle: fertility and hardiness of certain breeds. Farming. 15: 7–12.

Bowker, J.M.; Askew, A. 2012. U.S. outdoor recreation participation projections 2010 to 2060. In: Cordell, H.K. Outdoor recreation trends and futures: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-150. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 105–124.

Bowker, J.M.; Askew, A.; Cordell, H.K. [et al.]. 2012. Outdoor recreation participation in the United States: projections to 2060: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-GTR-160. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 34 p.

Bowker, J.M.; Askew, A.E. [N.d.]. Regional outdoor recreation participation in the U.S.: projections to 2060: a technical document supporting the Update to the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. In progress.

Bowker, J.M.; English, D.B.K.; Cordell, H.K. 1999. Outdoor recreation participation and consumption: projections 2000 to 2050. In: Cordell, H.K.; Betz, C.J.; Bowker, J.M. [et al.]. Outdoor recreation in American life: a national assessment of demand and supply trends. Champagne, IL: Sagamore Press: 323–350.

Bowker, J.M.; Murphy, D.; Cordell, H.K. [et al.]. 2006. Wilderness and primitive area recreation participation and consumption: an examination of demographic and spatial factors. Journal of Agricultural and Applied Economics. 38(2): 317–326.

Brackley, A.M. 2013. In South Korea, the answer is not as clear. Biomass Magazine. January 2013. http://biomassmagazine.com/articles/8837/asian-markets-for-wood-pellets. (2014 March 5).

Brekke, L.D.; Kiang, J.E.; Olsen, J.R. [et al.]. 2009. Climate change and water resources management: a Federal perspective. U.S. Geological Survey Circular 1331. 65 p.

Breshears, D.D.; Cobb, N.S.; Rich, P.M. [et al.]. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences. 102: 15144–15148.

Briske, D.D.; Joyce, L.A.; Polley, H. [et al.]. 2015. Climate-change adaptation on rangelands: linking regional exposure with diverse adaptive capacity. Frontiers in Ecology and the Environment. 13(5): 249–256, doi:10.1890/140266.

Brooks, N. 2003. Vulnerability, risk and adaptation: a conceptual framework. TCCC Working paper 38. Norwich, England: Tyndall Centre for Climate Change. 20 p.

Brown, T.C.; Binkley, D. 1994. Effect of management on water quality in North American forests. Gen. Tech. Rep. RM-GTR-248. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 27 p.

Brown, T.C.; Foti, R.; Ramirez, J.A. 2013. Projected freshwater withdrawals in the United States under a changing climate. Water Resources Research. 49(3): 1259–1276.

Brown, T.C.; Froemke, P. 2012. Nationwide assessment of nonpoint source threats to water quality. Bioscience. 62(2): 136–146.

Brown, T.C.; Froemke, P.; Mahat, W.; Ramirez, J.A. 2015. Mean annual water supply of the contiguous United States. Briefing paper. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 38 p. http://www.fs.fed.us/rmrs-beta/documents-and-media/mean-annual-water-supply-contiguous-united-states. [Beta].

Brown, T.C.; Hobbins, M.T.; Ramirez, J.A. 2008. Spatial distribution of water supply in the coterminous United States. Journal of the American Water Resources Association. 44: 1474–1487.

Brown-Brandl, T.M.; Eigenberg, R.A.; Hahn, G.L. [et al.]. 2005. Analyses of thermoregulatory responses of feeder cattle exposed to simulated heat waves. International Journal of Biometeorology. 49: 285–296.

Bullein, R. 2014. EC plans biomass sustainability review by summer. ENDSEurope. http://www.endseurope.com/34595/ec-plans-biomass-sustainability-review-by-summer. (March 5).

Burrell, A.; Gay, S.H.; Kavallari, A. 2012. The compatibility of EU biofuel policies with global sustainability and the WTO. The World Economy. 35: 784–798.

Butler, B.J. 2008. Family forest owners of the United States, 2006. Gen. Tech. Rep. NRS-27. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 72 p. http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs27.pdf.

Campbell, B.D.; Stafford-Smith, D.M.; McKeon, G.M. 1997. Elevated CO_2 and water supply interactions in grasslands: a pastures and rangelands management perspective. Global Change Biology. 3: 177–187.

Cayan, D.R.; Das, T.; Pierce, D.W. [et al.]. 2010. Future dryness in the Southwest US and the hydrology of the early 21st century drought. Proceedings of the National Academy of Sciences. 107: 21271–21276.

Cherkauer, K.A.; Bowling, L.C.; Lettenmaier, D.P. 2003. Variable infiltration capacity cold land process model updates. Global and Planetary Change. 38(1–2): 151–159.

Chow, J.; Kopp, R.J.; Portney, P.R. 2003. Energy resources and global development. Science. 302: 1528–1531.

Christensen, L.; Coughenour, M.B.; Ellis, J.E.; Chen, Z.Z. 2004. Vulnerability of the Asian typical steppe to grazing and climate change. Climatic Change. 63: 351–368.

Christensen, N.; Lettenmaier, D.P. 2006. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River basin. Hydrology and Earth System Sciences Discussions. 3(6): 3727–3770.

Cicchetti, C.J. 1973. Forecasting recreation in the United States. Lexington, MA: D.C. Heath and Co. 200 p.

City Policy Associates. 2008. Protecting and Developing the Urban Tree Canopy. The U.S. Conference of Mayors. http://www.usmayors.org/trees/treefinalreport2008.pdf. (2015 October 17).

Clark, C.M.; Lin, Y.; Bierwagen, B.G. [et al.]. 2013. Growing a sustainable biofuels industry: economics, environmental considerations, and the role of the Conservation Reserve Program. Environmental Research Letters. 8(2): 025016, doi:10.1088/1748-9326/8/2/025016.

Clark, J.S.; Grimm, E.C.; Donovan, J.J. [et al.]. 2002. Drought cycles and landscape responses to past aridity on prairies of the northern Great Plains, USA. Ecology. 83: 595–601.

Cocchi, M.; Nikolaisen, L.; Junginger, M. [et al.]. 2011. Global wood pellet industry market and trade study. IEA Bioenergy Task 40: Sustainable International Bioenergy Trade. 190 p. http://www.bioenergytrade.org/downloads/t40-global-wood-pellet-market-study_final_R.pdf. (2014 November 7).

Colnes, A.; Doshi, K.; Emick, H. [et al.]. 2012. Biomass supply and carbon accounting for southeastern forests. Montpelier, VT: Biomass Energy Resource Center, Forest Guild, and Spatial Informatics Group. 123 p. http://www.biomasscenter.org/images/stories/SE_Carbon_Study_FINAL_2-6-12.pdf. (2014 November 7).

Comer, P.J.; Schulz, K.A. 2007. Standardized ecological classification for mesoscale mapping in the Southwestern United States. Rangeland Ecology and Management. 60: 324–335.

Conservation Biology Institute. 2012. Protected Areas Database of the United States (PAD-US 2.0). Version 2. CBI Edition. Corvallis, OR: Conservation Biology Institute. http://consbio.org/products/projects/pad-us-cbi-edition. (2015 January 1).

Cook, E.R.; Seager, R.; Cane, M.A.; Stahle, D.W. 2007. North American drought: reconstructions, causes, and consequences. Earth-Science Reviews. 81: 93–134.

Cook, P.S.; Morgan, T.A.; Hayes, S.W. [et al.]. 2015. Idaho's forest products industry, current conditions and 2015 forecast. Sta. Bull. 102. Moscow, ID: University of Idaho, College of Natural Resources, Idaho Forest, Wildlife and Range Experiment Station. 4 p.

Cordell, H.K. 2012. Outdoor recreation trends and futures: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-150. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 167 p.

Coulson, D.P.; Joyce, L.A.; Price, D.T. [et al.]. 2010a. Climate scenarios for the conterminous United States at the 5 arc minute grid spatial scale using SRES scenarios A1B and A2 and PRISM climatology. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/data_archive/dataaccess/US_ClimateScenarios_grid_A1B_A2_PRISM.shtml. (2014 April 23).

Coulson, D.P.; Joyce, L.A.; Price, D.T.; McKenney, D.W. 2010b. Climate scenarios for the conterminous United States at the 5 arc minute grid spatial scale using SRES scenario B2 and PRISM climatology. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/data_archive/dataaccess/US_ClimateScenarios_grid_B2_PRISM.shtml. (2014 April 23).

Coulston, J.W.; Reams, G.A.; Wear, D.N.; Brewer, K. 2014. An analysis of forest land use, forest land cover and change at policy-relevant scales. Forestry. 87: 267–276, doi:10.1093/forestry/cpt056.

Coulston, J.W.; Wear, D.N.; Vose, J.M. 2015. Complex forest dynamics indicate potential for slowing carbon accumulation in the Southeastern United States. Scientific Reports. 5: 8002, doi:10.1038/srep08002.

Council on Environmental Quality. 1993. Incorporating biodiversity considerations into environmental impact analysis under the National Environmental Policy Act. Washington, DC: Council on Environmental Quality.

Creason, J. 2000. Analyzing the environmental and economic impacts of tourism. Proceedings of the 2000 National IMPLAN User's Conference. Fort Collins, CO: 12–13.

Cutter, S.L.; Boruff, B.J.; Shirley, W.L. 2003. Social vulnerability to environmental hazards. Social Science Quarterly. 84(2): 242–261.

Dale, V.H.; Joyce, L.A.; McNulty, S. [et al.]. 2001. Climate change and forest disturbance. BioScience. 51(9): 723–724, doi:10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2.

Daly, C.; Taylor, G.H.; Gibson, W.P. [et al.]. 2001. High-quality spatial climate data sets for the United States and beyond. Transactions of the American Society of Agricultural Engineers. 43: 1957–1962.

De Melo, J.; Tarr, D.G. 1992. A general equilibrium analysis of US foreign trade policy. Cambridge, MA: The MIT Press. 309 p.

Dobson, A.P.; Rodriguez, J.P.; Roberts, W.M.; Wilcove, D.S. 1997. Geographic distribution of endangered species in the United States. Science. 275: 550–553.

Eakin, H.; Conley, J. 2002. Climate variability and the vulnerability of ranching in southeastern Arizona: a pilot study. Climate Research. 21: 271–281.

