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Future Forests of the Northern United States

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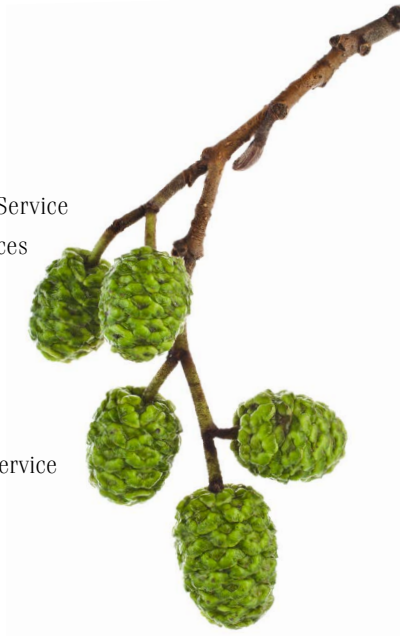

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ABSTRACT

The U.S. North—the 20 states bounded by Maine, Maryland, Missouri, and Minnesota—have a greater forest cover (42 percent of land area) and population density (194 people per square mile) than other large regions of the nation. Ecological, social, and economic changes anticipated over the next 50 years will profoundly affect future forest management needs and opportunities in the North. This report draws on data from numerous sources to analyze 13 scenarios that consider future forest change in response to assumptions about land-use change, economic change, greenhouse gas emissions, climate change, forest growth, forest harvest, and other factors. Results are organized using the Montréal Process Criteria and Indicator framework. Important trends for the U.S. North over the next 50 years include the following:

- Forest area is projected to decrease between 3.5 and 6.4 percent with losses concentrated around existing urban and suburban areas.
- Forest area is currently concentrated in the 40-to-80-year age class and is expected to increase in mean age over time, resulting in a paucity of early-successional habitats and low structural forest diversity.
- Closed-canopy habitat classes are expected to gain acreage at the expense of open-canopy habitat classes.
- The historical trend of steadily increasing live wood volume over time is projected to level off or decline under all scenarios, with little variation attributable to differing assumptions about future climate conditions.
- The area of the maple-beech-birch forest-type group is expected to increase relative to nearly all other groups.
- Projected forest removals resulting from land-use changes are likely to average about 13 percent of total removals, with the remainder resulting from harvesting; in some populous Eastern States, removals resulting from land-use changes could exceed 50 percent of all removals.
- Forests are under the expanding negative influence of numerous invasive species including emerald ash borer, Asian longhorned beetle, spruce budworm, Sirex woodwasp, winter moth, hemlock woolly adelgid, beech bark disease, gypsy moth, and dozens of invasive plants.
- Across the North, 76 million people depend on public and private forests for high quality water supplies.
- On average, the amount of water needed to meet societal demands is projected to increase and the supply of

high quality water is projected to decline, but water supplies for most watersheds would remain adequate.

- Aboveground forest biomass is expected to increase by about 4 percent, but total carbon sequestered by northern forests (including soils) is expected to decrease by about 2 percent, primarily as the result of reduced forest acreage combined with slower tree growth that is typical for aging forests.
- By 2030, U.S. electrical power generated from all biomass is expected to increase 350 percent over 2010 levels, but in Northern States biomass will still be used for less than 6 percent of total electric production, often by co-firing biomass and coal.
- Forest-associated employment has declined in the past decade, and real-dollar wages in forestry have been relatively constant, but productivity per employee is increasing.
- The North is the location of nearly all commercial U.S. maple syrup production—about 2.5 million gallons valued at about $90 million annually.
- Projected population increases in the North are expected to cause Federal and State park land area per capita to decrease by 19 percent and non-Federal forest land area per capita to decrease by 26 percent.
- Of all tax policies, those governing property taxes have the greatest potential to influence the behavior of family forest owners. However, future tax policies will likely hinge on issues that are larger than forestry.
- Partnerships among various institutions and organizations have become increasingly common for addressing large-scale, complex issues. This trend is likely to continue.
- U.S. urban tree cover is estimated at 35 percent but is declining in many cities.
- By 2050, urban land is expected to increase to about 8 percent in the conterminous United States and to 14 percent in the North.
- Practices that can support future management for sustainable, resilient northern forests include strengthening connections between rural and urban forest habitats and people; developing mutually beneficial partnerships among all stakeholders to support shared conservation goals; developing measurable State and regional goals for forest diversity and monitoring progress toward achieving them; promoting forward-looking forest management across all forest ownerships; and working to understand the many dimensions of expected forest change.

Key Words: climate change, land use change, biodiversity, Montréal Process, forest health, forest industry, invasive species, biomass, bioenergy, sustainable timber products, nontimber forest products, private forest owners, watershed, urban forest

This document draws on data and maps from many sources. Principal among these sources is the U.S. Forest Service, Forest Inventory and Analysis data set, which spans 60 years of forest change. These data have been collected by numerous field-going personnel, often working in adverse conditions. We have drawn inspiration from the Southern Forest Futures Project of the U.S. Forest Service, Southern Research Station. We have utilized methods and data prepared by the many contributors to the Forest Service 2010 Resources Planning Act Assessment.

We owe special thanks to Michael Rains, Director of the Northern Research Station and the Forest Products Laboratory of the U.S. Forest Service. He is a visionary leader in the Forest Service and among the broader natural resource community where for nearly five decades he has been *caring for the land and serving people* where they live. It was his vision and drive that initiated the Northern Forest Futures Project—a collaboration that laid the foundation for this report and many associated products.

We have been the beneficiaries of encouragement, advice, and constructive reviews from the administrators of State forestry and natural resource agencies, including their expert staffs and the Northeastern Area Association of State Foresters. Tom Schmidt, Dennis May, and Deb Dietzman of the U.S. Forest Service Northern Research Station consistently provided financial support, insight, and encouragement over many years. Susan Wright, Carol Whitlock, Amy Scherzer, and Rhonda Cobourn provided the editorial expertise and polish necessary to turn our technical manuscript into an attractive, coherent, and highly readable finished publication. Jim Lootens-White developed the Web interface that elegantly provides interactive access to the data and results.

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We thank them all

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Assessing and Forecasting Change in Northern Forests

1

Stephen R. Shifley, W. Keith Moser, Sherri Wormstead

Introduction

THE PURPOSE OF this report is to describe how yesterday's trends and today's choices might change the future forest landscape of the Northern United States from 2010 (the baseline year) to 2060. Its results are intended to help resource managers and policy makers identify actions that will sustain the health, productivity, diversity, and resilience of these forests, which provide for the well-being of the 125 million people who currently live in the 20 Northern States (Fig. 1.1) and for 32 million additional people expected by 2060.

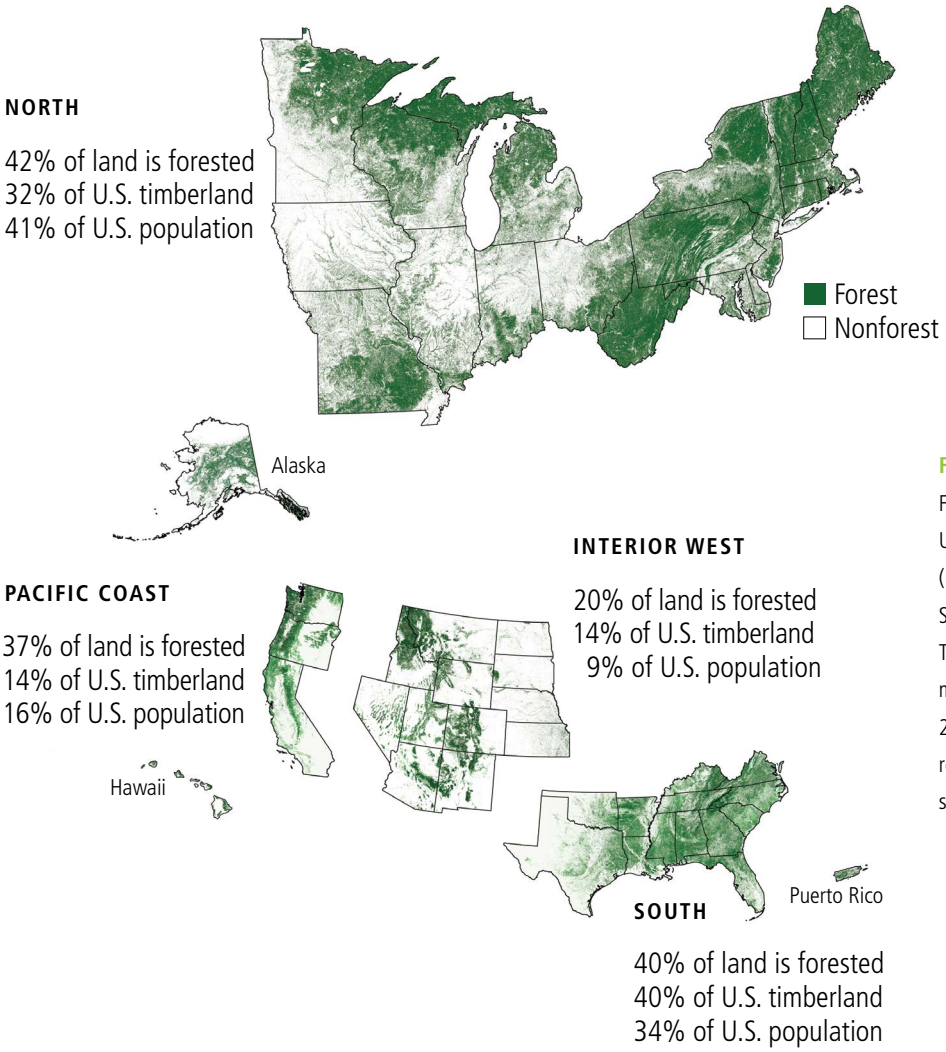


FIGURE 1.1
Forested area and population of the Northern United States compared with other U.S. regions (Homer et al. 2004, Shifley et al. 2012, Smith et al. 2009, U.S. Census Bureau 2010). Timberland is defined as forest land that maintains a minimum potential for growth of 20 cubic feet per acre per year and is not restricted from active forest management by statute or regulation.

Our attention is on issues that affect forest resources in the broadest sense, including urban and rural trees and forests; forest-associated plants and animals; tree and forest health; water and soil conservation; carbon sequestration; timber and nontimber forest products; forest-based employment; attitudes, laws, and policies affecting forest use and management; land-use change; and forest fragmentation.

A large component of forest change will be the result of normal forest growth, aging, natural regeneration, and species succession. In addition, we expect that a range of external forces will also drive forest change:

- Population increases will cause millions of acres of forest land to be converted to urban and other land uses.
- Economic conditions will affect forest products consumption, production, and harvesting rates.
- The spread of invasive species will exacerbate the effects of other disturbances on forest ecosystems.
- Changes in population, economic activity, energy consumption, and energy production will affect future climate change.
- Climate change will, in turn, affect dynamics within forested ecosystems, including patterns of vegetation growth and species succession.

Because we cannot know with certainty how the economy, population, or climate will change in the future, this report presents several alternative scenarios that cover a range of different assumptions about these and other driving forces. The assumptions were incorporated into analytical models that were used to estimate how northern forests are likely to change under each alternative scenario.

NORTHERN FORESTS IN CONTEXT

The U.S. North consists of 20 Central and Northeastern States (Fig. 1.1) that together constitute the most heavily forested and most densely populated quadrant of the Nation (Shifley et al. 2012). Maintaining diverse, healthy, productive forests requires managers and policy makers to anticipate future changes and respond proactively to avert negative consequences of those changes.

Past and current forest conditions and forest management issues for the North are presented in detail in previous products of the Northern Forest Futures Project. Northern forests today bear the imprint of land-use practices over prior centuries (Thompson et al. 2013). As European settlers migrated westward into forested areas in the 1700s and 1800s, they set in motion the following general sequence of processes that shaped the current condition of northern forests:

- Exploitive timber harvesting
- Forest clearing for agriculture
- Burning forests to open the understory and benefit livestock grazing

- Gradual abandonment of marginal agricultural lands with reversion to forest cover
- Aggressive forest fire suppression
- Urbanization
- Forest fragmentation
- Maturing timber resources
- Aging private forest owners
- Low management intensity among family forest owners

The cumulative consequences of human activities on northern forests have been dramatic over the past 50 years. Some changes have been remarkably positive—an increase of 11 million acres of forest land (7 percent) and an increase of 144 million cubic feet of timber (240 percent), both despite a population increase of 26 million people (27 percent). Other changes have been of great concern—the expanding impact of invasive species, loss of species diversity, increasing numbers of areas in which urban expansion is shrinking forest acreage, fragmentation of forest land, parcellation of forest ownerships, loss of forest-based employment, effects of burgeoning white-tailed deer (*Odocoileus virginianus*) populations on tree regeneration and forest composition, and increasing atmospheric carbon emissions.

We expect equally dramatic changes in northern forests over the next 50 years. Some will be the consequences of the natural forest processes that over time affect every forest acre.

Other changes will be determined by human activities including:

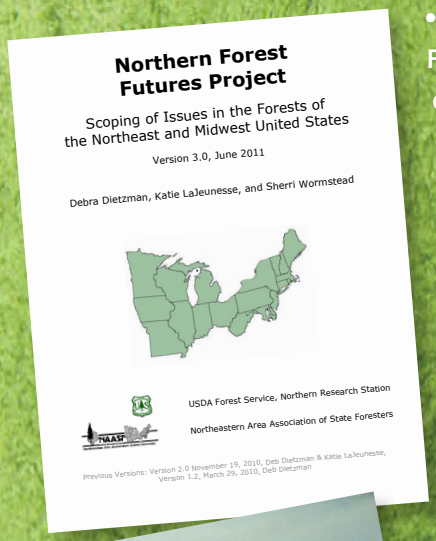
- Conversion of forests to other land uses
- Introduction and continued spread of invasive species
- Emphasis on management practices that focus on forest health and species diversity
- Consumption of forest products
- Production of wood-based bioenergy
- Extraction of gas and minerals beneath forest land
- Competing pressures and changing preferences among outdoor recreation enthusiasts
- Valuation of forest ecosystem services and commodities
- Federal and State policy and legislation
- Effectiveness of hunting as a tool for controlling white-tailed deer populations

Still other changes will be determined by emerging global-scale phenomena. An example is climate change, which is expected to gradually increase in impact over the next 50 years and beyond. It is a phenomenon that we have limited ability to control locally and for which mitigation through forest management is still in early stages.

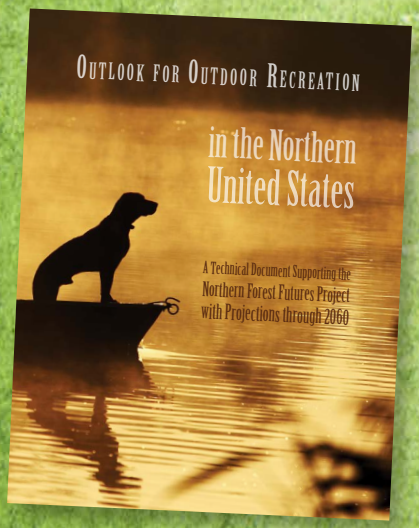
The processes of natural regeneration, species succession, growth, inter-tree competition, aging, senescence, and weather-related disturbances—when coupled with vast forest acreage—result in gradual forest changes at a landscape scale that is measured in thousands or millions of acres. The cumulative effects of human activities, when combined with normal forest dynamics, can take decades to unfold at State and regional scales.

The Northern Forest Futures Project is a multi-year, collaborative undertaking by the Northern Research Station of the U.S. Forest Service to provide a window on tomorrow's forests, demonstrating how today's trends and choices might change tomorrow's landscapes. The intent of this research is to provide forest owners, managers, and other decisionmakers with information to guide sustainable management of the public and private forests in the Northern United States.

Some previous outputs from the Northern Forest Futures Project include:

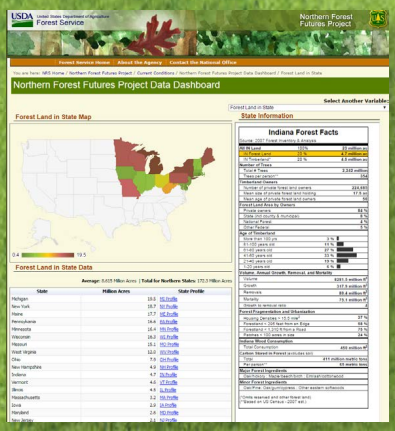


- "Northern Forest Futures Project: Scoping of Issues in the Forests of the Northeast and Midwest United States," by Debra Dietzman et al. (2011), offers a broad-scale summary and analysis of widespread issues affecting northern forests.

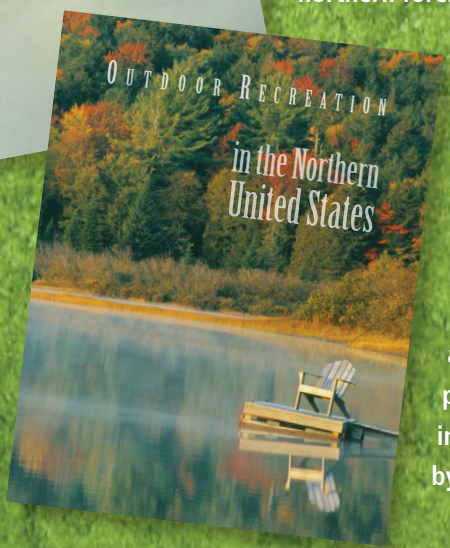


- "Outlook for Outdoor Recreation in the Northern United States…," by Bowker and Askew (2013), is a technical document supporting the Northern Forest Futures Project with recreation projections through 2060.

- "Forests of the Northern United States," by Stephen R. Shifley et al. (2012), reports on current baseline (2010) conditions of northern forests.



- Web-based tools for an interactive summary, mapping, and graphical visualization of forest-associated data for the North are available at http://www.nrs.fs.fed.us/futures/dashboard/.



- Detailed trends and projections for participation in dozens of outdoor recreation activities in the North are published in "Outdoor Recreation in the Northern United States," by H. Ken Cordell et al. (2012).

For example, local disturbances, such as forest clearing resulting from urban development or violent weather, can produce obvious changes in forest conditions at a particular location. However, such disturbances need to cumulatively affect millions of acres to represent a significant change in the collective condition of 174 million acres of northern forest land. Consequently this report takes a long-term, large-scale perspective in describing how scenario analysis and other forward-looking analytical tools will help society understand the magnitude of cumulative forest changes anticipated over the next 50 years.

SCENARIO ANALYSES

Subsequent chapters of this report present a methodology for and results of our efforts to describe how the conditions represented by the alternative scenarios would change northern forests over the next 50 years. The scenarios all start with forest conditions as of 2010, and they all incorporate predictable patterns of forest growth, mortality, aging, and species succession. Scenarios differ in assumptions about land-use changes, population growth, forest product output levels, invasive species impacts, and climate change.

For each scenario, a system of models was applied to make detailed, quantitative projections of forest area, age structure, volume, biomass, and forest-type group; and of characteristics that are linked to changes in forest condition, land use, and human demographics including measures of biodiversity, surface water quality, forest fragmentation, insect and disease impacts, and demand for outdoor recreation.

The analyses presented in this report drew on data and methods that had been developed for other national and regional analyses. Those prior efforts provided a context, data, and analytical techniques that helped us compare alternative scenarios. Collectively, the results of prior analyses and those described in later chapters of this report provide a window on future forest conditions in the North and insight into the choices that will be available for directing forest conditions along a path that society considers desirable. Ultimately it is the work of society to choose among options, make tradeoffs among desirable outcomes, and find effective and equitable solutions. We hope that our analyses provide society with a better understanding of possible futures for northern forests and therefore serve as a basis for making wise choices.

Related National and Regional Reports

The Northern Forest Futures Project benefited from several national and regional analyses, which provided guidance, data, and analytical methods that could sometimes be modified and applied to similar analyses for individual Northern States. Throughout the course of the project, prior publications helped set the ecological and socioeconomic context for the North.

The 2010 national report on sustainable forests (USDA FS 2011) is the most recent synthesis of U.S. forest resources for each of the seven Montréal Process criteria and their associated indicators. It provided the framework both for this report and for the report on past and current forest conditions (Shifley et al. 2012). Some of the data sources compiled for the national report were also used here.

The scenario analysis methods developed for the 2010 Resources Planning Act (RPA) assessment (USDA FS 2012c, Wear et al. 2013) provided a quantitative framework that was modified for the northern state-scale scenario analyses of forest change. Dozens of RPA technical reports document the estimation methods and underlying climate and socioeconomic assumptions used in the national scenario analyses of future forest conditions (USDA FS 2012d). To the extent possible, the Northern Forest Futures Project followed the assumptions and analytical methods for scenario analysis that were used for the national RPA analyses.

Individual State forest action plans (NAASF 2012), a regional collective summary of all the State action plans (Wormstead et al. 2011), and output from the Forest Sustainability Indicators Information System (USDA FS 2012b) provided detailed, state-scale information about forest resources, issues, and management priorities. This information sets the context for projecting conditions of individual Northern States.

State forest inventories repeated through time by the Forest Inventory and Analysis (FIA) Program of the U.S. Forest Service (USDA FS 2012a) provided the core descriptive forest data for individual States and for the region as a whole. The scenario analysis methods used in this report projected conditions for each FIA inventory plot forward in time, subject to the assumptions and conditions of each scenario. The highly refined FIA database summary and analysis tools simplified additional efforts to analyze and interpret the projection results (Miles 2013, USDA FS 2013).

The Southern Forest Futures Project (USDA FS 2012e, Wear and Greis 2013) is the forerunner of and inspiration for the Northern Forest Futures Project. Although the two projects differed somewhat in approach, the basic projection methodology that was used for the Northern States was developed as part of Southern Forest Futures Project and the national RPA.

As detailed in Chapter 2, the scenarios analyzed are closely tied to those used nationally for the Resources Planning Act assessment (USDA FS 2012c, 2012d). Moreover the format of the Montréal Process Criteria and Indicators (described on page 8) was followed when reporting results. The approach and methodology can provide a context for landscape-scale conservation and land-use planning across various scales, including national forest plans and State forest action plans. The projections of future forest conditions for the North and for the 20 individual States it encompasses are provided for use in the preparation of a range of assessment and planning documents.

Although the focus here is on forest conditions within the U.S. North, there are related ecological, social, and economic flows with the U.S. South and Canada. Those are not addressed in this report, but complimentary material for those regions is available from many sources including the Southern Forest Futures Project (Wear and Greis 2013) and Natural Resources Canada (2015).

Montréal Process Criteria and Indicators

As part of the Montréal Process Working Group the United States has joined with 11 other member nations to define seven criteria (essential components) that are described by 54 indicators (measures)—these collectively provide a structured approach for assembling and organizing information relevant to an assessment of sustainable management of temperate and boreal forests (Montréal Process Working Group, n.d.). This report is organized around the seven Montréal Process criteria plus an eighth that describes urban forest resources.

Individual indicators address resource conditions such as forest area, canopy cover, wood volume, forest health, and biodiversity as well as processes such as land-use change, tree growth, tree removals, and recreation. The Montréal Process Criteria and Indicators are scalable and have been the foundation for national (USDA FS 2011), regional (USDA FS 2012b), State (USDA FS 2011, Wormstead et al. 2011) and county assessments (Baltimore County Maryland Department of Environmental Protection and Resource Management 2007).

Criterion name[a]	Number of Montréal Process indicators used to describe the criterion	Corresponding chapters of this publication
1 Conservation of biological diversity	9	3
2 Maintenance of productive capacity of forest ecosystems	5	4
3 Maintenance of ecosystem health and vitality	2	5
4 Conservation and maintenance of soil and water resources	5	6
5 Maintenance of forest contribution to global carbon cycles	3	7
6 Maintenance and enhancement of long-term multiple socioeconomic benefits to meet the needs of societies	20	8
7 Legal, institutional, and economic framework for forest conservation and sustainable management	10	9
8 Urban forests	n/a	10

[a]*The first seven criteria are taken from the Montréal Process Working Group (2013).*

CRITERIA AND INDICATORS

We use the format of the Montréal Process Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Montréal Process Working Group 2013) to organize information about the expected future condition of northern forests. This organization matches the format used in the report on current conditions of northern forests (Shifley et al. 2012), a choice intended to simplify comparison of current and anticipated future forest conditions. The format is based on seven criteria that characterize the essential components of sustainable forest management and 54 indicators (metrics) that describe the criteria in terms of forest conditions.

Some of the 54 indicators of forest conditions included in the Montréal Process are well defined and readily quantified, but others are not. For example, indicators that report on forest area, wood volume, carbon, insects, diseases, species diversity, fragmentation, products, employment, recreation, or best management guidelines can be quantified with existing information and can sometimes be projected forward in time. Other indicators are ambiguously defined, or they lack the metrics needed for quantitative—or even qualitative—definition. Examples include measures of resilience in forest-dependent communities, the importance of forests to people, whether trade policies for forest products are discriminatory, or the success of efforts to conserve genetic diversity. Chapters 3 through 9 address the seven Montréal Process criteria, focusing on indicators that can be described quantitatively and offer some capacity for examining past trends and future expectations.

In addition to the seven Montréal Process criteria, our analysis included one additional criterion—urban forests—which addresses a forest component that is relatively small in area but expanding. Urban trees and forests are of high impact because they affect the quality of life of urban dwellers that constitute the majority of the North's population.

REPORT ORGANIZATION

Chapter 2 provides detailed descriptions of the scenarios, assumptions, and forecasting methods used to project future forest conditions from 2010 to 2060. Chapters 3 through 9 describe current trends and anticipated future changes for selected indicators that are associated with each Montréal Process criterion. Chapter 10 gives additional focus to urban trees and forests. Finally, Chapter 11 summarizes the major drivers of northern forest change and offers some of the associated implications. The appendices provide additional quantitative details for individual Northern States.

The Northern Forest Futures Project Web site (http://www.nrs.fs.fed.us/futures/) and the Northern Forest Futures database (online and included with the printed version of this report) provide an opportunity for users to interactively explore data and results related to these analyses.

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Projection Methods

2

Michael E. Goerndt, W. Keith Moser, Patrick D. Miles, David N. Wear, Ryan D. DeSantis, Robert J. Huggett, Jr., Stephen R. Shifley, Francisco X. Aguilar, Kenneth E. Skog

Introduction

ONE PURPOSE OF the Northern Forest Futures Project is to predict change in future forest attributes across the 20 States in the U.S. North (see Fig. 1.1) for the period that extends from 2010 to 2060. The forest attributes of primary interest are the 54 indicators of forest sustainability identified in the Montréal Process Criteria and Indicators (Montréal Process Working Group, n.d.; USDA FS 2011). However, some indictors are virtually impossible to forecast for future decades, so we concentrated on the forest characteristics that have quantitative or experiential bases for forecasting future change. When possible, future forest attributes for individual States were projected and summarized, and then aggregated to estimate change for the North.

The projections of forest change are based on underlying assumptions about future land-use change, population change, climate change, and rates of disturbance (primarily from timber harvesting). We focused on three primary alternative scenarios that have different assumptions about population change, land-use change, economic activity, timber harvesting, forest products consumption, and energy use and its association with climate change.

To the extent possible, methods followed those proven successful for projections at the national scale such as those from the Resources Planning Act (RPA) assessment of future forest conditions (USDA FS 2012a, 2012c). RPA forecasts generally report results for four regions: North, South, Rocky Mountain, and Pacific Coast (Fig. 2.1). For some forest attributes, the RPA proved to be the best available source of science-based information for the North. For other attributes, however, we needed to increase the spatial or temporal detail of the RPA data or add information from new sources.