Eastin, I.L.; Shook, S.R.; Fleishman, S.J. 2001. Material substitution in the U.S. residential construction industry, 1994 versus 1998. Forest Products Journal. 51(9): 30–37.

Ellis, E.C.; Ramankutty, N. 2008. Putting people in the map: anthropogenic biomes of the world. Frontiers in Ecology and the Environment. 6: 439–447.

English, D.B.K.; Kocis, S.M.; Zarnoch, S.J.; Arnold, J.R. 2002. Forest Service National Visitor Use Monitoring process: research method documentation. Gen. Tech. Rep. SRS-57. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 14 p.

Evans, D.M.; Che-Castaldo, J.P.; Crouse, D. [et al.]. 2016. Species recovery in the United States: assessing the Endangered Species Act. Issues in Ecology. 20(Winter): 1–28.

Eyre, F.H. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p.

Fargione, J.E.; Cooper, T.R.; Flaspohler, D.J. [et al.]. 2009. Bioenergy and wildlife: threats and opportunities for grassland conservation. BioScience. 59: 767–777.

Fay, P.A.; Carlisle, J.D.; Knapp, A.K. [et al.]. 2003. Productivity responses to altered rainfall patterns in a C-4-dominated grassland. Oecologia. 137: 245–251.

Feng, H.; Hennessy, D.A.; Miao, R. 2013. The effects of government payments on cropland acreage, Conservation Reserve Program enrollment, and grassland conversion in the Dakotas. American Journal of Agricultural Economics. 95(2): 412–418, doi:10.1093/ajae/aas112.

Finch, D.M.; Pendleton, R.L.; Reeves, M.C. [et al.]. 2016. Rangeland drought: effects, restoration and adaptation. In: Vose, J.M.; Clark, J.S.; Luce, C.H.; Patel-Weynand, T., eds. Effects of drought on forests and rangelands in the United States: a comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: Department of Agriculture, Forest Service, Washington Office. 298 p.

Finch, V.A. 1986. Body temperature in beef cattle: its control and relevance to production in the tropics. Journal of Animal Science. 62: 531–542.

Flather, C.H. 1996. Fitting species-accumulation functions and assessing regional land use impacts on avian diversity. Journal of Biogeography. 23: 155–168.

Flather, C.H.; Knowles, M.S.; Jones, M.F.; Schilli, C. 2013. Wildlife population and harvest trends in the United States: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-296. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 94 p.

Flather, C.H.; Knowles, M.S.; Kendall, I.A. 1998. Threatened and endangered species geography: characteristics of hot spots in the conterminous United States. BioScience. 48: 365–376.

Flather, C.H.; Wilson, K.R.; Shriner, S.A. 2009. Geographic approaches to biodiversity conservation: implications of scale and error to landscape planning. In: Millspaugh, J.J.; Thompson, F.R., III, eds. Models for planning wildlife conservation in large landscapes. Amsterdam, Netherlands: Academic Press: 85–212.

Foley, J.A.; DeFries, R.; Asner, G.P. [et al.]. 2005. Global consequences of land use. Science. 309: 570–574.

Food and Agriculture Organization of the United Nations [FAO]. 2014. FAOSTAT. http://faostat.fao.org/site/626/default.aspx#ancor. (2015 August 19).

Fore, S.; Overmoe, K.; Hill, M.J. 2013. Grassland conservation in North Dakota and Saskatchewan: contrasts and similarities in protected areas and their management. Journal of Land Use Science. doi:10.1080/1747423X.2013.858787.

Forisk Consulting. 2014. Wood bioenergy US. [Dataset]. 2014 version. http://forisk.com/products/category/bioenergy-2/. (November 7).

Forisk Consulting. 2015. Wood bioenergy US. [Dataset]. 2015 version. http://forisk.com/products/category/bioenergy-2/. (September 15).

Forman, R.T.T.; Alexander, L.E. 1998. Roads and their major ecological effects. Annual Review of Ecology, Evolution, and Systematics. 29: 207–231.

Foster, K. 2012. Protected Areas Database of the United States [PAD-US]. Version 2. CBI Edition. http://databasin.org/articles/d15a266600834ebbb4b0807fb7379093. (2015 April 29).

Foti, R.; Ramirez, J.A.; Brown, T.C. 2012. Vulnerability of U.S. water supply to shortage: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-295. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 147 p.

Foti, R.; Ramirez, J.A.; Brown, T.C. 2014a. A probabilistic framework for assessing vulnerability to climate variability and change: the case of the US water supply system. Climatic Change. 125(3-4): 413–427.

Foti, R.; Ramirez, J.A.; Brown, T.C. 2014b. Response surfaces of vulnerability to climate change: the Colorado River Basin, the High Plains, and California. Climatic Change. 125(3-4): 429–444.

Fry, J.; Xian, G.; Jin, S. [et al.]. 2011. Completion of the 2006 National Land Cover Database for the conterminous United States. Photogrammetric Engineering & Remote Sensing. 77: 858–864.

Fry, J.A.; Coan, M.J.; Homer, C.G. [et al.]. 2009. Completion of the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit product. U.S. Geological Survey Open-File Report 2008–1379. Reston, VA: U.S. Geological Survey. 18 p.

Fye, F.K.; Stahle, D.W.; Cook, E.R. 2003. Paleoclimatic analogs to twentieth-century moisture regimes across the United States. Bulletin of the American Meteorological Society. 84(7): 901–909.

Galik, C.S.; Abt, R.C. 2012. The effect of assessment scale and metric selection on the greenhouse gas benefits of woody biomass. Biomass and Bioenergy. 44: 1–7.

Gill, J.K.; Bowker, J.M.; Bergstrom, J.C.; Zarnoch, S.J. 2010. Accounting for trip frequency in Importance-Performance Analysis. Journal of Park and Recreation Administration. 28(1): 16–35.

Goh, C.S.; Junginger, M.; Cocchi, M. [et al.]. 2013a. Wood pellet markets and trade: a global perspective. Biofuels, Bioproducts and Biorefining. 7(1): 24–42.

Goh, C.S.; Junginger, M.; Joudrey, J. [et al.]. 2013b. Task 3: impacts of sustainability certification on bioenergy markets and trade. Paris, France: IEA Bioenergy. 61 p. http://www.bioenergytrade.org/downloads/iea-sust-cert-task-3-final2013.pdf. (2014 November 7).

Gomez, C.M.; Tirado, D.; Rey-Maquieira, J. 2004. Water exchanges versus water works: insights from a computable general equilibrium model for the Balearic Islands. Water Resources Research. 40(10): W10502, doi:10.1029/2004WR003235.

Goodman, D.J. 2000. More reservoirs or transfers? A computable general equilibrium analysis of projected water shortages in the Arkansas River Basin. Journal of Agricultural and Resource Economics. 25(2): 698–713.

Groves, C.R. 2003. Drafting a conservation blueprint: a practitioner's guide to planning for biodiversity. Washington, DC: Island Press. 457 p.

H. John Heinz III Center for Science, Economics and the Environment [Heinz Center]. 2008. Landscape pattern indicators for the Nation: a report from the Heinz Center's Landscape Pattern Task Group. Washington, DC: H. John Heinz Center for Science, Economics and the Environment. 108 p.

Hahn, G.L. 1997. Dynamic responses of cattle to thermal heat loads. Journal of Animal Science. 77(suppl 2): 10–20.

Hahn, G.L.; Gaughan, J.B.; Mader, T.L.; Eigenberg, R.A. 2009. Thermal indices and their application for livestock environments. In: DeShazer, J.A., ed. Livestock energetics and thermal environmental management. St. Joseph, MI: American Society of Agricultural and Biological Engineers: 113–130.

Hall, C.M.; Page, S.J. 1999. The geography of tourism and recreation. New York: Routledge. 309 p.

Hammer, R.B.; Stewart, S.I.; Winkler, R.L. [et al.]. 2004. Characterizing dynamic spatial and temporal residential density patterns from 1940–1990 across the North Central United States. Landscape and Urban Planning. 69: 183–199.

Hanak, E.; Lund, J.R. 2012. Adapting California's water management to climate change. Climatic Change. 111(1): 17–44.

Hardie, I.; Parks, P.; Gottleib, P.; Wear, D. 2000. Responsiveness of rural and urban land uses to land rent determinants in the U.S. South. Land Economics. 76(4): 659–673.

Harper, K.A.; MacDonald, S.E.; Burton, P.J. [et al.]. 2005. Edge influence on forest structure and composition in fragmented landscapes. Conservation Biology. 19: 768–782.

Heath, L.S.; Smith, J.E.; Skog, K.E. [et al.]. 2011. Managed forest carbon estimates for the U.S. Greenhouse Gas Inventory, 1990–2008. Journal of Forestry. April/May: 167–173.

Heisler, G.M. 1986. Energy savings with trees. Journal of Arboriculture. 12(5): 113–125.

Henifin, K. 2012. PAD-US (CBI edition) version 2: standards and procedures. Corvallis, OR: The Conservation Biology Institute. 13 p.

Hetemäki, L.; Hurmekoski, E. 2014. Forest products market outlook. In: Hetemäki, L.; Lindner, M.; Mavsar, R.; Korhonen, M., eds. What science can tell us: future of the European forest-based sector: structural changes toward bioeconomy. Joensuu, Finland: European Forest Institute. 6: 15–32.

Hewitt, J. 2011. Flows of biomass to and from the EU: an analysis of data and trends. Moreton in Marsh, United Kingdom: FERN. 54 p. http://www.fern.org/sites/fern.org/files/Biomass%20imports%20to%20the%20EU%20final_0.pdf. (2014 November 7).

Hof, J.G.; Kaiser, H.F. 1983. Projections of future forest recreation use. Res. Bull. WO–2. Washington, DC: U.S. Department of Agriculture, Forest Service. 12 p.

Holechek, J.L. 1988. An approach for setting the stocking rate. Rangelands. 10: 10–14.

Homer, C.; Dewitz, J.; Fry, J. [et al.]. 2007. Completion of the 2001 National Land Cover Database for the conterminous United States. Photogrammetric Engineering & Remote Sensing. April: 337–341.

Homer, C.; Huang, C.Q.; Yang, L.M. [et al.]. 2004. Development of a 2001 National Land Cover Database for the United States. Photogrammetric Engineering & Remote Sensing. 70: 829–840.

Homer, C.G.; Dewitz, J.A.; Yang, L. [et al.]. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States: representing a decade of land cover change information. Photogrammetric Engineering & Remote Sensing. 81(5): 345–354.

Howard, J.L.; McKeever, D.B. 2014. U.S. forest products annual market review and prospects 2010–2014. Res. Note FPL-RN-0331. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 16 p.

Howard, J.L.; McKeever, D.B. 2015. U.S. forest products annual market review and prospects, 2011–2015. Res. Note FPL-RN-0336. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 11 p.

Howard, J.L.; Westby, R.M. 2013. U.S. timber production, trade, consumption and price statistics 1965–2011. Res. Pap. FPL-RP-676. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 99 p.

Howden, S.M.; Crimp, S.J.; Stokes, C.J. 2008. Climate change and Australian livestock systems: impacts, research and policy issues. Australian Journal of Experimental Agriculture. 48: 780–788.

Howden, S.M.; Turnpenny, J. 1998. Modelling heat stress and water loss of beef cattle in subtropical Queensland under current climates and climate change. In: McDonald, D.A.; McAleer, M., eds. MODSIM 1997. International Congress on Modelling and Simulation Society of Australia and New Zealand, December 1997: 1103–1108.

Hughes, M.K.; Brown, P.M. 1992. Drought frequency in central California since 101 BC recorded in giant sequoia tree rings. Climate Dynamics. 6: 161–167.

Hurd, B.; Leary, N.; Jones, R.; Smith, J. 1999. Relative regional vulnerability of water resources to climate change. Journal of the American Water Resources Association. 35: 1399–1409.

Hurtt, G.C.; Pacala, S.W.; Moorcroft, P.R. [et al.]. 2002. Projecting the future of the U.S. carbon sink. Proceedings of the National Academy of Sciences. 99(3): 1389–1394.

Ice, G.G.; Schilling, E.; Vowell, J. 2010. Trends for forestry best management practices implementation. Journal of Forestry. 108: 267–273.

Ince, P.; Schuler, A.; Spelter, H.; Luppold, W. 2007. Globalization and structural change in the U.S. forest sector: an evolving context for sustainable forest management. Gen. Tech. Rep. FPL-GTR-170. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 62 p. http://www.treesearch.fs.fed.us/pubs/27661.

Ince, P.J.; Akim, E.L.; Lombard, B.; Parik, T. 2010. Rebound from steep drop in demand amid simmering global trade issues: markets for paper, paperboard and woodpulp, 2009–2010. In: Forest products annual market review, 2009–2010. Geneva Timber and Forest Study Papers No. 25. Geneva, Switzerland: United Nations Economic Commission for Europe, Food and Agriculture Organization of the United Nations, Forestry and Timber Section: 85–97. Chapter 8.

Ince, P.J.; Nepal, P. 2012. Effects on U.S. timber outlook of recent economic recession, collapse in housing construction, and wood energy trends. Gen. Tech. Rep. FPL-GTR-219. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 18 p.

Interagency Working Group on Social Cost of Carbon, United States Government [U.S. Interagency Working Group]. 2010. Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866. Washington, DC: Environmental Protection Agency. 51 p. http://www.epa.gov/oms/climate/regulations/scc-tsd.pdf. (2012 June 17).

Intergovernmental Panel on Climate Change [IPCC]. 2007. Climate change 2007: synthesis report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Core writing team: Pachauri, R.K.; Reisinger, A., eds.]. Geneva, Switzerland: Intergovernmental Panel on Climate Change. 104 p.

IPCC. 2014. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: Stocker, T.F.; Qin, D.; Plattner, G.-K. [et al.], eds. Cambridge, United Kingdom; New York, NY, USA: Cambridge University Press. 1,535 p.

Iverson, L.R.; Prasad, A.M.; Hale, B.J.; Sutherland, E.K. 1999. Atlas of current and potential future distributions of common trees of the Eastern United States. Gen. Tech. Rep. NE-265. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area. 245 p.

Izaurralde, R.C.; Thomson, A.M.; Morgan, J.A. [et al.]. 2011. Climate impacts on agriculture: implications for forage and rangeland production. Agronomy Journal. 103: 371–381.

Jenkins, M.L., comp. 2015. Major forest insect and disease conditions in the United States, 2013. FS-1054. Washington, DC: U.S. Department of Agriculture, Forest Service. 44 p.

Jin, S.; Yang, L.; Danielson, P.; Homer, C. [et al.]. 2013. A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sensing of Environment. 132: 159–175.

Johnson, W.C.; Millett, B.V.; Gilmanov, T. [et al.]. 2005. Vulnerability of northern prairie wetlands to climate change. BioScience. 55: 863–872.

Johnston, C.A. 2014. Agricultural expansion: land use shell game in the U.S. Northern Plains. Landscape Ecology. 29: 81–95.

Joppa, L.N.; Visconti, P.; Jenkins, C.N.; Pimm, S.L. 2013. Achieving the convention of biological diversity's goals for plant conservation. Science. 6(341): 1100–1103.

Joudrey, J.; McDow, W.; Smith, T.; Larson, B. 2012. European power from U.S. forests: how evolving EU policy is shaping the transatlantic trade in wood biomass. New York: Environmental Defense Fund. 34 p. http://www.edf.org/sites/default/files/europeanPowerFromUSForests.pdf. (2014 November 7).

Joyce, L.A. 1989. An analysis of the forage situation in the United States: 1989–2040. Gen. Tech. Rep. RM-GTR-180. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 136 p.

Joyce, L.A., ed. [N.d.] Geographic variation in availability of renewable resources. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. In progress.

Joyce, L.A.; Briske, D.D.; Brown, J.R. [et al.]. 2013. Climate change and North American rangelands: assessment of mitigation and adaptation strategies. Rangeland Ecology and Management. 66: 512–528.

Joyce, L.A.; Flather, C.H.; Koopman, M.E. 2008. Analysis of potential impacts of climate change on wildlife habitats in the U.S. Final Report to the National Council for Science and the Environment. Washington, DC: National Council for Science and the Environment, Wildlife Habitat Policy Research Program. 69 p.

Joyce, L.A.; Price, D.T.; Coulson, D.P. [et al.]. 2014a. Projecting climate change in the United States: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-320. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Joyce, L.A.; Running, S.W.; Breshears, D.D. [et al.]. 2014b. Forests. In: Melillo, J.M.; Richmond, T.C.; Yohe, G.W., eds. Climate change impacts in the United States: the third national climate assessment. U.S. Global Change Research Program: 175–194. Chapter 7. doi:10.7930/J0Z60KZC.

Keegan, C.E.; Sorenson, C.B.; Morgan, T.A. [et al.]. 2011. Impact of the Great Recession and housing collapse on the forest products industry in the Western United States. Forest Products Journal. 61(8): 625–634.

Keeney, R.; Hertel, T.W. 2009. The indirect land use impacts of United States biofuel policies: the importance of acreage, yield, and bilateral trade responses. American Journal of Agricultural Economics. 91: 895–909.

Kenny, J.F.; Barber, N.L.; Hutson, S.S. [et al.]. 2009. Estimated use of water in the United States in 2005. Circular 1344. Reston, VA: U.S. Geological Survey.

Kerr, R.A. 2011. Vital details of global warming are eluding forecasters. Science. 334: 173–174.

Kinnaman, T.C. 2011. The economic impact of shale gas extraction: A review of existing studies. Ecological Economics. 70(7): 1243–1249.

Kittler, B.; Price, W.; McDow, W.; Larson, B. 2012. Pathways to sustainability: an evaluation of forestry programs to meet European biomass supply chain requirements. New York: Environmental Defense Fund. 54 p. http://www.edf.org/sites/default/files/pathwaysToSustainability.pdf. (2014 November 7).

Knapp, A.K.; Briggs, J.M.; Koelliker, J.K. 2001. Frequency and extent of water limitation to primary production in a mesic temperate grassland. Ecosystems. 4: 19–28.

Konikow, L.F. 2013. Groundwater depeletion in the United States (1900–2008). Scientific Investigations Report 2013–5079. Reston, VA: U.S. Geological Survey.

Krist, F.J., Jr.; Ellenwood, J.R.; Woods, M.E. [et al.]. 2014. 2013–2027 national insect and disease forest risk assessment. FHTET-14-01. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Health Protection, Forest Health Technology Enterprise Team. 199 p.

Ladanai, S.; Vinterbäck, J. 2010. Certification criteria for sustainable biomass for energy. Report 026. ISSN 1654–9406. Uppsala, Sweden: Swedish University of Agricultural Sciences, Department of Energy and Technology. 38 p. http://www.worldbioenergy.org/sites/default/files/Report_Certifiering_110405_SL.pdf. (2014 November 7).

Lamers, P.; Marchal, D.; Heinimö, J.; Steierer, F. 2014. Global woody biomass trade for energy. In: Junginger, M.; Goh, C.S.; Faaij, A., eds. International bioenergy trade: history, status and outlook on securing sustainable bioenergy supply, demand and markets. New York: Springer: 41–63. Chapter 3.

Latta, G.S.; Baker, J.S.; Beach, R.H. [et al.]. 2013. A multi-sector intertemporal optimization approach to assess the GHG implications of U.S. forests and agricultural biomass electricity expansion. Journal of Forest Economics. 19: 361–383.

Laurance, W.F. 2008. Theory meets reality: how habitat fragmentation research has transcended island biogeography theory. Biological Conservation. 141: 1731–1744.

Lawler, J.J. 2009. Climate change adaptation strategies for resource management and conservation planning. Annals of the New York Academy of Sciences. 1162(1): 79–98.

Leeworthy, V.R.; Bowker, J.M.; Hospital, J.D.; Stone, E.A. 2005. Projected participation in marine recreation: 2005 & 2010. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects Division. 152 p. http://www.srs.fs.usda.gov/pubs/ja/ja_leeworthy002.pdf. (2010 August 31).

Lerman, S.B.; Warren, P.S. 2011. The conservation value of residential yards: linking birds and people. Ecological Applications. 21: 1327–1339.

Liang, X.; Lettenmaier, D.P.; Wood, E.F.; Burges, S.J. 1994. A simple hydrologically based model of land surface water and energy fluxes for general circulation models. Journal of Geophysical Research. 99(D7): 14415–14428.

Liang, X.; Wood, E.F.; Lettenmaier, D.P. 1996. Surface soil moisture parameterization of the VIC-2L model: evaluation and modification. Global and Planetary Change. 13(1996): 195–206.