Summary of Projection Methods

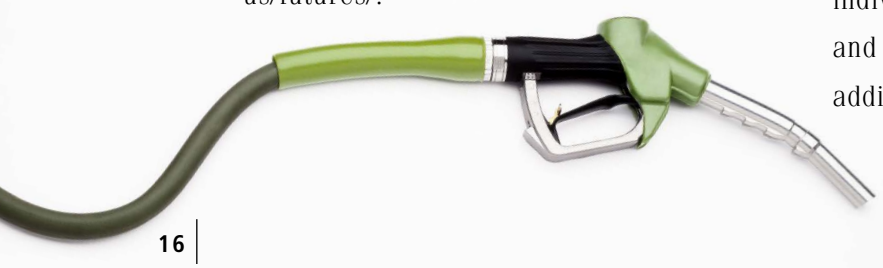
- We examined three storylines, or coordinated groups of assumptions that describe future population, economic activity, land use, bioenergy use, and associated greenhouse gas emissions.
- We coupled the storylines with general circulation models that predict and map future climate conditions.
- We combined storylines and general circulation models to examine 13 alternative future scenarios of forest change for the Northern States; the scenarios differ in assumptions about economic growth, population change, climate change, and disturbances (such as harvesting, conversion of forest to urban areas, or spread of emerald ash borers).
- For each of 13 scenarios, we used a statistical imputation model to forecast change over time from 2010 to 2060 for all survey plots within a given State, group of States, or section within a State; the model accounted for the effects of climate change, land-use change, harvesting, growth, and species succession.
- Results were saved in a database (Miles and Wear 2015) to summarize predicted survey plot conditions and to interpolate those results into predictions of forest conditions, by decade from 2010 to 2060, for States and for the region as a whole.
- The forest conditions that we projected directly for each scenario include forest area, volume, biomass, and forest type.
- For one scenario, we included algorithms to model the potential impacts of emerald ash borer (*Agrilus planipennis*), a nonnative, invasive insect that is spreading through northern forests, killing virtually all the ash trees (*Fraxinus* spp.) in areas of infestation.
- We created an interactive, Web-based tool that can be used to summarize and tabulate a range of projected forest conditions, by State and from 2010 to 2060, for a wide range of possible futures.
- We used the projected forest conditions as input to auxiliary models to estimate associated attributes such as wildlife habitat suitability and water quality; those techniques and their results are described in subsequent chapters.

FIGURE 2.1
Four regions and eight subregions of the United States.

Forecasts from 2010 to 2060 of forest attributes for the Northern States were based on the following four general procedures, which were also used to project future changes for numerous indicators of forest condition and sustainable management:

1. Statistical imputation was used to project changes over time for long-term survey plots established by the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service (Appendix 2) in a process that is similar to the procedures used for RPA projections (USDA FS 2012a, Wear et al. 2013) but that downscales data for individual States or groups of States. This process was used to develop 13 future scenarios that have different assumptions about future conditions—harvesting rates, land-use change, insect pests, and climate change—and to select seven scenarios for detailed analysis. The predicted future FIA plot conditions for all 13 scenarios are published in a Northern Forest Futures database (Miles and Wear 2015) that summarizes estimates of future values for many forest attributes by States or for the entire region (further described in this chapter). The database is on a DVD found in the back cover of this report and is also available from the Northern Forest Futures Web site at http://www.nrs.fs.fed.us/futures/.
2. Some forest attributes, such as wildlife habitat diversity or water quality, can be at least partially discerned from projected changes in forest area, tree species composition, and age class. Consequently, the second analysis used the predicted changes in forest trees and stands in statistical models that estimated future values for nontimber forest attributes. Often this required the use of additional maps or supplementary data sets.
3. Analyses of some forest attributes relied solely on external maps and data sets for estimates of future conditions. For example, future outdoor recreation activity was explicitly modeled from projected socioeconomic trends (Bowker and Askew 2013).
4. The data and insights needed for detailed forecasts were not available for some attributes of interest. In these cases, a procedure was used that draws inferences from current conditions and recent trends.

The remainder of this chapter describes in detail: assumptions about changes in population, economic activity, land use, climate, and utilization of woody biomass and bioenergy; how those assumptions were incorporated in imputation procedures used to forecast change in FIA inventories for individual States and the region as a whole; and availability of data and tools for access to additional summaries and analyses.



STORYLINES, SCENARIOS, AND CLIMATE MODELS

Population, economic conditions, new technologies, wood removals for products and energy, land use, greenhouse gas emissions, and climate change all influence future forest conditions. The Intergovernmental Panel on Climate Change (IPCC 2007) described four global "storylines" or combinations of plausible assumptions about future socioeconomic conditions that would affect greenhouse gas emissions, which would in turn affect climate. The IPCC refined global scenarios within each storyline and ultimately developed estimates of future greenhouse gas emissions for a range of alternative futures (Nakićenović et al. 2000).

Climatologists have applied multiple models (competing hypotheses) to estimate and map future change in temperature and precipitation for a given future trend in greenhouse gas emissions. These general circulation models vary considerably in the rate of climate change that they predict. For example, all circulation models indicate increasing average temperature with increasing greenhouse gas emissions, but they differ in how much and how rapidly temperature will rise at a given location. Some models tend to be consistently "hotter" or "cooler" than others. Combinations of a predicted future pattern of greenhouse gas emissions (based on IPCC storylines) with a specific general circulation model have been used to map future patterns of precipitation and temperature over time.

The number of possible combinations of future greenhouse gas emission storylines with alternative circulation models can quickly become overwhelming. Therefore, for the analyses used in this report, we focused primarily on results from two versions of the Canadian Global Circulation Model (Canadian Centre for Climate Modelling and Analysis 2012a, Canadian Centre for Climate Modelling and Analysis 2012b), which predicts neither the highest nor the lowest temperature levels, and has been widely applied across multiple greenhouse gas emission storylines.

Greenhouse gas emission scenarios and climate change based on three of the IPCC storylines (IPCC 2012, Nakićenović et al. 2000, Solomon et al. 2007) were selected. The storylines (Table 2.1) define combinations of assumptions about population growth, land-use change, gross domestic product growth, energy use, technological change, bioenergy use, and projected greenhouse gas emissions. The labeling system for these storylines uses a combination of letters and numbers and was maintained here to provide a reference to other analyses that use it, such as the RPA reports.

Table 2.1—Overview of the Intergovernmental Panel on Climate Change greenhouse-gas emissions storylines (Ince et al. 2011, Nakićenović et al. 2000, USDA FS 2012b).

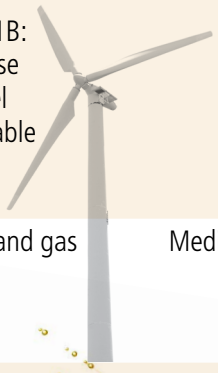
Storyline	Description	Characteristics		
		Land-use change	Population growth	Economic activity and growth in gross domestic product
A1, A1B	Globalization and economic growth; introduction of ne and more efficient energy technologies; emphasis o capacity building. Storylin variation A1B assumes m greenhouse gas emission a balanced use of fossil a renewable fuels.	High	Medium Global: 1.2x	Global: Very High (6.2x) Uni
A2	A more differentiated wo less trade compared to st A1B; uneven economic gr slower technological char			Glo United States: low (2.0x)
B2	Sustainable development and diversified technolog increased concern for environmental and social sustainability.			Global: medium (3.5x) United States: low (2.2x)

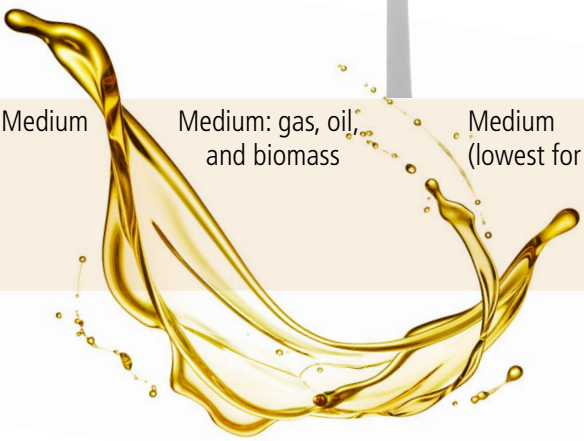
The key point for readers is that the labels identify relatively high (A2), medium (A1B), and low (B2) future emissions of greenhouse gases:

Storyline A1—A future in which the rest of the world approaches the United States in terms of per capita wealth, technology use, and population growth. Storyline A1 is characterized by rapid economic growth, increasing global trade, and population peaking in mid-century and then declining. A variation of storyline A1, storyline A1B, predicts moderate greenhouse gas emissions, a balanced use of fossil and renewable fuels, with an early dependence on fossil fuel followed by a relatively rapid increase in renewable energy sources.

Table 2.1 continued

Storyline	Characteristics				
	Global energy use	Oil and gas availability	Energy technological pace and sources	Global expansion of primary biomass energy production	Relative increase in greenhouse gasses
A1, A1B	Very high	High	Rapid: gas, biomass, and other renewables Storyline A1B: Balanced use of fossil fuel and renewable energy	High (highest for the United States)	Medium
A2	High	Low	Slow: coal and gas	Medium	High
B2	Medium	Medium	Medium: gas, oil, and biomass	Medium (lowest for United States)	Low





Storyline A2—A future in which the focus is regional, in contrast to the global approach of storyline A1. Storyline A2 assumes relatively high greenhouse gas emissions, continuously increasing global population, and more regionally centered economic growth. Among the storylines, it has the highest total global population growth but the lowest long-term economic growth.

Storyline B2—A future of global sustainable development, with some regional economic convergence. The B2 storyline assumes relatively low greenhouse gas emissions. It is similar to A2 in that regional and local institutions and economies are emphasized over global integration. Economic growth is intermediate, but population growth is significantly lower than for storylines A1 and A2. Thus, per capita income is closer to A2 than to A1. Storyline B2 also has the lowest projected growth in biomass energy for the United States and its neighbors.

After evaluating 13 different scenarios that combined general circulation models and storylines (with and without the effects of bioenergy and invasive species), seven were selected for further analysis (Table 2.2); projections of forest conditions for the remaining alternate six scenarios can be summarized using the Northern Forest Futures database (Miles and Wear 2015). Each of the selected scenarios has three components:

- A general storyline and associated assumptions as described above; for consistency with prior Forest Service research products, variations of the assumptions adapted for the 2010 RPA Assessment were used (USDA FS 2012a, 2012b, 2012c; Wear et al. 2013).
- A general circulation model that estimates by geographic area the temperature and precipitation change associated with the different levels of greenhouse gas emissions projected under alternative storylines (Meehl et al. 2007, USDA FS 2012b); part of the RPA analyses was to downscale the global climate change estimates from the IPCC (Figs. 2.2, 2.3) to a finer grid so that current and projected conditions could be associated with individual FIA plots (USDA FS 2013).
- A set of future harvesting assumptions, with one including forecasts of insect-induced mortality.

Table 2.2 summarizes the combinations for each scenario selected for the Northern Forest Futures Project. The scenarios differ from the IPCC/RPA efforts in two ways: assumptions about future harvesting and the scenario naming convention used. Scenarios labeled A1B-C, A2-C, and B2-C include the effects of climate change on forest growth and composition and include projected land-use change, but rather than using harvesting projections that reflect increases in wood used for energy, they project future harvesting based on the recent past probability of harvesting—thus they represent a continuation of recent harvesting rates.

Scenarios labeled A1B-BIO, A2-BIO and B2-BIO include the same respective climate and land-use change effects, but incorporate the projections of increasing future harvesting (with more wood biomass used for energy) that Wear et al. (2013) applied in RPA projections of northern forest conditions. Projected harvesting levels for scenarios A1B-BIO, A2-BIO, and B2-BIO are similar to the IPCC market-based projections of future biomass utilization for energy (projections of forest markets including production, consumption, trade, and prices of timber and wood products by storyline). Those projections (Ince et al. 2011) include very large increases in wood energy use under storyline A1B. For our scenario A1B-BIO, the market-based harvesting levels would eventually have exceeded any realistic harvesting expectations for the Northern States. Consequently, the post-2030 rate of harvesting was set below the projections of Ince et al. (2011).

Table 2.2—Scenarios used to project future forest conditions in the North; scenarios combine a greenhouse gas storyline (IPCC 2007) and a general circulation model with additional assumptions about future harvest levels.