Liu, S.; Liu, J.; Wu, Y. [et al.]. 2014a. Baseline and projected future carbon storage, carbon sequestration, and greenhouse-gas fluxes in terrestrial ecosystems of the Eastern United States. In: Zhu, Z.; Reed, B.C., eds. Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of the Eastern United States. U.S. Geological Survey Professional Paper 1804. Reston, VA: U.S. Geological Survey: 115–156. http://dx.doi.org/10.3133/pp1804.

Liu, Y.; Goodrick, S.; Heilman, W. 2014b. Wildland fire emissions, carbon, and climate: wildfire-climate interactions. Forest Ecology and Management. 317: 80–96.

Loftus, A.J.; Flather, C.H. 2012. Fish and other aquatic resource trends in the United States: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-283. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 81 p.

Luo, Y.; Melillo, J.; Niu, S. [et al.]. 2011. Coordinated approaches to quantify long-term ecosystem dynamics in response to global change. Global Change Biology. 17: 843–854.

Mahat, V.; Ramirez, J.A.; Brown, T.C. 2015. 21st century climate in CMIP5 simulations: implications for snow and water yield across the contiguous United States. Unpublished manuscript. On file with Thomas C. Brown, Rocky Mountain Research Station, Fort Collins, CO.

Marcoullier, D.W.; Xia, X. 2008. Distribution of income from tourism-sensitive employment. Tourism Economics. 14(3): 545–565.

Marshall, E.; Aillery, M.; Malcolm, S.; Williams, R. 2015. Climate Change, Water Scarcity, and Adaptation in the U.S. Fieldcrop Sector. ERR-201. USDA, Economic Research Service. 119 p.

Martilla, J.A.; James, J.C. 1977. Importance-Performance Analysis. Journal of Marketing. 41(1): 77–79.

Mashiri, F.E.; McClaran, M.P.; Fehmi, J.S. 2008. Short- and long-term vegetation change related to grazing systems, precipitation, and mesquite cover. Rangeland Ecology & Management. 61(4): 368–379.

Master, L.L.; Stein, B.A.; Kutner, L.S.; Hammerson, G.A. 2000. Vanishing assets: conservation status of U.S. species. In: Stein, B.A.; Kutner, L.S.; Adams, J.S., eds. Precious heritage: the status of biodiversity in the United States. New York: Oxford University Press: 93–118.

McIver, C.; Sorenson, C.B.; Keegan, C. [et al.]. 2013. Montana's forest products industry and timber harvest, 2009. Res. Bull. RMRS-RB-16. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 42 p.

McKeon, G.M.; Stone, G.S.; Syktus, J.I. [et al.]. 2009. Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues. Rangeland Journal. 31: 1–29.

Melillo, J.M.; Richmond, T.C.; Yohe, G.W., eds. 2014. Climate change impacts in the United States: the third national climate assessment. Washington, DC: U.S. Global Change Research Program. 841 p. doi:10.7930/J0Z31WJ2.

Millar, C.I.; Stephenson, N.L.; Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications. 17: 2145–2151.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: biodiversity synthesis. Washington, DC: World Resources Institute. 85 p.

Miner, R.A.; Abt, R.C.; Bowyer, J.L. [et al.]. 2014. Forest carbon accounting considerations in U.S. bioenergy policy. Journal of Forestry. 112(6): 591–606.

Mitchell, A.; Tran, C. 2010. The consistency of the European Union renewable energy directive with World Trade Organization agreements: the case of biofuels. Renewable Energy Law and Policy Review. 1: 33–44.

Mitchell, J.; Devine, N.; Jagger, K. 1989. A contextual model of natural hazards. Geographical Review. 79: 391–409.

Morgan, J.A.; Derner, J.D.; Milchunas, D.G.; Pendall, E. 2008. Management implications of global change for Great Plains rangelands. Rangelands. 30: 18–22.

Morgan, J.A.; LeCain, D.R.; Pendall, E. [et al.]. 2011. C4 grasses prosper as carbon dioxide eliminates desiccation in warmed semi-arid grassland. Nature. 476: 202–205.

Morgan, J.A.; Milchunas, D.G.; LeCain, D.R. [et al.]. 2007. Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. Proceedings of the National Academy of Sciences. 104: 14724–14729.

Moss, R.H.; Edmonds, J.A.; Hibbard, K.A. [et al.]. 2010. The next generation of scenarios for climate change research and assessment. Nature. 463: 747–756.

Munasib, A.; Rickman, D.S. 2015. Regional economic impacts of the shale gas and tight oil boom: a synthetic control analysis. Regional Science and Urban Economics. 50: 1–17.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution. 10: 58–62.

Naidoo, R.; Ricketts, T.H. 2006. Mapping the economic costs and benefits of conservation. PLOS Biology. 4: 2153–2164.

Nakicenovic, N.; Alcamo, J.; Davis, G. [et al.]. 2000. IPCC special report on emissions scenarios. Cambridge, United Kingdom: Cambridge University Press. 570 p. http://www.grida.no/climate/ipcc/emission/index.htm.

National Association of Home Builders [NAHB]. 2013. Housing economics. Washington, DC: National Association of Home Builders. http://www.nahb.org/showpage_details.aspx?showPageID=311&sectionID=1163. (2015 November 6).

NAHB. 2014. Housing economics. Washington, D.C.: National Association of Home Builders. http://www.nahb.org/showpage_details.aspx?showPageID=311&sectionID=1163. (October 21).

National Research Council. 2010. Adapting to the impacts of climate change. Washington, DC: The National Academies Press. 292 p.

NatureServe. 2010. NatureServe Central Databases. Metadata on file with Michael S. Knowles, Rocky Mountain Research Station, Fort Collins, CO. Arlington, VA: NatureServe. (2013 October 13).

NatureServe. 2014. NatureServe Central Databases. Metadata on file with Curtis H. Flather, Rocky Mountain Research Station, Fort Collins, CO. Arlington, VA: NatureServe.

Nijssen, B.; Lettenmaier, D.P.; Liang, X. [et al.]. 1997. Streamflow simulation for continental-scale river basins. Water Resources Research. 33(4): 711–724.

Noon, B.R.; Murphy, D.D.; Beissinger, S.R. [et al.]. 2003. Conservation planning for US national forests: conducting comprehensive biodiversity assessments. BioScience. 53: 1217–1220.

Nowak, D.J. 2012. Contrasting natural regeneration and tree planting in 14 North American cities. Urban Forestry and Urban Greening. 11: 374–382.

Nowak, D.J.; Civerolo, K.L.; Rao, S.T. [et al.]. 2000. A modeling study of the impact of urban trees on ozone. Atmospheric Environment. 34: 1610–1613.

Nowak, D.J.; Crane, D.E. 2002. Carbon storage and sequestration by urban trees in the USA. Environmental Pollution. 116(3): 381–389.

Nowak, D.J.; Dwyer, J.F. 2007. Understanding the benefits and costs of urban forest ecosystems. In: Kuser, J., ed. Urban and community forestry in the Northeast. New York: Springer: 25–46.

Nowak, D.J.; Greenfield, E.J. 2010. Evaluating the National Land Cover Database tree canopy and impervious cover estimates across the conterminous United States: a comparison with photo-interpreted estimates. Environmental Management. 46(3): 378–390.

Nowak, D.J.; Greenfield, E.J. 2012. Tree and impervious cover change in U.S. Urban Forestry & Urban Greening. 11(1): 21–30.

Nowak, D.J.; Greenfield, E.J.; Hoehn, R.; LaPoint, E. 2013a. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution. 178: 229–236.

Nowak, D.J.; Hirabayashi, S.; Bodine, A.; Greenfield, E. 2014. Trees and forest effects on air quality and human health in the United States. Environmental Pollution. 193: 119–129.

Nowak, D.J.; Hoehn, R.E.; Bodine, A.R. [et al.]. 2013b. Urban forest structure, ecosystem services and change in Syracuse, NY. Urban Ecosystems. doi:10.1007/s11252-013-0326-z.

Nowak, D.J.; Hoehn, R.E.; Crane, D.E. [et al.]. 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture & Urban Forestry. 34(6): 347–358.

Nowak, D.J.; Noble, M.H.; Sisinni, S.M.; Dwyer, J.F. 2001. Assessing the U.S. urban forest resource. Journal of Forestry. 99(3): 37–42.

Nowak, D.J.; Walton, J.T.; Dwyer, J.F. [et al.]. 2005. The increasing influence of urban environments on U.S. forest management. Journal of Forestry. 103: 377–382.

O'Brien, K.; Eriksen, S.; Schjolden, A.; Nygaard, L. 2004a. What's in a word? Conflicting interpretations of vulnerability in climate change research. CICCER Working Paper 2004:04. Oslo, Norway: Center for International Climate Change and Environmental Research. 16 p.

O'Brien, K.; Leichenko, R.; Kelkar, U. [et al.]. 2004b. Mapping vulnerability to multiple stressors: climate change and globalization in India. Global Environmental Change. 14: 303–313.

Ogle, S.M.; Eve, M.D.; Breidt, F.J.; Paustian, K. 2003. Uncertainty in estimating land use and management impacts on soil organic carbon storage for U.S. agroecosystems between 1982 and 1997. Global Change Biology. 9: 1521–1542.

Ogle, S.M.; Swan, A.; Paustian, K. 2012. No-till management impacts on crop productivity, carbon input and soil carbon sequestration. Agriculture, Ecosystems and Environment. 149: 37–49.

Oswalt, S.N.; Smith, W.B.; Miles, P.D.; Pugh, S.A. 2014. Forest resources of the United States, 2012: a technical document supporting the Forest Service Update of the 2010 RPA Assessment. Gen. Tech. Rep. WO-91. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 218 p.

Otkin, J.A.; Anderson, M.C.; Hain, C. [et al.]. 2013. Examining rapid onset drought development using the thermal infrared-based evaporative stress index. Journal of Hydrometeorology. 14: 1057–1074.

Paredes, D.; Komarek, T.; Loveridge, S. 2015. Income and employment effects of shale gas extraction windfalls: evidence from the Marcellus region. Energy Economics. 47: 112–120.

Parton, W.J.; Hartman, M.D.; Ojima, D.S.; Schimel, D.S. 1998. DAYCENT: its land surface submodel: description and testing. Global and Planetary Change. 19: 35–48.