General circulation model[a]	Storyline[b] A1B[c]	A2	B2
CGCM3.1[d]	Scenario A1B-C Scenario A1B-BIO (Primary scenarios)	Scenario A2-C Scenario A2-BIO Scenario A2-EAB (Primary scenarios)	No scenario developed
MIROC3.2	Alternate scenario[e]	Alternate scenario[e]	No scenario developed
CSIRO-Mk3.5	Alternate scenario[e]	Alternate scenario[e]	No scenario developed
CGCM2[d]	No scenario developed	No scenario developed	Scenario B2-C Scenario B2-BIO (Primary scenarios)
CSIRO-Mk2	No scenario developed	No scenario developed	Alternate scenario[e]
UKMO-HadCM3	No scenario developed	No scenario developed	Alternate scenario[e]

[a]*The models that were developed into scenarios were chosen because their climate sensitivities were above or near the mean of all general circulation models assessed (Randall et al. 2007). The choice of models was also governed by the desire to maintain compatibility among projections for the Northern Forest Futures Project and those for the national Resources Planning Act assessment (USDA FS 2012b). Sources of models: CGCM3.1 = Canadian Centre for Climate Modeling and Analysis Coupled Global Climate Model, medium resolution (T47) (http://www.ec.gc.ca/ccmac-cccma); MIROC3.2 = Center for Climate System Research, University of Tokyo, National Institute for Environmental Studies and Frontier Research Center for Global Change (Japan), model for Interdisciplinary Research on Climate Version 3.2, medium resolution (http://www.ccsr.u-tokyo.ac.jp/kyosei/hasumi/MIROC/tech-repo.pdf); CSIRO-Mk3.5 = Commonwealth Scientific and Industrial Research Organization (Australia), CSIRO Mk3 Climate System Model (http://www.cawcr.gov.au/publications/technicalreports/CTR_021.pdf); CGCM2 = Coupled Global Climate Model, medium resolution (T47), Canadian Centre for Climate Modelling and Analysis (http://www.ec.gc.ca/ccmac-cccma); CSIRO-Mk2 = Australia's Commonwealth Scientific and Industrial Research Organization Australia (http://www.cmar.csiro.au/e-print/open/hennessy_1998a.html#ccm); UKMO-HadCM3 = Hadley Centre for Climate Prediction and Research UK (http://wwwpcmdi.llnl.gov/ipcc/model_documentation/HadCM3.pdf).*

[b]*Variations of the A1B-C, A2-C, and B2-C scenarios predict the impact of increased harvest and utilization of woody biomass for energy. They are referred to as scenarios A1B-BIO, A2-BIO, and B2-BIO. A variation of scenario A2-C, A2-EAB, examines the potential impact of continued spread of the emerald ash borer with associated mortality of all ash trees in the affected areas.*

[c]*A variation of the A1 storyline. Other variations predict different energy portfolios.*

[d]*Note that CGCM3.1 is actually the third generation of the same model group as CGCM2. The primary difference for CGCM3.1 is updated data and predictors.*

[e]*Additional projections of forest conditions from 2010 to 2060 were made by pairing IPCC storylines A1B, A2, and B2 with different general circulation models. Those alternate scenarios are not discussed in this report, but the projected plot conditions by decade for those combinations are available in Miles and Wear (2015).*

Potential impacts of the invasive emerald ash borer (EAB) (*Agrilus planipennis*) were modeled in a variation of scenario A2-C and relabeled A2-EAB. Details for that scenario are provided later in this chapter, in Chapter 5, and in Appendix 2.

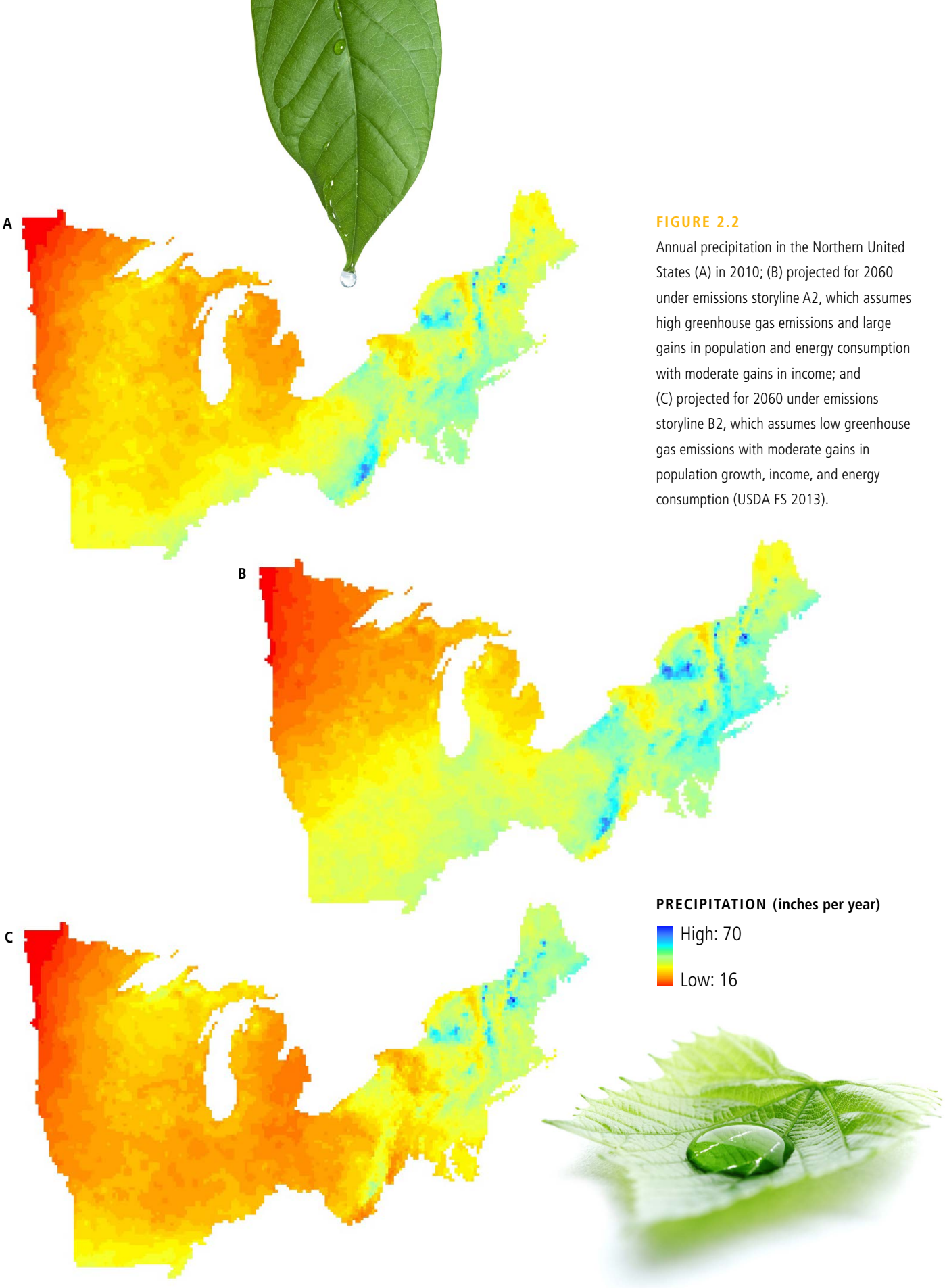


FIGURE 2.2

Annual precipitation in the Northern United States (A) in 2010; (B) projected for 2060 under emissions storyline A2, which assumes high greenhouse gas emissions and large gains in population and energy consumption with moderate gains in income; and (C) projected for 2060 under emissions storyline B2, which assumes low greenhouse gas emissions with moderate gains in population growth, income, and energy consumption (USDA FS 2013).

A

B

C

TEMPERATURE (degrees fahrenheit)

High: 104

Low: 63

FIGURE 2.3

Maximum June temperature in the Northern United States (A) for 2010; (B) projected for 2060 under emissions storyline A2, which assumes high greenhouse gas emissions and large gains in population growth and energy consumption with moderate gains in income; and (C) projected for 2060 under emissions storyline B2, which assumes low greenhouse gas emissions with moderate gains in population growth, income, and energy consumption (USDA FS 2013).

ASSUMPTIONS FOR PRIMARY SCENARIOS

Population Projections

We used U.S. population projections from 2000 to 2060 that were developed for the RPA analyses (USDA FS 2012b), which in turn followed IPCC trends that were originally based on 1990 census data. The RPA values were subsequently updated to incorporate the 2004 census estimates, projected forward to 2060, and then allocated spatially among the States and their individual counties (Zarnoch et al. 2010). The RPA projected a nationwide population increase from the 2010 census (309 million) to 2060: 397 million (29 percent) under scenario B2-C, 447 million (45 percent) under scenario A1B-C, and 505 million (64 percent) under scenario A2-C (USDA FS 2012b, Zarnoch et al. 2010).

Population in the Northern States (125 million in 2010) is expected to follow the same trends (Fig. 2.4), with lower rates of increase: 140 million (12 percent) under storyline B2; 158 million (25 percent) under storyline A1B; and 178 million (39 percent) under storyline A2 (Zarnoch et al. 2010). The projected change varies spatially (Fig. 2.5), with the largest increase in population density in areas that are nearest to urban centers (Cordell et al. 2012, Zarnoch et al. 2010).

Under storyline A1B, the Northern States account for 41 percent of the total U.S. population in 2010, but that proportion is projected to drop to 35 percent of the total by 2060.

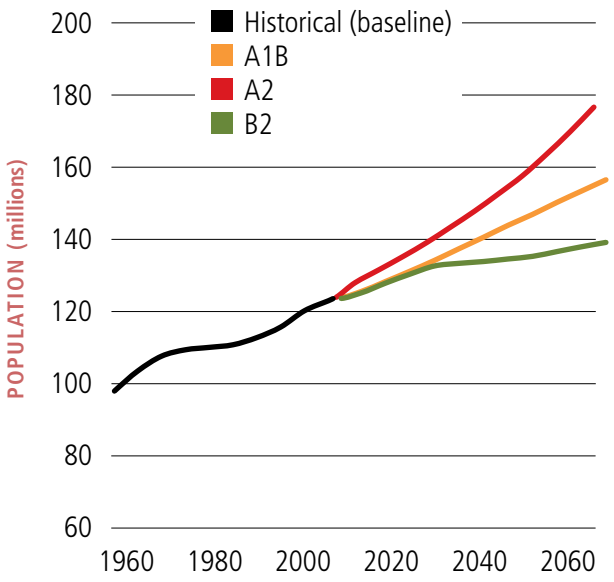


FIGURE 2.4

Historical and projected population growth in the Northern United States under three greenhouse gas storylines (U.S. Census Bureau 2004, USDA FS 2012b): A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

Under storyline A1B, the rate of population increase from 2010 to 2060 would be larger than the U.S. average (45 percent) for New Hampshire (64 percent), Maryland (55 percent), Vermont (49 percent), and Minnesota (49 percent). States with the lowest rate of growth would be New York (13 percent), West Virginia (12 percent), and Ohio (12 percent). Population in Washington, D.C., is projected to decrease by 12 percent (Appendix 2).

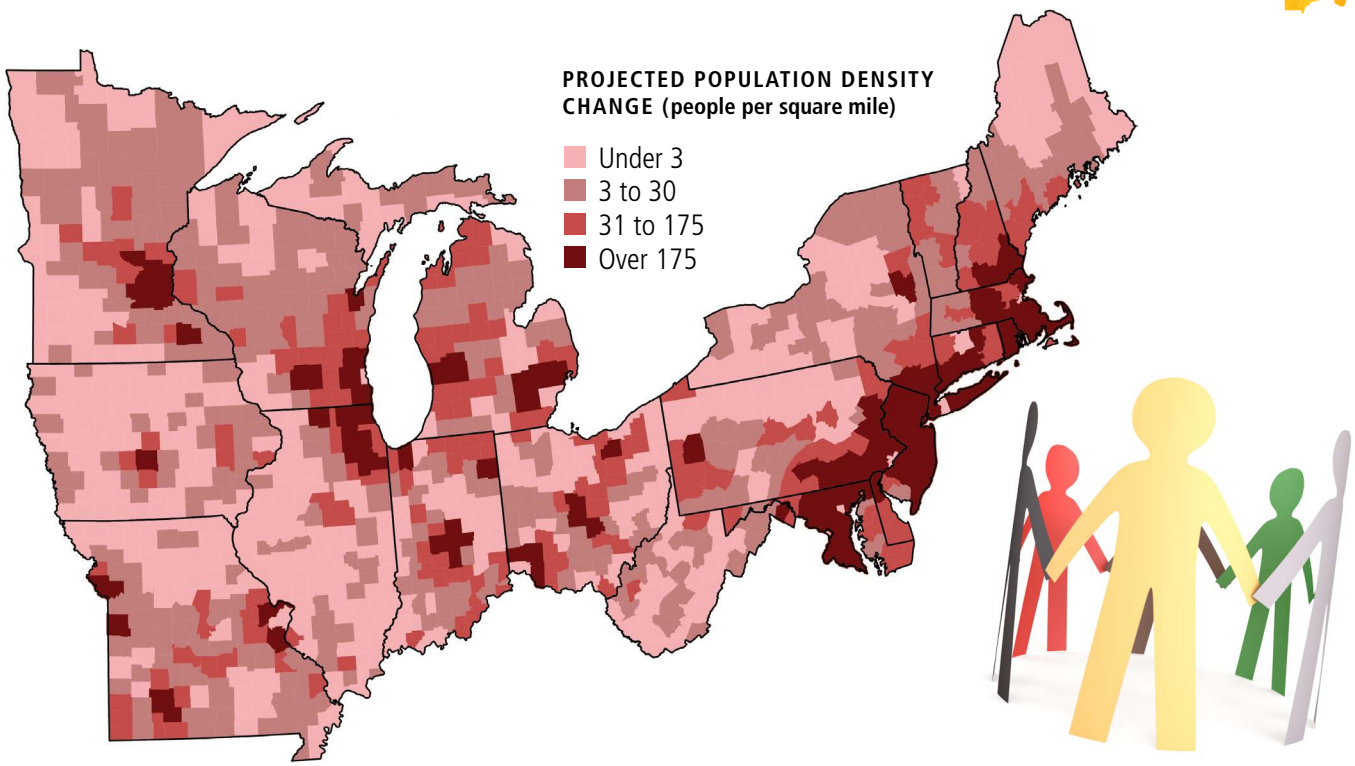


FIGURE 2.5

Pattern of projected increases in population density from 2010 to 2060 under storyline A1B which assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio) (Cordell et al. 2012).

Counties with the highest growth, which are expected to add >175 persons per square mile, would be concentrated mainly in the Washington-to-Boston urban corridor and in other suburban areas throughout the region. Second-tier growth counties would either be found adjacent to counties with the fastest growth rates, or in lower Michigan, Wisconsin, and southern Missouri.

Economic Projections

Projections of U.S. gross domestic product were developed for the RPA analyses (USDA FS 2012b) and used to estimate future forest product demand and production by region (Ince et al. 2011).

Projections of total personal income and disposable personal income from 2010 to 2060 were also developed by region as part of the RPA analyses and then disaggregated to State and county levels (Zarnoch et al. 2010) for subsequent use as predictor variables for modeled trends in land use, water use, and recreation use.

At the time that the economic projections were constructed, the 2006 economic data were the most recent available. Thus, the projections do not explicitly capture the U.S. economic downturn that began at the end of 2007, address annual variations in economic indicators, or anticipate periods of economic recession. Instead, their focus is on long-term averages. Figure 2.6 shows projections to 2060 for gross domestic product, personal income, and disposable personal income for storylines A1B, A2, and B2 (Ince et al. 2011, Zarnoch et al. 2010).