Perry, L.G.; Andersen, D.C.; Reynolds, L.V. [et al.]. 2012. Vulnerability of riparian ecosystems to elevated CO_2 and climate change in arid and semiarid western North America. Global Change Biology. 18: 821–842.

Peterman, W.; Bachelet, D.; Ferschweiler, K.; Sheehan, T. 2014. Soil depth affects simulated carbon and water in the MC2 dynamic global vegetation model. Ecological Modelling. 294: 84–93.

Peterson, D.L.; Millar, C.I.; Joyce, L.A. [et al.]. 2011. Responding to climate change in national forests: a guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-855. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 109 p.

Pidgeon, A.M.; Flather, C.H.; Radeloff, V.C. [et al.]. 2014. Systematic temporal patterns in the relationship of housing development with forest bird biodiversity. Conservation Biology. 28: 1291–1301.

Pimentel, D.; Lach, L.; Zuniga, R.; Morrison, D. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience. 50(1): 53–65.

Polasky, S. [N.d.]. Using the Resources Planning Act Assessment in social vulnerability analyses. In: Joyce, L.A., ed. Geographic variation in availability of renewable resources. Gen. Tech. Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. In progress.

Poling, M. 1991. Legal milestones in range movement. Renewable Resources Journal. 9: 7–10.

Polley, H.W.; Briske, D.D.; Morgan, J.A. [et al.]. 2013. Climate change and North American rangelands: trends, projections, and implications. Rangeland Ecology and Management. 66(5): 493–511.

Polley, H.W.; Jin, V.L.; Fay, P.A. 2012. Feedback from plant species change amplifies CO_2 enhancement of grassland productivity. Global Change Biology. 18: 2813–2823.

Porter, M.E. 1990. The competitive advantage of nations. Harvard Business Review. 68(2): 73–93.

Porter, M.E. 2000. Location, competition, and economic development: local clusters in a global economy. Economic Development Quarterly. 14(1): 15–34.

Postel, S.L.; Thompson, B.H. 2005. Watershed protection: capturing the benefits of nature's water supply services. Natural Resources Forum. 29: 98–108.

Potter, K.M. 2013. Large-scale patterns of insect and disease activity in the conterminous United States and Alaska from the national insect and disease detection survey, 2009. In: Potter, K.M.; Conkling, B.L., eds. Forest health monitoring: national status, trends and analysis, 2010. Gen. Tech. Rep. SRS-176. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 15–30.

Potter, K.M.; Paschke, J.L. 2015a. Large-scale patterns of insect and disease activity in the conterminous United States and Alaska from the national insect and disease survey, 2012. In: Potter, K.M.; Conkling, B.L., eds. Forest health monitoring: national status, trends, and analysis, 2013. GTR-SRS-207. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 19–26.

Potter, K.M.; Paschke, J.L. 2015b. Large-scale patterns of insect and disease activity in the conterminous United States, Alaska and Hawaii from the national insect and disease survey, 2014. In: Potter, K.M.; Conkling, B.L., eds. Forest health monitoring: national status, trends and analysis, 2014. Gen. Tech. Rep. SRS-209. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 19–38.

Power, T.M. 1998. Lost landscapes and failed economies: the search for a value of place. Washington, DC: Island Press. 304 p.

Prestemon, J.P.; Wear, D.N.; Foster, M.O. 2015. The global position of the U.S. forest products industry. e-Gen. Tech. Rep. SRS-204. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 24 p. http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs204.pdf.

Probert, T. 2012. Biomass industry outlook 2013: dogged by regulatory uncertainty. Renewable Energy World.com. http://www.renewableenergyworld.com/rea/news/article/2012/12/biomass-industry-outlook-2013-dogged-by-regulatory-uncertainty. (2014 March 7).

Purkey, D.R.; Joyce, B.; Vicuna, S. [et al.]. 2008. Robust analysis of future climate change impacts on water for agriculture and other sectors: a case study in the Sacramento Valley. Climatic Change. 87: S109–S122.

Radeloff, V.C.; Stewart, S.I.; Hawbaker, T.J. [et al.]. 2010. Housing growth in and near United States protected areas limits their conservation value. Proceedings of the National Academy of Sciences. 107: 940–945.

Randall, D.A.; Wood, R.A.; Bony, S. [et al.]. 2007. Climate models and their evaluation. In: Solomon, S.D.; Qin, M.; Manning, Z. [et al.], eds. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge, United Kingdom; New York, NY, USA: Cambridge University Press: 589–662.

Rasker, R. 1993. Rural development, conservation, and public policy in the Greater Yellowstone Ecosystem. Society & Natural Resources. 6: 109–126.

Ray, A.J.; Barsugli, J.J.; Averyt, K.B. [et al.]. 2008. Climate change in Colorado: a synthesis to support water resources management and adaptation. Report for the Colorado Water Conservation Board. Boulder, CO: University of Colorado. 3 p.

Reeves, M.C.; Baggett, L.S. 2014. A remote sensing protocol for identifying rangelands with degraded productive capacity. Ecological Indicators. 43: 172–182.

Reeves, M.C.; Mitchell, J.E. 2011. Extent of coterminous US rangelands: quantifying implications of differing agency perspectives. Rangeland Ecology & Management. 64: 585–597.

Reeves, M.C.; Mitchell, J.E. 2012. A synoptic review of U.S. rangelands: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-288. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 128 p.

Reeves, M.C.; Moreno, M.L.; Bagne, K.E.; Running, S.W. 2014. Estimating climate change effects on net primary production of rangelands in the United States. Climatic Change. 126(3-4): 429–442.

Ricketts, T.H.; Dinerstein, E.; Boucher, T. [et al.]. 2005. Pinpointing and preventing imminent extinctions. Proceedings of the National Academy of Sciences. 102: 18497–18501.

Riebsame, W.E.; Gosnell, H.; Theobald, D. 1997. Atlas of the New West. New York: WW Norton and Company.

Ries, L.; Fletcher, R.J.; Battin, J. [et al.]. 2004. Ecological responses to habitat edges: mechanisms, models, and variability explained. Annual Review of Ecology, Evolution and Systematics. 35: 491–522.

Riitters, K.; Wickham, J. 2012. Decline of forest interior conditions in the conterminous United States. Scientific Reports. 2: 653, doi:10.1038/srep00653.

Riitters, K.H. 2011. Spatial patterns of land cover in the United States: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-136. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 64 p.

Riitters, K.H.; Coulston, J.W.; Wickham, J.D. 2012. Fragmentation of forest communities in the Eastern United States. Forest Ecology and Management. 263: 85–93.

RISI, Inc. 2013. North American Bioenergy Forecast, June 2013. http://www.risiinfo.com/risi-store/do/product/detail/north-american-bioenergy-forecast-5-year.html.

Robb, G.N.; McDonald, R.A.; Chamberlain, D.E.; Bearhop, S. 2008. Food for thought: supplementary feeding as a driver of ecological change in avian populations. Frontiers in Ecology and the Environment. 6: 476–484.

Robinson, S.K.; Thompson, F.R.; Donovan, T.M. [et al.]. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science. 267: 1987–1990.

Robles, M.D.; Flather, C.H.; Stein, S.M. [et al.]. 2008. The geography of private forests that support at-risk species in the conterminous United States. Frontiers in Ecology and the Environment. 6: 301–307.

Roe, T.; Dinar, A.; Tsur, Y.; Diao, X. 2005. Feedback links between economy-wide and farm-level policies: with application to irrigation water management in Morocco. Journal of Policy Modeling. 27(8): 905–928.

Rollins, M. 2009. LANDFIRE: a nationally consistent vegetation, wildland fire and fuel assessment. International Journal of Wildland Fire. 18: 235–249.

Roos, J.A.; Brackley, A.M. 2012. The Asian wood pellet markets. Gen. Tech. Rep. PNW-GTR-861. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 25 p.

Rose, A.; Liao, S-Y. 2005. Modeling regional economic resilience to disasters: a computable general equilibrium analysis of water service disruptions. Journal of Regional Science. 45(1): 75–112.

Rosenzweig, M. 1995. Species diversity in space and time. Cambridge, United Kingdom: Cambridge University Press. 437 p.

Ruefenacht, B.; Finco, M.V.; Nelson, M.D. [et al.]. 2008. Conterminous U.S. and Alaska forest type mapping using Forest Inventory and Analysis data. Photogrammetric Engineering and Remote Sensing. 74: 1379–1388.

Running, S.W.; Hunt, E.R.J. 1993. Generalization of a forest ecosystem process model for other biomes, BIOME-BGC and an application for global-scale models. In: Ehleringer, J.R.; Field, C.B., eds. Scaling physiological processes: leaf to globe. San Diego, CA: Academic Press: 141–158.

Russo, T.; Lall, U.; Wen, H.; Williams, M. 2014. Assessment of trends in groundwater levels across the United States. New York: Columbia University, Columbia Water Center.

Ryan, M.G.; Harmon, M.E.; Birdsey, R.A. [et al.]. 2012. A synthesis of the science on forests and carbon for U.S. forests. Issues in Ecology. 13: 1–16.

Sala, O.E.; Chapin, F.S., III; Armesto, J.J. [et al.]. 2000. Global biodiversity scenarios for the year 2100. Science. 287: 1770–1774.

Sampson, N.; DeCoster, L. 2000. Forest fragmentation: implications for sustainable private forests. Journal of Forestry. 98(3): 4–8.

Sauer, J.R.; Hines, J.E.; Fallon, J. 2008. The North American Breeding Bird Survey: results and analysis, 1966–2007. Version 5.15. Laurel, MD: U.S. Geological Survey, Patuxent Wildlife Research Center. http://www.mbr-pwrc.usgs.gov/bbs/bbs2007.html. (2011 November 18).

Scarlat, N.; Dallemand, J. 2011. Recent developments of biofuels/bioenergy sustainability certification: a global overview. Energy Policy. 39: 1630–1646.

Scarlett, L.; Epanchin-Niell, R.; McKinney, M. 2013. The Endangered Species Act at 40: new tools for conservation. Resources. 184: 20–27.

Schueler, V.; Weddige, U.; Beringer, T. [et al.]. 2013. Global biomass potentials under sustainability restrictions defined by the European Renewable Energy Directive 2009/28/EC. GCB Bioenergy. 5: 652–663.

Schwarz, A.; Marr, S.; Schwinn, K. [et al.]. 2011. Climage change handbook for regional water planning. San Francisco, CA; Sacramento, CA: U.S. Environmental Protection Agency, Region 9; California Department of Water Resources. 246 p.

Scott, J.M.; Csuti, B.; Jacobi, J.D.; Estes, J.E. 1987. Species richness: a geographic approach to protecting future biological diversity. Bioscience. 37: 782–788.

Seager, R.; Mingfang, T.; Held, I. [et al.]. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science. 316: 1181–1184.

Sherry, R.A.; Zhou, X.H.; Gu, S.L. [et al.]. 2007. Divergence of reproductive phenology under climate warming. Proceedings of the National Academy of Sciences. 104: 198–202.

Simmons, E.A.; Hayes, S.W.; Morgan, T.A. [et al.]. 2014. Idaho's forest products industry and timber harvest 2011 with trends through 2013. Res. Bull. RMRS-RB-19. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 46 p.

Skog, K.E. 2008. Sequestration of carbon in harvested wood products for the United States. Forest Products Journal. 58(6): 56–72.

Skog, K.E.; McKeever, D.B.; Ince, P.J. [et al.]. 2012. Status and trends for the U.S forest products sector: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. FPL-GTR-207. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 35 p.

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 336 p.

Sorenson, C.; Morgan, T.; Simmons, E. [et al.]. 2014. The Four Corners timber harvest and forest products industry, 2012. Missoula, MT: University of Montana, Bureau of Business and Economic Research. 1 p. http://www.bber.umt.edu/FIR/H_States.asp.

Stephenson, A.L.; MacKay, D.J.C. 2014. Life cycle impacts of biomass electricity in 2020. United Kingdom Department of Energy and Climate Change. https://www.gov.uk/government/publications/life-cycle-impacts-of-biomass-electricity-in-2020. (August 8).

Stoddart, L.A.; Smith, A.D. 1943. Range management. New York: McGraw-Hill Book Co. 433 p.

Stubbs, M. 2014. Conservation Reserve Program (CRP): status and issues. Congressional Research Service Report 42783. Washington, DC: Congressional Research Service. 24 p. http://www.nationalaglawcenter.org/wp-content/uploads/assets/crs/R42783.pdf.

Suarez-Rubio, M.; Wilson, S.; Leimgruber, P.; Lookingbill, T. 2013. Threshold responses of forest birds to landscape changes around exurban development. PLOS ONE. 8: e67593, doi:org/10.1371/journal.pone.0067593.

Suttle K.B.; Thomsen, M.A.; Power, M.E. 2007. Species interactions reverse grassland responses to changing climate. Science. 315: 640–642.

Swinbank, A. 2009. Presidential address: EU policies on bioenergy and their potential clash with the WTO. Journal of Agricultural Economics. 60: 485–503.

Taha, H. 1996. Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. Atmospheric Environment. 30(20): 3423–3430.

Tarr, J.M.; Adair, S. 2014. Policy brief: the EPA's proposed guidelines for regulating carbon dioxide emissions from existing power plants. NI-PB-14. Durham, NC: Duke University, Nicholas Institute for Environmental Policy Solutions. 5 p. http://nicholasinsitute.duke.edu/sites/default/files/publications/ni_pb_14-01_0.pdf. (November 7).

Thornton, P.K. 2010. Livestock production: recent trends, future prospects. Philosophical Transactions of the Royal Society B. 365: 2853–2867.

Tietjen, B.; Jeltsch, F.; Zehe, E. [et al.]. 2010. Effects of climate change on the coupled dynamics of water and vegetation in drylands. Ecohydrology. 3: 226–237.

Trakhtenbrot, A.; Kadmon, R. 2005. Environmental cluster analysis (ECA) as a tool for selecting complementary networks of conservation sites. Ecological Applications. 15: 335–345.

Trakhtenbrot, A.; Kadmon, R. 2006. Effectiveness of environmental cluster analysis in representing regional species diversity. Conservation Biology. 20: 1087–1098.

Turner, D.P.; Koerper, G.J.; Harmon, M.E.; Lee, J.J. 1995. Carbon sequestration by forests of the United States: current status and projections to the year 2040. Tellus. 47B: 232–239.

Umoff, A.A. 2008. An analysis of the 1944 U.S.-Mexico Water Treaty: its past, present, and future. Environs: Environmental Law & Policy Journal. 32: 69–98.

United Kingdom Department of Energy and Climate Change. 2014. Guidance: timber standard for heat & electricity. London, United Kingdom: Department of Energy and Climate Change. 17 p. https://www.gov.uk/government/publications/timber-standard-for-heat-electricity. (April 8).

United Nations Framework Convention on Climate Change [UNFCCC]. 2013. Report on the individual review of the inventory submission of the United States of America submitted in 2012. FCCC/ARR/2012/USA. 42 p. http://unfccc.int/resource/docs/2013/arr/usa.pdf.

U.S. Bureau of Labor Statistics [U.S. BLS]. 2014a. Current employment statistics—CES (national): historical data for series in the selected news releases from the Current Employment Statistics survey (national). Washington, DC: U.S. Bureau of Labor Statistics. http://www.bls.gov/ces/. (September 19).

U.S. BLS. 2014b. National employment, hours, and earnings (SIC). Washington, DC: U.S. Bureau of Labor Statistics. http://data.bls.gov/pdq/querytool.jsp?survey=ee. (March 11).

U.S. Census Bureau. 2010. Census 2010 U.S. Gazetteer Files. Washington, DC: U.S. Census Bureau. http://www.census.gov/geo/maps-data/data/gazetteer2010.html.

U.S. Census Bureau. 2013. 2010 Census urban and rural classification and urban area criteria. Washington, DC: U.S. Census Bureau. http://www.census.gov/geo/reference/ua/urban-rural-2010.html.

U.S. Census Bureau. 2014a. Annual estimates of the resident population for the United States, regions, States, and Puerto Rico: April 1, 2010 to July 1, 2013. NST-EST2013-01. Washington, DC: U.S. Census Bureau. http://www.census.gov/popest/data/national/totals/2013/index.html. (September 30).

U.S. Census Bureau. 2014b. Characteristics of new housing. Washington, DC: U.S. Census Bureau. https://www.census.gov/construction/chars/highlights.html. (October 7).

U.S. Census Bureau. 2014c. Historical national population estimates: July 1, 1900 to July 1, 1999. Washington, DC: U.S. Census Bureau. http://www.census.gov/popest/data/national/totals/pre-1980/tables/popclockest.txt. (September 30).

U.S. Census Bureau. 2014d. Housing units started: United States—not seasonally adjusted total units (thousands of units). Washington, DC: U.S. Census Bureau. http://www.census.gov/econ/currentdata/dbsearch?program=RESCONST&startYear=1959&endYear=2013&categories=STARTS&dataType=TOTAL&geoLevel=US&notAdjusted=1&submit=GET+DATA. (October 1).

U.S. Census Bureau. 2014e. Intercensal estimates of the resident population by sex and age for the United States: April 1, 2000 to July 1, 2010. Washington, DC: U.S. Census Bureau. http://www.census.gov/popest/data/intercensal/national/nat2010.html. (September 30).

U.S. Census Bureau. 2014f. Projections of the population and components of change for the United States: 2015 to 2060. NP2014-T1. Washington, DC: U.S. Census Bureau, Population Division. http://www.census.gov/search-results.html?q=NP2014-T1&page=1&stateGeo=none&searchtype=web&search.x=0&search.y=0. (September 30).

U.S. Census Bureau. 2015. New privately owned housing units started. Washington, DC: U.S. Census Bureau. https://www.census.gov/construction/nrc/xls/starts_cust.xls. (February 24).

U.S. Court of Appeals for the District of Columbia. 2013. *In re*: Endangered Species Act Section 4 Deadline Litigation. MDL No. 2165. Federal Reporter 3d. 704: 973–980.

U.S. Department of Agriculture [USDA]. 2015. Summary report: 2012 National Resources Inventory. Washington, DC; Ames, IA: U.S. Department of Agriculture, Natural Resources Conservation Service; Iowa State University, Center for Survey Statistics and Methodology. 210 p. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd396218.pdf.

USDA Economic Research Service [USDA ERS]. 2012. International macroeconomic data set. Washington, DC: U.S. Department of Agriculture, Economic Research Service. http://www.ers.usda.gov/Data/Macroecoenomics/. (2013 January 8).

USDA Foreign Agricultural Service [USDA FAS]. 2013. The market for wood pellets in the Benelux. Global Agricultural Information Network Report Number NL3001. 9 p. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/The%20Market%20for%20Wood%20Pellets%20in%20the%20Benelux_The%20Hague_Netherlands_1-4-2013.pdf. (2014 April 8).

USDA Forest Service. 2004. Forest type groups of the United States [map]. Salt Lake City, UT: U.S. Department of Agriculture, Forest Service, Remote Sensing Applications Center. http://fsgeodata.fs.fed.us/rastergateway/forest_type/. (2011 April 28).

USDA Forest Service. 2007. Interim Update of the 2000 Renewable Resource Planning Act Assessment. FS-874. Washington, DC: U.S. Department of Agriculture, Forest Service. 114 p.

USDA Forest Service. 2010. The Forest Inventory and Analysis Database: database description and user's manual for phase 2, version 4.0, revision 3. Washington, DC: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis Program. 368 p. http://fia.fs.fed.us/library/database-documentation/. (2011 February 18).

USDA Forest Service. 2011. National report on sustainable forests, 2010. FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 210 p.

USDA Forest Service. 2012a. Future of America's forest and rangelands: Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-87. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 198 p.

USDA Forest Service. 2012b. Future scenarios: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-272. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 34 p.

USDA Forest Service. 2012c. National Forest System land management planning. Federal Register. 77: 21162–21276.

USDA Forest Service. 2014a. Forest Inventory and Analysis, FIA data and tools. [Online database]. http://fia.fs.fed.us/tools-data/default.asp. (January 15).

USDA Forest Service. 2014b. Forest Inventory and Analysis, timber product output database. http://srsfia1.fia.srs.fs.fed.us/php/tpo2/tpo.php. (March 5).