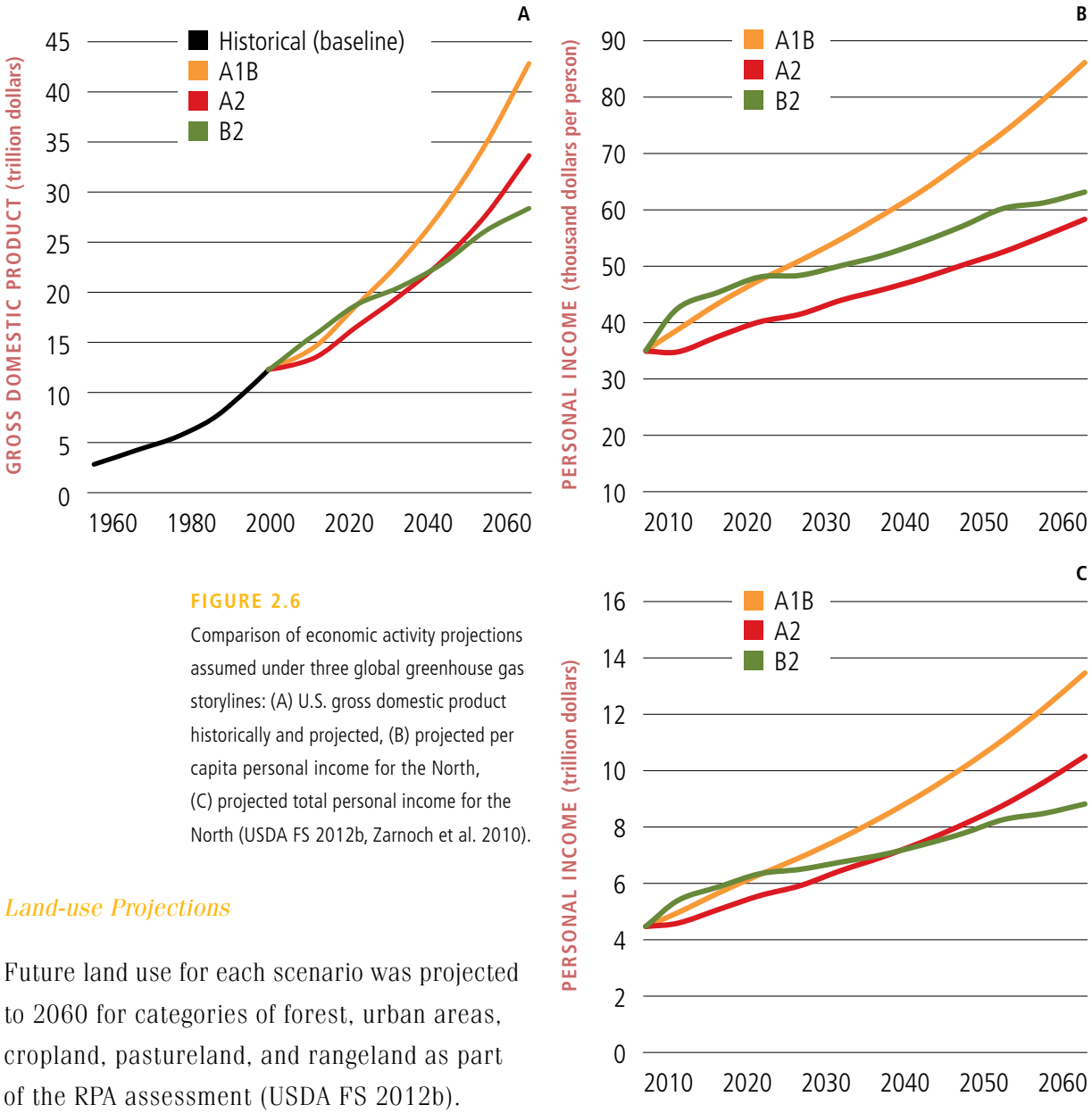


FIGURE 2.6

Comparison of economic activity projections assumed under three global greenhouse gas storylines: (A) U.S. gross domestic product historically and projected, (B) projected per capita personal income for the North, (C) projected total personal income for the North (USDA FS 2012b, Zarnoch et al. 2010).

Land-use Projections

Future land use for each scenario was projected to 2060 for categories of forest, urban areas, cropland, pastureland, and rangeland as part of the RPA assessment (USDA FS 2012b). Projected areas for land-use categories were used as predictor variables in several auxiliary resource analysis models. Land-use change was assumed to be a function of the population and economic forecasts for each scenario, but not to be directly affected by climate change (for instance, it ignores potential conversion of marginal cropland to other uses in a warmer or drier climate). Wear (2011) describes in detail the methodology used to project and map land-use change at the county scale.

Projected losses of non-Federal forest acreage in the Northern States from 2010 to 2060 range from 6 to 11 million acres, depending on the scenario considered (Fig. 2.7). The focus is on non-Federal land because it is assumed that Federal land (for example, national forests and national parks) will remain forested and in Federal ownership. Losses in the North would likely be about half the losses predicted for the South, but more than twice what is predicted for regions farther west. In all scenarios and for all regions of the United States, urban area is projected to increase and all other land uses are projected to decrease.

Under all scenarios, urban areas in the North would increase at the expense of forest, cropland, and pastureland land (Wear 2011). The rate of change would be highest for scenario A1B followed by A2 and then B2, but the pattern of change is similar among all three (Fig. 2.8).

When forest is converted to other land uses, any biomass, wood volume, or carbon associated with those acres is considered to be lost from the forest. Thus, projected changes in attributes such as total forest biomass, volume, or carbon have two components: (1) change attributed to growth and/or disturbance on land that remains forested, and (2) decreases attributed to conversion of forest to nonforest uses. Projected changes in land-use area by scenario are reported in Appendix 2, as is projected forest area by State and scenario.

Forest acreage decreases under every storyline for every Northern State. The States with the highest percentage decreases are those with high population density along the Atlantic seaboard such as Delaware, Maryland, Rhode Island, and New Jersey. For almost all States, A1B predicts the largest decrease in forest acreage over the 50-year period (almost twice that of B2).

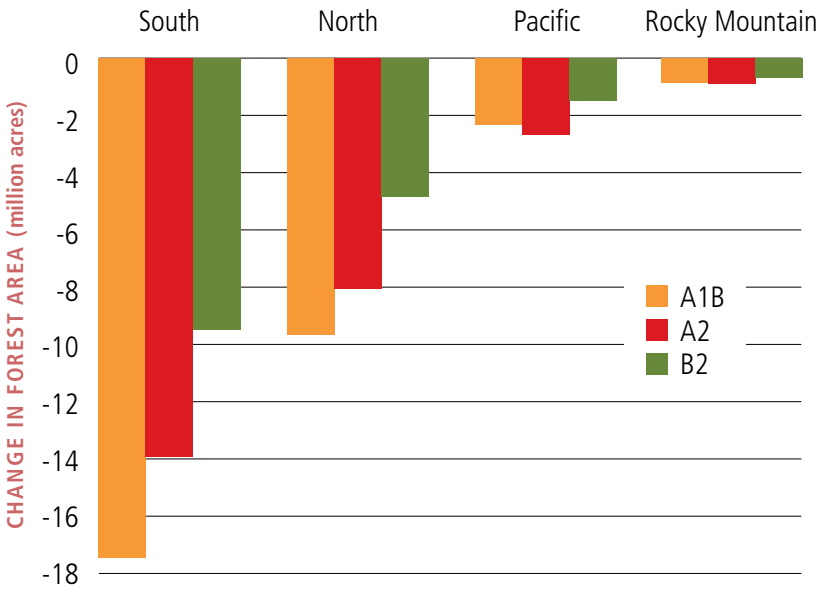


FIGURE 2.7

Projected loss of non-Federal forest area, 2010 to 2060, for the regions of the conterminous United States under three global greenhouse storylines (USDA FS 2012b, Wear 2011). Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

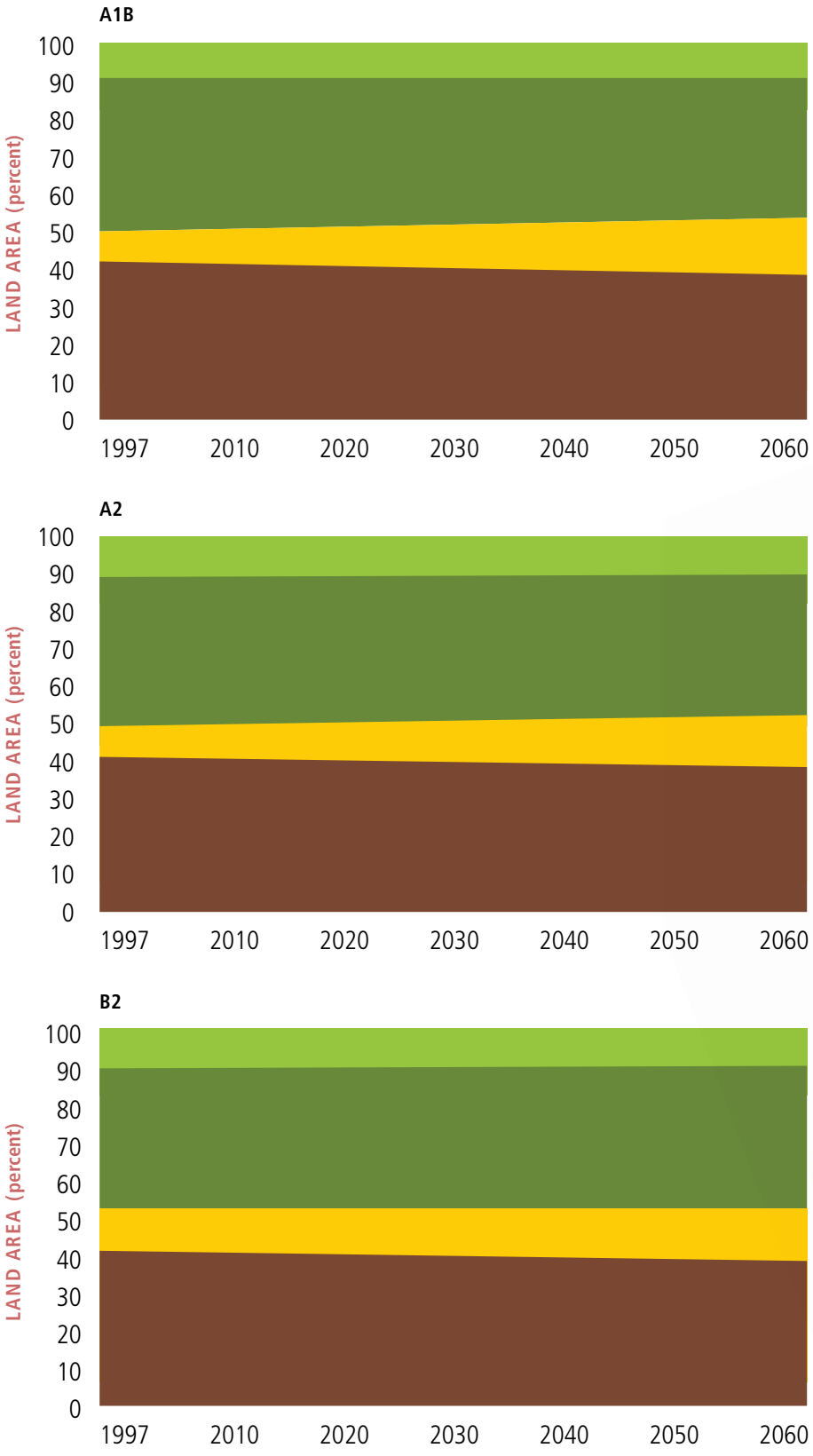


FIGURE 2.8

Percent of area in primary land uses (forest, urban areas, cropland, and pastureland) for the North, 1997 to 2010 with projections to 2060, under three global greenhouse storylines: A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

Removals

Projected removals for scenarios A1B-C, A2-C, and B2-C were based on a continuation of observed harvesting patterns from the recent past (generally the 10-year period that started in the mid-1990s) as observed in the FIA State data sets that were used to calibrate the Forest Dynamics Model. As described by Wear et al. (2013):

> [A] two-step empirical harvest probability model was estimated for each forest type in each of the Northern States. In the first step, harvest probability was modeled as a function of a set of biophysical attributes in the inventory, including sawtimber volumes observed at the beginning and predicted for the end of the period, stand age, slope, ownership class, average stand diameter, and an index that gauges the diversity of the tree species on the plot. In the second step, harvests were defined as full or partial, based on the frequency of the harvest types observed for the paired inventories for each State [by] forest type permutation.

For each State, the harvesting probability model was applied to each FIA plot at each projected time interval to calculate the probability and type of harvesting for that plot. Modeled harvesting probabilities were compared to a random draw from a uniform probability distribution (think of the computer rolling the harvesting dice). Based on the outcome, a given plot was either selected for harvesting in that interval or it was not selected.

For each plot that was "harvested," additional stochastic algorithms determined the type of harvesting and selected a suitable replacement plot representing post-harvesting conditions.

A simple scaling function permitted the plot harvesting probabilities to be increased or decreased, so that the predicted cumulative harvest volume could be increased or decreased to adjust the State total harvest volume without changing the relative priority of harvesting among the individual plots. That scaling function was used to ensure that the predicted harvest volumes matched the observed harvest volumes for the recent past, and it was used to model alternative future harvesting scenarios. The following section describes how the scaling function was used to model scenarios A1B-BIO, A2-BIO, and B2-BIO, with increased harvesting associated with increased utilization of biomass for energy.

VARIATIONS ON PRIMARY SCENARIOS

Woody Biomass and Bioenergy Projections

Projected removals for scenarios A1B-BIO, A2-BIO, and B2-BIO (Table 2.2) were based on projected harvesting (including increasing biomass use for energy) in the IPCC storylines (Nakićenović et al. 2000). Our modeled removals from 2010 through 2060 for scenarios A2-BIO and B2-BIO were very close to the market-based projections made using the U.S. Forest Products Module in combination with the Global Forest Products Model (Ince et al. 2011, USDA FS 2012b).