USDA Forest Service. 2015a. National Visitor Use Monitoring results version 2.1.2.37. Washington, DC: U.S. Department of Agriculture, Forest Service, Natural Resource Manager. http://apps.fs.fed.us/nrm/nvum/results/.

USDA Forest Service. 2015b. Introduction for NVUM 2.1 results web, satisfaction reports. Washington, DC: U.S. Department of Agriculture, Forest Service, Natural Resource Manager. http://www.fs.fed.us/nrm/nvum/results/WebHelp/.

USDA National Agricultural Statistics Service [NASS]. 2014. NASS surveys: cattle inventory. Washington, DC: USDA Agricultural Statistics Service. https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Cattle_Inventory/index.php. (2014 August 12).

U.S. Department of Commerce. 2015. Harmonized trade data: port level exports. Washington, DC: U.S. Department of Commerce. https://usatrade.census.gov/.

U.S. Department of Energy [U.S. DOE]. 2011. U.S. billion-ton update: biomass supply for a bioenergy and bioproducts industry. ORNL/TM-2011/224. Oak Ridge, TN: Oak Ridge National Laboratory. 227 p.

U.S. DOE, Energy Information Administration [U.S. DOE EIA]. 2013. Annual energy outlook 2013. Washington, DC: U.S. Department of Energy, Energy Information Administration. 244 p. http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf. (2014 April 8).

U.S. DOE EIA. 2014. Annual energy outlook, 2014. Washington, DC: U.S. Department of Energy, Energy Information Administration. 269 p. http://www.eia.gov/forecasts/archive/aeo14/pdf/0383(2014).pdf (2014 April 8).

U.S. DOE EIA. 2015. 2015 annual energy outlook. Washington, DC: U.S. Department of Energy, Energy Information Administration. 154 p. http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf. (2015 March 10).

U.S. DOE EIA. 2016. Monthly energy review, February. Washington, DC: U.S. Department of Energy, Energy Information Administration. http://www.eia.gov/totalenergy/data/monthly/#renewable. (2016 March 15).

U.S. Department of the Interior [USDI], U.S. Fish and Wildlife Service [FWS]. 2010. Endangered and threatened wildlife and plants: determination of endangered status for 48 species on Kauai and designation of critical habitat: final rule. Federal Register. 75: 18960–19165.

USDI FWS. 2014. Environmental Conservation Online System. Listed species summary (boxscore). http://ecos.fws.gov/tess_public/reports/box-score-report. (July 14).

U.S. Department of State. 2015. Second biennial report of the United States of America under the United Nations Framework Convention on Climate Change. Washington, DC: U.S. Department of State. 80 p.

U.S. Environmental Protection Agency [U.S. EPA]. 1997. State source water assessment and protection program: final guidance. EPA 816-R-97-009. Washington, DC: U.S. Environmental Protection Agency, Office of Water. 156 p.

U.S. EPA. 2010. Prevention of significant deterioration and Title V greenhouse gas tailoring rule. Washington, DC: U.S. Environmental Protection Agency. 16 p. www.epa.gov/nsr/documents/20100413final.pdf. (2012 November 6).

U.S. EPA. 2011a. Fact sheet: proposed rule—deferral for CO_2 emissions from bioenergy and other biogenic sources under the prevention of significant deterioration (PSD) and Title V programs. Washington, DC: U.S. Environmental Protection Agency. 4 p. www.epa.gov/nsr/ghgdocs/biogenicfs.pdf. (2012 November 6).

U.S. EPA. 2011b. Guidance for determining best available control technology for reducing carbon dioxide emissions from bioenergy production. Washington, DC: U.S. Environmental Agency. http://www.epa.gov/nsr/ghgdocs/bioenergyguidance.pdf. (2012 November 6).

U.S. EPA. 2012. Environmental benefits mapping and analysis program (BenMAP). Washington, DC: U.S. Environmental Protection Agency. http://www.epa.gov/benmap.

U.S. EPA. 2014a. Framework for assessing biogenic CO_2 emissions from stationary sources. Washington, DC: U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Atmospheric Programs, Climate Change Division. 69 p. https://www3.epa.gov/climatechange/downloads/Framework-for-Assessing-Biogenic-CO2-Emissions.pdf.

U.S. EPA. 2014b. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2011. EPA 430-R-14-003. Washington, DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs. 529 p.

U.S. EPA 2015. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2012. EPA 430-R-15-004. Washington, DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs. 529 p.

U.S. Geological Survey [USGS]. 2014a. Multi-Resolution Land Characteristics Consortium. (MRLC). http://www.mrlc.gov/. (June 7).

USGS. 2014b. NLCD 2011 land cover. 2011 ed. Sioux Falls, SD: U.S. Geological Survey.

USGS. 2014c. NLCD 2006 land cover. 2011 ed. Sioux Falls, SD: U.S. Geological Survey.

USGS. 2014d. NLCD 2001 land cover. 2011 ed. Sioux Falls, SD: U.S. Geological Survey.

U.S. North American Bird Conservation Initiative Committee. 2000. Bird Conservation Region descriptions: a supplement to the North American Bird Conservation Initiative Bird Conservation Regions map. Arlington, VA: U.S. Fish and Wildlife Service, Division of Bird Habitat Conservation. (Map available on line: http://www.nabci-us.org/bcrs.htm).

van Dam, J.; Junginger, M.; Faaij, A.P.C. 2010. From the global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning. Renewable and Sustainable Energy Reviews. 14: 2445–2472.

Vano, J.A.; Das, T.; Lettenmaier, D.P. 2012. Hydrologic sensitivities of Colorado River runoff to changes in precipitation and temperature. Journal of Hydrometeorology. 13(3): 932–949.

Vetter, S. 2009. Drought, change and resilience in South Africa's arid and semi-arid rangelands. South African Journal of Science. 105(1-2): 29–33.

Vis, M.W.; Vos, J.; van den Berg, D. 2008. Sustainability criteria and certification systems for biomass production. Project No. 138; prepared for Directorate-General for Energy and Transport, European Commission. Enschede, Netherlands: BTG Biomass Technology Group. 117 p. http://rpd-mohesr.com/uploads/custompages/sustainability_criteria_and_certification_systems.pdf. (2014 November 7).

Walker, T., ed. 2010. Massachusetts biomass sustainability and carbon policy study: report to the Commonwealth of Massachusetts Department of Energy Resources. Natural Capital Initiative Report NCI-2010-03. Brunswick, ME: Manomet Center for Conservation Sciences. 182 p. http://www.mass.gov/eea/docs/doer/renewables/biomass/manomet-biomass-report-full-hirez.pdf. (2014 November 7).

Walther, G.R. 2010. Community and ecosystem responses to recent climate change. Philosophical Transactions of the Royal Society B. 365: 2019–2024.

Walther, G.R.; Roques, A.; Hulme, P.E. [et al.]. 2009. Alien species in a warmer world: risks and opportunities. Trends in Ecology and Evolution. 12: 686–693.

Wang, S.Y.; Hipps, L.; Gillies, R.R.; Yoon, J.H. 2014. Probable causes of the abnormal ridge accompanying the 2013–2014 California drought: ENSO precursor and anthropogenic warming footprint. Geophysical Research Letters. 41(9): 3220–3226.

Warziniack, T.W. 2014. A general equilibrium model of ecosystem services in a river basin. Journal of the American Water Resources Association. 50(3): 683–695.

Warziniack, T.W. [N.d.]. Estimating future water demand in the Upper Colorado River basin with a general equilibrium modeling of ecosystem services. Working paper in progress. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Warziniack, T.W.; Creason, J. 2001. National Estuary Program coastal bend bays and estuaries economic profile. Washington, DC: U.S. Environmental Protection Agency, National Center for Environmental Economics. 5 p.

Water Resources Council. 1978. The Nation's water resources. Vol. I: Summary. Washington, DC: U.S. Government Printing Office. 86 p.

Weakley, H.E. 1965. Recurrence of drought in the Great Plains during the last 700 years. Agricultural Engineering. 46: 85.

Wear, D.N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 41 p. http://www.treesearch.fs.fed.us/pubs/39404.

Wear, D.N.; Coulston, J. 2015. From sink to source: Regional variation in U.S. forest carbon futures. Scientific Reports. 5: 16518, doi:10.1038/srep16518.

Wear, D.N.; Greis, J.G. 2012. The Southern Forest Futures Project: summary report. Gen. Tech. Rep. GTR-SRS-168. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 54 p.

Wear, D.N.; Huggett, R.; Li, R. [et al.]. 2013. Forecasts of forest conditions in U.S. regions under future scenarios: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. GTR-SRS-170. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 101 p.

Western Wood Products Association [WWPA]. 2014. Lumber Track. [Monthly]. December 2014. Portland, OR: Western Wood Products Association.

Wickham, J.D.; Flather, C.H. 2013. Integrating biodiversity and drinking water protection goals through geographic analysis. Diversity and Distributions. 19: 1198–1207.

Wickham, J.D.; Wade, T.G.; Riitters, K.H. 2011. An environmental assessment of United States drinking water watersheds. Landscape Ecology. 26: 605–616.

Wilson, B.T.; Woodall, C.W.; Griffith, D.M. 2013. Forest carbon stocks of the contiguous United States (2000–2009). Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. http://dx.doi.org/10.2737/RDS-2013-0004.

Wood, E.M.; Pidgeon, A.M.; Radeloff, V.C. [et al.]. 2014. Housing development outside protected area boundaries erode avian community structure within. Ecological Applications. 24: 1445–1462.

Wood Resources International. 2014. North American wood fiber review—February 2014. 36 p. http://www.wri-ltd.com/woodfibre.html. (August 8).

Woodall, C.W. 2012. Personal communication. In country review of the U.S.' LULUCF Sector, UNFCCC Secretariat. October 2, 2012. Washington, DC.

Woodall, C.W.; Coulston, J.W.; Domke, G.M. [et al.]. 2015. The U.S. forest carbon accounting framework: stocks and stock change, 1990–2016. Gen. Tech. Rep. NRS-154. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 49 p.

Woodall, C.W.; Ince, P.J.; Skog, K.E. [et al.]. 2012. An overview of the forest products sector downturn in the United States. Forest Products Journal. 61(8): 595–603.

Woodhouse, C.A.; Meko, D.M.; MacDonald, G.M. [et al.]. 2010. A 1,200-year perspective of 21st century drought in southwestern North America. Proceedings of the National Academy of Sciences. 107: 21283–21288.