Scenario A1B-BIO results are similar to the market-based harvesting projections for 2010 to 2030 but are lower than the market-based projections for the remainder of the forecasting period. The scope of the market-based harvesting projections is large-scale (multi-national), with the U.S. results reported as part of the Organization for Economic Cooperation and Development (OECD) macro-region along with Japan, Canada, Australia, New Zealand, and Western Europe (Ince et al. 2011). The projections from 2010 to 2060 identify three major sources of biomass: cropland crops and residues, dedicated biomass energy plantations, and roundwood fuelwood from forests (Fig. 2.9).

Under scenarios A1B-C and A2-C, the wood component (from forests and plantations) of bioenergy is expected to be largest from 2030 to 2060 (Fig. 2.9). Because projections are based on broad-scale assumptions for the United States and several other countries combined, we were unable to delineate this information specifically for the Northern States. Consumption of roundwood from forests is projected to increase rapidly from 2030 to 2050 and then begin to stabilize as energy plantations mature. Agricultural crops and energy plantations dominate biomass energy consumption under scenario B2-C. For all scenarios, biomass from agricultural crops and residue is expected to vary less over time than biomass from roundwood or energy plantations. In contrast to other areas of the macro-region, however, the U.S. North is not expected to dramatically increase energy plantations because the value of biomass will likely be lower than other wood uses.

The U.S. Forest Products Module (Ince et al. 2011) was used to project harvesting levels in response to roundwood demand for traditional products and increasing wood energy demand for the entire United States and for the northern, southern, and western regions under scenarios A1B-C, A2-C, and B2-C. We synchronized the projected wood removal levels for scenarios A2-BIO, B2-BIO, and A1B-BIO (through 2030) with the harvesting levels from the U.S. Forest Products Module projections (Ince et al. 2011) by adjusting the scaling function in the harvesting probability model within the Forest Dynamics Model (Wear et al. 2013). A comparison with the corresponding market-based removals estimates by Ince et al. (2011) showed that scenario A1B-BIO was 21 percent lower, scenario A2-BIO was 7 percent lower, and scenario B2-BIO was virtually the same (Ince et al. 2011, Wear et al. 2013).

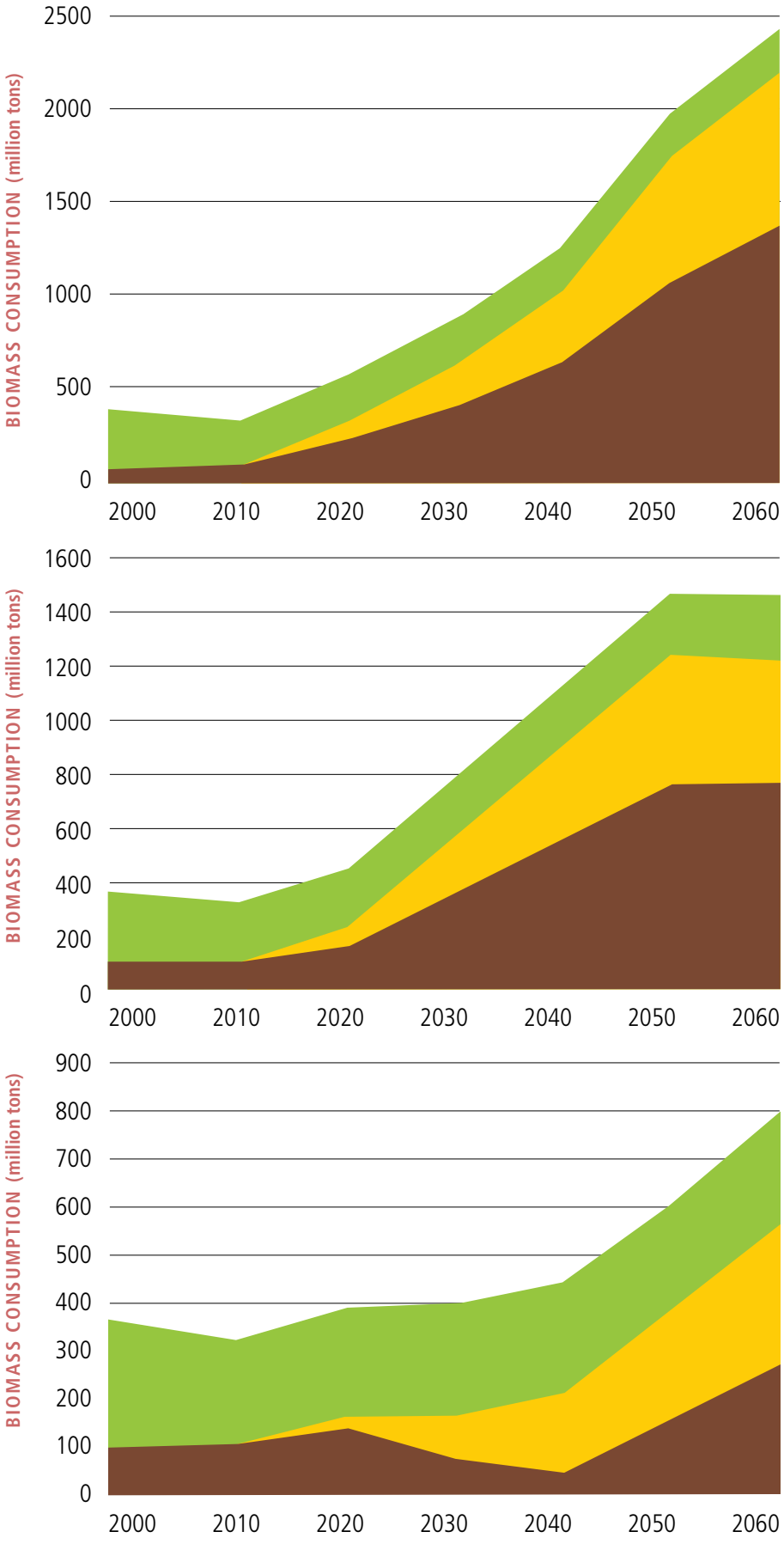


FIGURE 2.9

Projected annual biomass consumption for energy for the macro-region composed of the United States, Japan, Canada, Australia, New Zealand, and Western Europe under three global greenhouse storylines (Ince et al. 2011): A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

Figure 2.10 illustrates the modeled removals over time for all seven scenarios discussed in the remainder of this chapter. Scenarios that are coded with the same initial characters (for example, A2-C, A2-BIO, and A2-EAB) share the same assumptions about future population increase, land-use change, economic change, and greenhouse gas emissions, but they differ in removals assumptions. Scenarios A1B-C, A2-C, and B2-C assume future removals will follow the trends observed in the recent past—roughly 3.5 billion cubic feet annually for the Northern States. Scenarios A1B-BIO, A2-BIO, and B2-BIO assume increased harvesting removals over time to satisfy increased bioenergy demands.

Scenario A2-EAB is similar to scenario A2-C and assumes that future removals will follow the trends observed in the recent past. However, in scenario A2-EAB all live ash trees within the expanding projected range of the emerald ash borer are converted to dead trees to simulate the potential impact of that invasive insect. Additional information about scenario A2-EAB is presented later in this chapter and in Chapter 5.

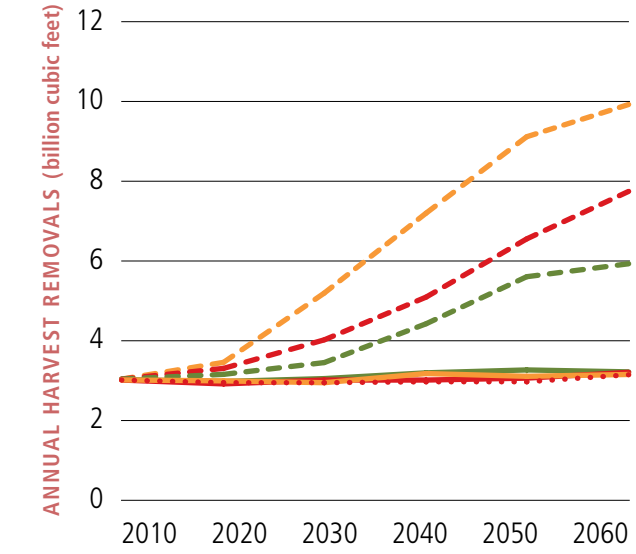


FIGURE 2.10

Projected harvest removals by scenario for North, 2010 to 2060, for seven scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

Modeling Emerald Ash Borer Effects

The nonnative, invasive emerald ash borer continues to spread relatively unimpeded across North America, causing considerable damage to the North American ash (*Fraxinus* spp.) resource. Further ash decline appears likely considering that mortality in infested black (*Fraxinus nigra*), green (*Fraxinus pennsylvanica*), and white ashes (*Fraxinus americana*) is ≥99 percent for trees >1 inch diameter at breast height (d.b.h.) (Herms et al. 2010). To examine the extremes in its anticipated effects on tree species composition in northern forests, we created a variation of scenario A2-C that modeled patterns of ash mortality from 2010 to 2060. This scenario is labeled A2-EAB, and it assumes that the emerald ash borer expands from currently infested areas at a rate of 12 miles per year (Prasad et al. 2010), that it kills all infested ash trees, and that it prevents successful ash regeneration in affected areas. We used data from the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine program (USDA APHIS, n.d.) and the Canadian Food Inspection Agency (2011) to identify the core infested areas of United States counties and Canadian municipalities where emerald ash borer was detected at the end of December 2010. We simulated complete ash mortality within each FIA plot after the plot was completely engulfed by the projected area of spread.

Projections commenced in simulation year 2015, calculated using the 2010 range data. The spread of emerald ash borer was modeled spatially and used to simulate locations of affected FIA plots in future decades. More information on the modeling methods can be found in DeSantis et al. (2013). Additional details on the projected spread and impact of emerald ash borer in the Northern States can be found in Chapters 4 and 5 and in Appendix 2.

MODELING FOREST CHANGE

Model Design

Changes in tree and stand conditions for each scenario were projected using the Forest Dynamics Model developed by Wear et al. (2013). Their model is a set of interlinked submodels that uses FIA forest plot results to produce predictions of future inventories, given assumptions about growth, succession, climate, timber market conditions, and land-use changes. The principal advantage of this modeling framework is that it can be calibrated and applied using the existing FIA forest sampling design. Climate, market, and land-use assumptions link the forest forecasts to alternative scenarios (Wear et al. 2013). Modeling for northern forests was carried out for broad scale analysis units, generally whole States, but sometimes multiple small States or sections within large States: Minnesota, Michigan, Wisconsin, Missouri, Iowa, New York, Maine, Connecticut, New Jersey plus Delaware, Massachusetts plus Rhode Island, Vermont plus New Hampshire, West Virginia plus western

Maryland, eastern Maryland, Illinois and Indiana plus western Ohio, eastern Ohio, western Pennsylvania, and eastern Pennsylvania. Additional information about the Forest Dynamics Model can be found in Appendix 2.

The FIA database provides the source data for the Forest Dynamics Model. FIA inventories for each analysis unit were summarized by plot (technically by the FIA condition variable). Only plots classified as forest were included, and FIA data for the base year of 2010 were used as the starting point for model projections. For each plot for each inventory:

- The major forest-type group was assigned based on observed forest cover type.
- Variables for physical characteristics (such as slope and aspect) were retained.
- Biophysical attributes (such as basal area, growing-stock volume, and number of trees) were calculated for each 5-year model time step.
- Transition, partitioning, and imputation submodels were used to predict changes in forest plot conditions through time.

Transition submodel—Based on linked plot observations from the two most recent FIA inventories for Northern States, the transition submodel calibrates a regression equation that predicts changes in plot age over time and a probability transition matrix that predicts whether the species composition will change over time. The average remeasurement period between the two linked inventories (generally 5 years for this analysis) defines the time step for the simulation algorithm. Plots were examined for evidence of harvesting activity over the observed remeasurement interval and were classified as unharvested, partially harvested, or clearcut. Harvesting probability models were calibrated and separate forest-type transition matrices were estimated for harvested plots to model probabilities of post-harvesting changes in species composition.

Partitioning submodel—The partitioning submodel groups plots with similar attributes based on a set of biological, physical, stand age, and climate characteristics. Partitions of similar plots are constructed using regression tree analysis applied to FIA data. Growing stock per acre (softwood and hardwood) was selected as the appropriate biophysical attribute for measuring similarity within each group. The plot characteristics that defined the groups included stand age, slope, aspect, ownership category, and a set of climate variables that reflect average temperature, precipitation, and aridity over the life of the plot.

Imputation submodel—After (1) the transition submodel projects changes in forest age and harvesting/regeneration, and (2) the climate models project changes in key climate variables by geographic area, the imputation submodel finds (or imputes) the subset of observed FIA inventory plots that best matches the conditions

that are projected for each plot location—the "bucket" of suitable plots (termed donor plots) that the partitioning submodel grouped by matching age class, predominant species grouping, hardwood/softwood mix, and climate conditions. Then a random donor plot (with replacement) is drawn from the appropriate group (bucket). For example, if the transition probabilities state that a 50-year-old oak-hickory (*Quercus* spp. – *Carya* spp.) plot will become a 55-year-old oak-hickory plot—instead of a elm-ash-cottonwood (*Ulmus* spp. – *Fraxinus* spp. – *Populus* spp.) plot, for instance—then the imputation model would describe what it would look like in 5 years by randomly selecting an oak-hickory plot from the group of existing 55-year-old plots whose ecological characteristics and climate conditions are similar to those anticipated for the future year. The selected plot would then be substituted for the 50-year-old plot during the next 5-year time step.

The completed simulation projects the results for future decades by summarizing the conditions of the rearranged FIA plots in the same way that one would summarize current or past forest conditions using FIA plots inventoried in the field (Miles 2012). These forecasts are further refined by adjusting the per-acre expansion factors to reflect the projected land-use changes that are generated by an external land-use model (for instance, a smaller plot area expansion factor would be applied to model the loss of forest acreage).

Removals of wood products are estimated from the Forest Dynamics Model (described earlier), summarized by hardwood and softwood major species groups, and "imputed" by replacing some FIA plots with representative harvested (and subsequently regenerated) plots from the appropriate "bucket" of harvested FIA plots. Additional forest dynamics information, estimation of harvesting removals, and calculation of change variables can be found in Appendix 2.

Although complex, the imputation model provides results that can be stored, distributed, and summarized for many different attributes using the desktop database interface described in the next section.

Predictions of Forest Conditions

Output from the Forest Dynamics Model was combined with data from the FIA database (Woudenberg et al. 2010) to produce the Northern Forest Futures database (Miles and Wear 2015, Miles et al. 2015), which in turn was the basis for reporting current forest conditions as well as a range of possible futures through the year 2060 for the 20 Northern States.

Future projections were made for 13 scenarios that reflect varying climatic and socioeconomic assumptions, including the A1B-C, A2-C, B2-C, A1B-BIO, A2-BIO, B2-BIO, and A2-EAB scenarios that are the focus of this report.

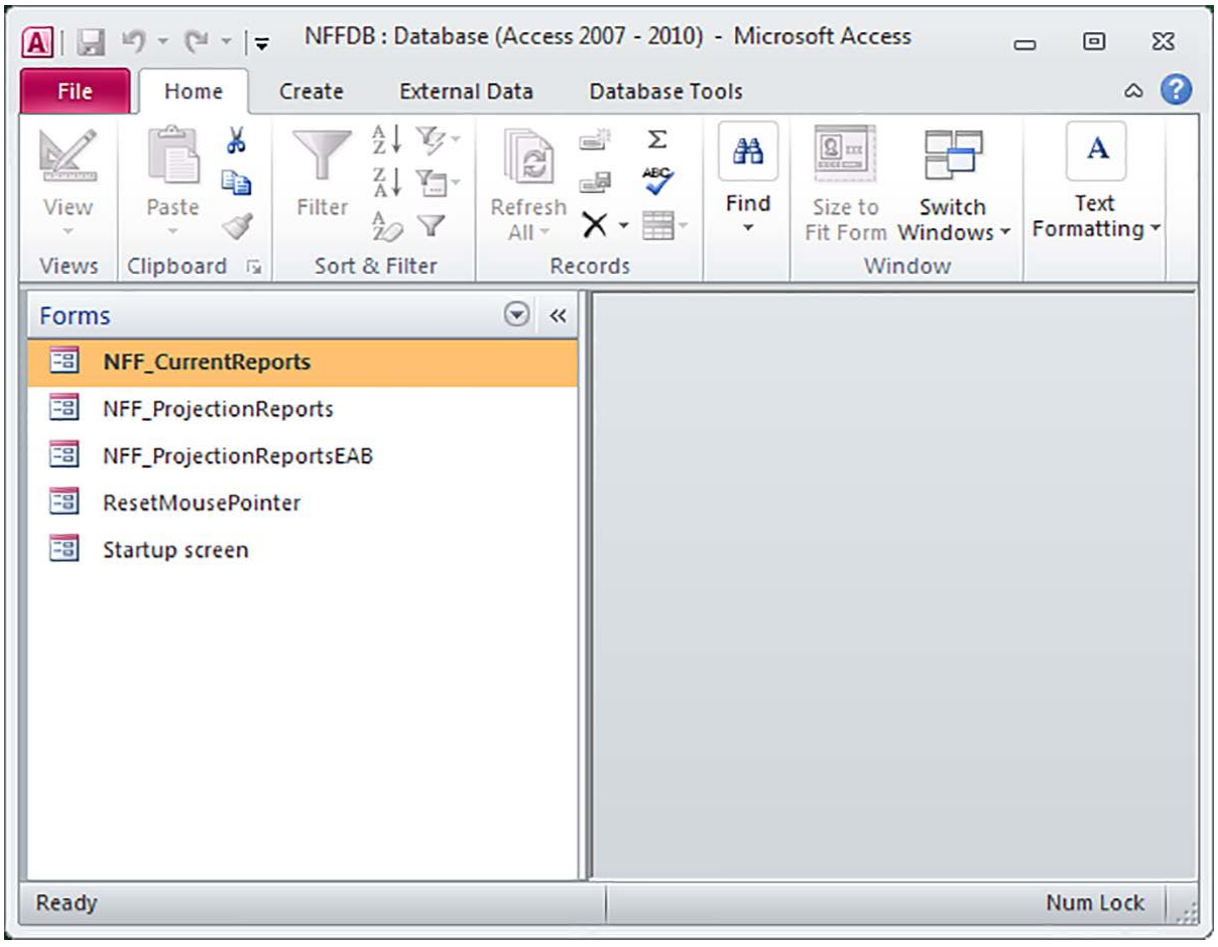
Programs were developed to enable customized futures reporting using the Northern Forest Futures database (Miles and Wear 2015). The underlying plot data for each scenario and the programs used to access and summarize scenario results are available on the DVD (included in the back cover of this report or on the Northern Forest Futures Web site at http://www.nrs.fs.fed.us/futures/), enabling users to conduct additional data summaries and analyses for any scenario.

FIGURE 2.11

Screenshot of the three reporting forms available in the Northern Forest Futures database (Miles and Wear 2015).

Reporting Using the Northern Futures Database

To simplify reporting (Fig. 2.11), three programs were developed in Microsoft® Access: the NFF_CurrentReports form to generate baseline estimates (up to 2008), the NFF_ProjectionReports form to generate projections of forest conditions under the 12 scenarios without emerald ash borer, and the NFF_ProjectionReportsEABscenario form to generate projections of forest conditions under a scenario (A2-EAB, a version of scenario A2-C) that models the emerald ash borer threat (as described earlier in this chapter). Additional documentation and example retrievals are provided on the enclosed DVD (Miles and Wear 2015, Miles et al. 2015).



The NFF_ProjectionReports form offers four types of projection retrieval: (1) single scenario for a single year, (2) single scenario for multiple years, (3) multiple scenarios for a single year, and (4) multiple scenarios for multiple years. Each type of retrieval represents a tradeoff between summarization detail and level of confidence (Fig. 2.12).

The single scenario/single year retrieval, though capable of providing state-level estimates, is best used for broad scale retrievals (multiple States). If used for a single State, the data would likely be stretched very thin, depending on the forest attributes of interest. For example, only 12 plots were used to generate the 2060 projection of 48,821 acres of overstocked white-red-jack pine (*Pinus strobus–P. resinosa–P. banksiana*) forests in New Hampshire (Table 2.3). This kind of retrieval is best used to study a very specific resource over a large geographic area at a single point in time. Note that when <50 plots are used to generate a projection in a northern futures database summary table, that projection is printed in red to indicate a potentially large sampling error.

The Northern Forest Futures database (Miles and Wear 2015) was created to assist with the creation of the assessment and reporting tools for the Northern Forest Futures Project. All were developed in an effort to promote transparency and to provide access for further review and analysis, thereby providing a framework for evaluating potential forest futures given various scenarios.

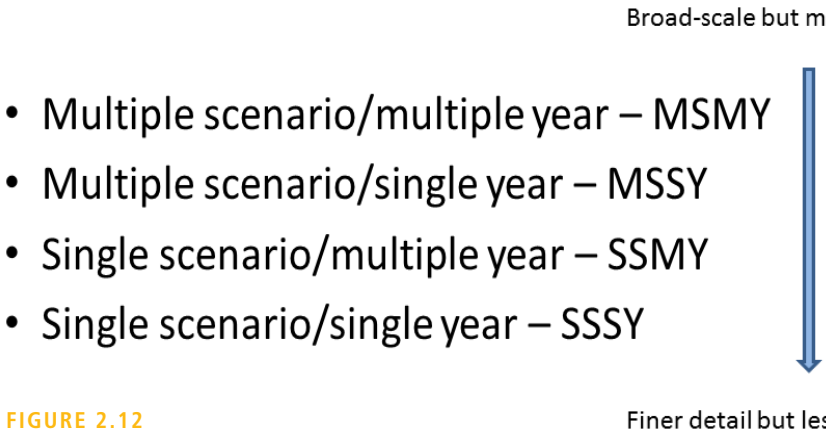


FIGURE 2.12
Tradeoffs between detail and level of confidence for the Northern Forest Futures database (Miles and Wear 2015) reporting forms.

Table 2.3—Forecasts for forest area by stocking class in New Hampshire, 2060, under scenario A1B-C that assumes moderate greenhouse gas emissions, moderate gains in population growth with large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio), and a continuation of 2010 harvesting levels.

Forest-type group	Total	Overstocked	Fully stocked	Medium stocked	Poorly stocked	Nonstocked
	All live stocking (acres)					
Total	4,400,903	466,007	2,555,042	1,141,830	223,750	14,274
White-red-jack pine	423,663	48,821	165,164	172,166	37,512	0
Spruce-fir	399,182	67,410	182,181	117,824	31,767	0
Oak-hickory	497,596	6,046	387,981	81,124	22,446	0
Maple-beech-birch	2,839,496	305,601	1,693,942	717,076	122,876	0
Aspen-birch	41,964	17,055	6,543	14,414	3,952	0
Other	199,002	21,074	119,231	39,226	5,197	14,274
	Number of FIA plots included					
Total	943	106	534	248	49	6
White-red-jack pine	96	12	40	37	7	0
Spruce-fir	78	12	33	25	8	0
Oak-hickory	110	2	85	17	6	0
Maple-beech-birch	603	72	347	158	26	0
Aspen-birch	7	3	1	2	1	0
Other	49	5	28	9	1	6

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Conservation of Biological Diversity

3

Brian G. Tavernia, Mark D. Nelson, Rachel Riemann, Brent Dickinson, W. Keith Moser, B. Tyler Wilson, James D. Garner

Introduction

PEOPLE ENJOY A variety of ecosystem services, or benefits, from forests, including water purification, recreation, income from tourism, timber products, and the cultural and economic benefits from hunting, fishing, and gathering (Shvidenko et al. 2005). Across the Northern United States, growing human populations will place increased service demands on forests for the foreseeable future. The type, magnitude, and stability of future services from northern forests will depend in part on the level of biological diversity in those forests.

Biodiversity and Climate

Biological diversity, or biodiversity, is broadly defined as the variety of life, which encompasses diversity within species, diversity among species, and diversity among organisms. As defined by the Convention on Biological Diversity (2010), forest biodiversity consists of the multiplicity and genetic diversity of plants, animals, and micro-organisms that inhabit forests. Biodiversity can be an important asset by itself, for instance when an infusion of genetic material from wild stocks increases crop productivity (Myers 1997). A high level of biodiversity in forests increases resiliency and helps ensure an uninterrupted flow of services, even when resources are subjected to natural or human-caused disturbances that inevitably occur (Bengtsson et al. 2000, Tilman et al. 2006). Shifley et al. (2012) describe current contributions of northern forests to biological diversity. Because of the links among biodiversity, ecosystem health and function, and ecosystem services, assessments of the potential effects of alternative futures on forest biodiversity are a useful source of information for policy makers and natural resource managers.

Because climate affects the spatial distribution and diversity of forest ecosystems and species across the landscape, changing climate and land-use patterns can be expected to affect levels of forest biodiversity during the coming decades and centuries (Iverson and Prasad 1998, Schwartz et al. 2006). As climate changes, some forest ecosystems and forest-associated species can shift their distributions to track the conditions that favor them, and other species are able to adapt to their new

environment (Parmesan 2006). But if a species is unable to move or adapt, its geographic range may shrink or it may become extirpated from portions of its former range (Parmesan 2006).

Key Findings

Present Day

- Forests cover 174 million acres in the North, or 41 percent of the total land area.
- Current tree species richness by State ranges from 49 species sampled in Rhode Island to 99 species sampled in West Virginia, with 160 tree species recorded regionwide.
- Northern forests provide habitat for more than 363 terrestrial vertebrate species, with richness varying among habitat classes and wildlife taxa; the highest level of richness is associated with birds, and with forests of open-canopy structure and hardwood dominance.
- With one exception—amphibians in closed-canopy hardwoods—most forest wildlife species also frequent one or more nonforest habitats.

Projected 2010 to 2060

- Forest area is projected to decrease slightly across the North, with the rate ranging from 3.5 to 6.4 percent and with losses concentrated around existing urban and suburban areas.
- Under all scenarios, area is projected to decrease for four forest-type groups (aspen-birch, elm-ash-cottonwood, oak-hickory, and spruce-fir) and increase for one group (maple-beech-birch); white-red-jack pine, which is projected to increase under current rates of biomass utilization, would decrease under high biomass-utilization scenarios.
- Under all scenarios, the forest area in the large diameter size class is projected to increase by 3.5 to 5.7 percent and the medium diameter size class is projected to decrease; the small diameter size class is projected to decrease under scenarios that assume no increase in biomass harvesting for energy, but increase or remain stable under high biomass utilization scenarios.
- Closed-canopy habitat classes are projected to gain acreage whereas open-canopy habitat classes are projected to lose acreage; intensive biomass harvesting rates for bioenergy are projected to result in losses for closed-canopy classes and to a lesser degree for open-canopy classes.
- Increasing fragmentation and parcellation are expected to reduce high-density core forests within large patches and the average size of family forest landholdings in every State; these changes would decrease the ecological services and socioeconomic benefits of core forests and diminish the ability to manage large patches of forest.
- Overall tree species richness is projected to decline through 2060; projected reductions in early successional habitats such as oak-hickory could have a large effect on tree species richness in such ecosystems.