Wyman, K.M. 2010. Rethinking the ESA to reflect human dominion over nature. Environmental Law and Policy Annual Review. 40: 10803–10808.

Xian, G.; Homer, C.; Fry, J. 2009. Updating the 2001 National Land Cover Database land cover classification to 2006 by using Landsat imagery change detection methods. Remote Sensing of Environment. 113: 1133–1147.

Yates, D.; Sieber, J.; Purkey, D.; Huber-Lee, A. 2005. WEAP21—a demand-, priority-, and preference-driven water planning model part 1: model characteristics. Water International. 30(4): 487–500.

Zargar, A.; Sadiq, R.; Naser, B.; Khan, F.I. 2011. A review of drought indices. Environmental Reviews. 19: 333–349.

Zarnoch, S.J.; White, E.M.; English, D.B.K. [et al.]. 2011. The National Visitor Use Monitoring methodology and final results for round 1. Gen. Tech. Rep. SRS-144. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 74 p.

Zemanek, S.L. 2013. U.S. travel and tourism satellite accounts for 2009 to 2012. Survey of Current Business. June 2013: 35–43. http://www.bea.gov/scb/pdf/2013/06%20June/0613_travel_and_tourism_text.pdf.

Zhu, Z., ed. 2010. A method for assessing carbon stocks, carbon sequestration, and greenhouse-gas fluxes in ecosystems of the United States under present conditions and future scenarios. U.S. Geological Survey Scientific Investigations Report 2010-5233. Reston, VA: U.S. Geological Survey. 188 p. pubs.usgs.gov/sir/2010/5233/.

Appendix A. List of Abbreviations and Acronyms

2010 RPA	2010 Resources Planning Act Assessment
ALB	Asian longhorned beetle
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
ASR	assessment subregion
BBS	Breeding Bird Survey (North American)
BenMAP	Environmental Benefits Mapping and Analysis Program
BLM	Bureau of Land Management
BMPs	best management practices
CGE	computable general equilibrium
CO_2	carbon dioxide
CRP	Conservation Reserve Program
DUDS	day use developed site
EISA	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
ERS	Economic Research Service
ESA	Endangered Species Act
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCAF	U.S. Forest Carbon Accounting Framework
FHM	Forest Health Monitoring program
FIA	Forest Inventory and Analysis
FWS	U.S. Fish and Wildlife Service
GATT	General Agreement on Tariffs and Trade
GCM	general circulation model
GFA	general forest area
GFPM	Global Forest Products Model
GHG	greenhouse gas
GRG	grasslands remaining grasslands
HSI	heat stress index
HWP	harvested wood products
IPA	Importance-Performance Analysis
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LCG	lands converted to grasslands
LCRB	Lower Colorado River Basin
LQ	location quotient
MBF	million board feet
mgt	million green short tons
MPB	mountain pine beetle
MODIS	Moderate Resolution Imaging Spectroradiometer
NAICS	North American Industry Classification System
NDVI	Normalized Difference Vegetation Index
NFS	National Forest System
NFV	national forest visit
NGHGI	National Greenhouse Gas Inventory
NLCD	National Land Cover Database
NO_2	nitrogen dioxide
NPP	net primary productivity
NRI	National Resources Inventory
NSRE	National Survey of Recreation and the Environment
NVUM	National Visitor Use Monitoring Program
O_3	ozone
OSB	oriented strandboard
OUDS	overnight use developed site
PAD-US	Protected Areas Database of the United States
PM	particulate matter
PRISM	Parameter-elevation Relationships on Independent Slopes Model
R1	Region 1, Northern Region (NFS)
R2	Region 2, Rocky Mountain Region (NFS)
R3	Region 3, Southwestern Region (NFS)
R4	Region 4, Intermountain Region (NFS)
R5	Region 5, Pacific Southwest Region (NFS)
R6	Region 6, Pacific Northwest Region (NFS)
R8	Region 8, Southern Region (NFS)
R9	Region 9, Eastern Region (NFS)

R10	Region 10, Alaska Region (NFS)
RED	Renewable Energy Directive
RPA	Resources Planning Act
SD	standard deviation
SGCN	species of greatest conservation need
SO_2	sulfur dioxide
SOC	soil organic carbon
SoVI	Social Vulnerability Index
SV	site visit
TAR	Third Assessment Report
TBD	transbasin diversion
TCSI	terrestrial climate stress index
Tg	teragram
THI	temperature-humidity index
UCRB	Upper Colorado River Basin
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USDA	U.S. Department of Agriculture
USFPM	U.S. Forest Products Module
VIC	Variable Infiltration Capacity
VOC	volatile organic compound
WILD	designated wilderness
WRR	water resource region
WTO	World Trade Organization

Appendix B. List of Scientific Names

	Common name	Scientific name
Plants	American elm	*Ulmus americana*
	ash	*Fraxinus* spp.
	aspen	*Populus* spp.
	bald cypress	*Taxodium* Rich.
	balsam fir	*Abies balsamea*
	balsam poplar	*Populus balsamifera*
	basswood	*Tilia* spp.
	beech	*Fagus grandifolia*
	bigleaf maple	*Acer macrophyllum*
	black ash	*Fraxinus nigra*
	black cherry	*Prunus serotina*
	black locust	*Robinia pseudoacacia*
	black oak	*Quercus velutina*
	black spruce	*Picea mariana*
	black walnut	*Juglans nigra*
	blackjack oak	*Quercus marilandica*
	blue oak	*Quercus douglasii*
	blue spruce	*Picea pungens*
	bur oak	*Quercus macrocarpa*
	California black oak	*Quercus kelloggii*
	California laurel	*Umbellularia californica*
	California white oak	*Quercus lobata*
	canyon live oak	*Quercus chrysolepis*
	cherry	*Prunus* spp.
	cherrybark oak	*Quercus falcata* var. *pagodifolia*
	chestnut oak	*Quercus prinus*
	coast live oak	*Quercus agrifolia*
	cottonwood	*Populus* spp.
	Douglas-fir	*Pseudotsuga menziesii*
	eastern hemlock	*Tsuga canadensis*
	eastern redcedar	*Juniperis virginiana*
	eastern white pine	*Pinus strobus*
	elm	*Ulmus americana*
	Engelmann spruce	*Picea engelmannii*
	foxtail pine/bristlecone pine	*Pinus balfouriana*
	giant chinkapin	*Castanopsis chrysophylla*
	grand fir	*Abies grandis*
	gray birch	*Betula populifolia*
	gray pine	*Pinus sabiniana*
	hackberry	*Celtis occidentalis*
	hard maple	*Acer saccharum*
	hickory	*Carya* spp.
	interior live oak	*Quercus wislizeni*
	jack pine	*Pinus banksiana*
	Jeffrey pine	*Pinus jeffreyi*
	juniper	*Juniperus* spp.
	limber pine	*Pinus flexilis*
	loblolly pine	*Pinus taeda*
	lodgepole pine	*Pinus contorta*
	longleaf pine	*Pinus palustris*
	lowland red maple	*Aver rubrum*
	mesquite	*Prosopis* spp.
	mountain hemlock	*Tsuga mertensiana*
	noble fir	*Abies procera*
	northern red oak	*Quercus rubra*
	northern white-cedar	*Thuja occidentalis*
	Norway spruce	*Picea abies*
	Nuttall oak	*Quercus nuttallii*

	Common name	Scientific name
Plants	Oregon white oak	*Quercus garryana*
	overcup oak	*Quercus lyrata*
	Pacific madrone	*Arbutus menziesii*
	Pacific silver fir	*Abies amabilis*
	paper birch	*Betula papyrifera*
	pecan	*Carya illinoinensis*
	persimmon	*Diospyros virginiana*
	pin cherry	*Prunus pensylvanica*
	pinyon pine	*Pinus edulis*
	pitch pine	*Pinus rigida*
	pond cypress	*Taxodium ascendens*
	pond pine	*Pinus serotina*
	ponderosa pine	*Pinus ponderosa*
	post oak	*Quercus stellata*
	red alder	*Alnus rubra*
	red fir	*Abies magnifica*
	red maple	*Acer rubrum*
	red oak	*Quercus falcata*
	red pine	*Pinus resinosa*
	red spruce	*Picea rubens*
	redwood	*Sequoioideae*
	river birch	*Betula nigra*
	Rocky Mountain juniper	*Juniperus scopulorum*
	sand pine	*Pinus clausa*
	sassafras	*Sassafras albidum*
	scarlet oak	*Quercus coccinea*
	shortleaf pine	*Pinus echinata*
	silver maple	*Acer saccharinum*
	Sitka spruce	*Picea sitchensis*
	slash pine	*Pinus elliottii*
	southern scrub oak	*Quercus inopina*
	subalpine fir	*Abies lasiocarpa*
	sugar maple	*Acer saccharum*
	sugarberry	*Celtis laevigata*
	swamp chestnut oak	*Quercus michauxii*
	swamp tupelo	*Nyssa Sylvatica*
	sweetbay	*Laurus nobilis*
	sweetgum	*Liquidambar styraciflua*
	sycamore	*Platanus occidentalis*
	tamarack	*Larix laricina*
	tanoak	*Notholithocarpus densiflorus*
	upland red maple	*Acer rubrum*
	Virginia pine	*Pinus virginiana*
	water hickory	*Carya aquatica*
	water tupelo	*Nyssa sylvatica*
	western hemlock	*Tsuga heterophylla*
	western larch	*Larix occidentalis*
	western redcedar	*Thuja plicata*
	western white pine	*Pinus monticola*
	white ash	*Fraxinus americana*
	white fir	*Abies concolor*
	white oak	*Quercus alba*
	white spruce	*Picea glauca*
	whitebark pine	*Pinus albicaulis*
	willow	*Salix* spp.
	willow oak	*Quercus phellos*
	yellow birch	*Betula alleghaniensis*
	yellow poplar	*Liriodendron tulipifera*
Other	Asian longhorned beetle	*Anoplophora glabripennis*
	Dutch elm disease	*Ophiostoma* spp.
	emerald ash borer	*Agrilus planipennis*
	gypsy moth	*Lymantria dispar*
	hemlock woolly adelgid	*Adelges tsugae*
	mountain pine beetle	*Dendroctonus ponderosae*
	southern pine beetle	*Dendroctonus frontalis*