Human Impacts on Forests

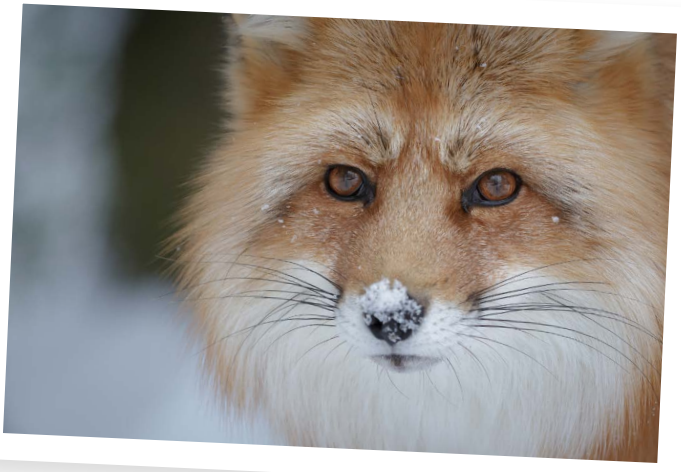
Within the large-scale patterns established by climate, land-use decisions further modify the extent and configuration of forests ecosystems, ecosystem functioning, species diversity, and genetic diversity (Opdam and Wascher 2004).

Landscape patterns, landowner objectives, and the area, composition, and structure of forests all affect the amount and quality of habitat for wildlife. Conversion to urban or other uses reduces forest area and potentially fragments forest ecosystems; this increases the proximity and exposure of remaining forests to human influences. Public and private land management decisions affect forest structure and composition. Species and genetic diversity can be reduced by forest loss, fragmentation, and urbanization, or can be increased by forest management strategies (Battles et al. 2001, Pimm and Askins 1995).

Assessments of forest biodiversity under a range of plausible climate and land-use change scenarios can help answer questions about current actions and future outcomes: How will the areas of forest ecosystem types change in the future? What are the potential consequences of climate and land-use changes for species in protected areas? What changes will occur in the area of forest habitats and how will changes affect at-risk wildlife? Answers to these questions will be valuable input for informing policy and management decisions that influence the trajectories of climate change and land-use patterns.

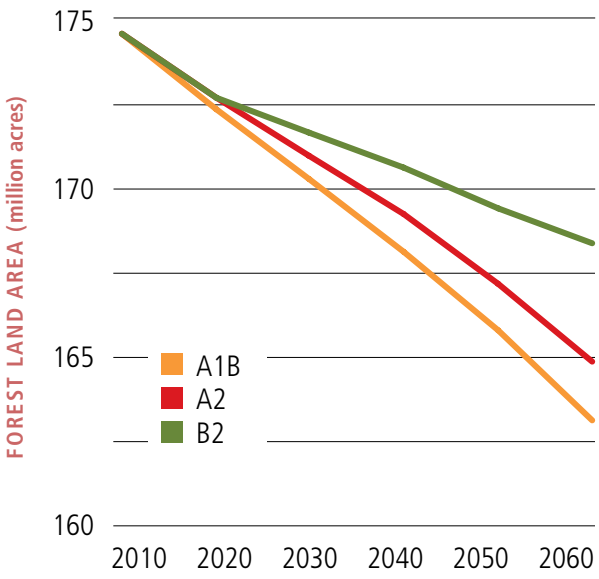
Modeling Change

The projections for changes in forest condition used three greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007, Chapter 2): A1B assumes moderate greenhouse gas emissions associated with moderate gains in population and large gains in income and energy consumption—but with a balanced renewable/fossil fuel portfolio; A2 assumes high greenhouse gas emissions associated with large gains in population, high energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions associated with moderate gains in population, income, and energy consumption. General circulation models (climate models) provide estimates of temperature and precipitation changes by geographic area. The scenarios discussed in this chapter refer to combinations of storylines with general circulation models (climate change models) and assumptions about future forest harvest rate—either a continuation of harvest rates observed in the recent past or greatly increased biomass harvesting for energy. See Chapter 2 for detailed descriptions of storylines, climate models, and scenarios.



PREDICTED CHANGES IN FOREST CONDITIONS AND OWNERSHIP

In 2010, forest area in the North was estimated at 174 million acres, accounting for 41 percent of total land cover. Projections of future conditions suggest a decrease from 2010 to 2060 under all three storylines (Fig. 3.1), with the largest decrease projected for A1B (-6.4 percent), the smallest decrease for B2 (-3.5 percent), and an intermediate decrease for A2 (-5.4 percent) (Wear 2011).



Forest Composition

Under the three scenarios that predict a continuation of current harvesting levels, two major groups—maple-beech-birch (*Acer* spp.–*Fagus* spp.–*Betula* spp.) and white-red-jack pine (*Pinus strobus* – *P. resinosa* – *P. banksiana*)—are projected to increase from 2010 to 2060 and four others[1] are projected to decrease (Fig. 3.2). Under scenarios of increased harvesting to support high biomass utilization, similar trends are expected with the exception of white-red-jack pine, which is expected to decrease, albeit slightly (Fig. 3.2). The white-red-jack pine group is projected to experience a large increase in harvesting rates under the high biomass utilization scenarios, which suggests a potential explanation for its switch from increasing to decreasing forest area among the alternative scenarios, although other processes and model uncertainty may also be at play.

[1] *spruce-fir (Picea spp.—Abies spp.); oak-hickory (Quercus spp.—Carya spp.); elm-ash-cottonwood (Ulmus spp.–Fraxinus spp.–Populus spp.); and aspen-birch (Populus spp.—Betula spp.).*

FIGURE 3.1

Forest land area estimates under baseline conditions (2010) and projections (2020 to 2060) under greenhouse gas emission storylines A1B, A2, and B2 (IPCC 2007) for the North (Wear 2011). Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

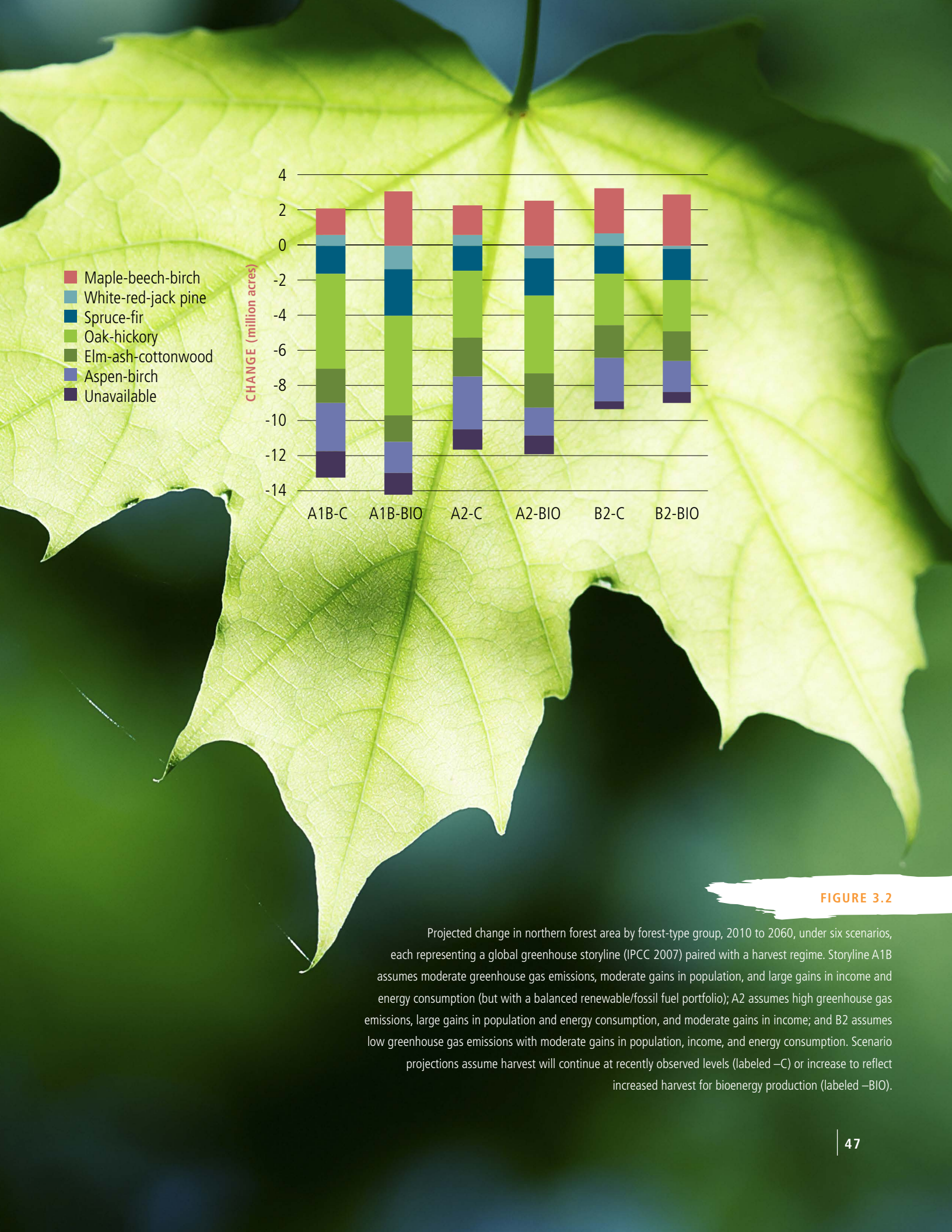


FIGURE 3.2

Projected change in northern forest area by forest-type group, 2010 to 2060, under six scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO).

Tree diameter provides a reliable measure of forest stand structural stage, which in turn is indicative of successional stage. Under the three scenarios that predict a continuation of current harvesting levels (A1B-C, A2-C, and B2-C), the forest area in the large diameter size class (≥11 inches d.b.h. for hardwoods and ≥9 inches d.b.h. for softwoods) is projected to increase by 3.5 to 5.7 percent from 2010 to 2060.

The forest area is projected to decrease for both the medium diameter class (≥5 inches d.b.h. and smaller than the large diameter class) and the small diameter class (<5 inches d.b.h.) (Fig. 3.3). However, under scenarios of high biomass utilization, forest area in the small-diameter size classes is projected to increase under A1B-BIO and A2-BIO, and to remain unchanged under B2-BIO.

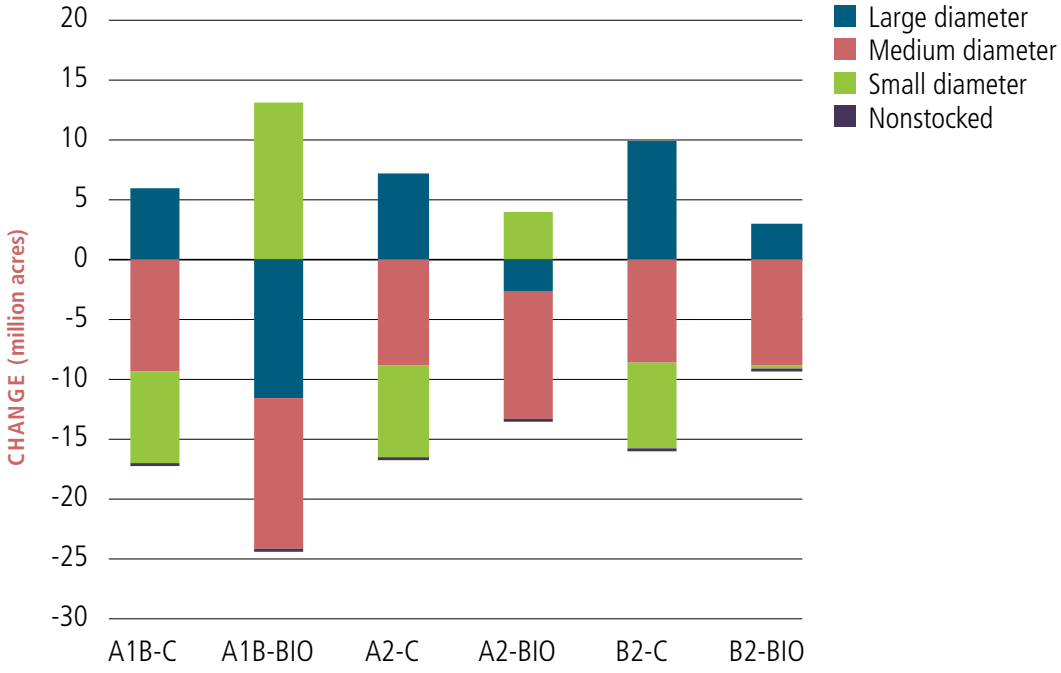


FIGURE 3.3

Projected change in northern forest area by stand-size class, 2010 to 2060, for six scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Small diameter class <5 inches d.b.h.; medium diameter class ≥5 inches d.b.h. and smaller than large diameter class; large diameter class ≥11 inches d.b.h. (hardwoods) or ≥9 inches d.b.h. (softwoods).

Although trends in forest tree species composition for the entire North are likely to be relatively consistent across scenarios, the direction and magnitude of change would vary dramatically among States, with projected increases in some States offset by decreases in others. For example, the elm-ash-cottonwood (*Ulmus* spp.–*Fraxinus* spp.–*Populus* spp.) group is projected to decrease by 12 to 18 percent from 2010 to 2060. On a per-State basis, however, this group would decrease by ≥25 percent in a number of States and actually increase by ≥25 percent in several other States within the same scenario, suggesting subregional variations (Fig. 3.4). These trends do not address additional threats from Dutch elm disease (*Ophiostoma ulmi*) nor threats from the emerald ash borer (*Agrilus planipennis*), a nonnative insect pest discussed in detail in Chapter 5.

Forest Structure

Unlike forest composition, forest structure projections vary widely among States, both in response to the greenhouse gas storylines and in response to levels of harvesting. Some States would experience increases in large or small diameter classes under continued harvesting levels, but trends would reverse under high biomass utilization scenarios. For instance, a continuation of current forest harvesting rates (scenarios A1B-C, A2-C, and B2-C) would result in modest or major reductions in forest acreage in the small diameter class, for the vast majority of States. However under high biomass utilization scenarios (A1B-BIO, A2-BIO, and B2-BIO), many of those States would experience moderate or major increases in small diameter forest area (Fig. 3.5).

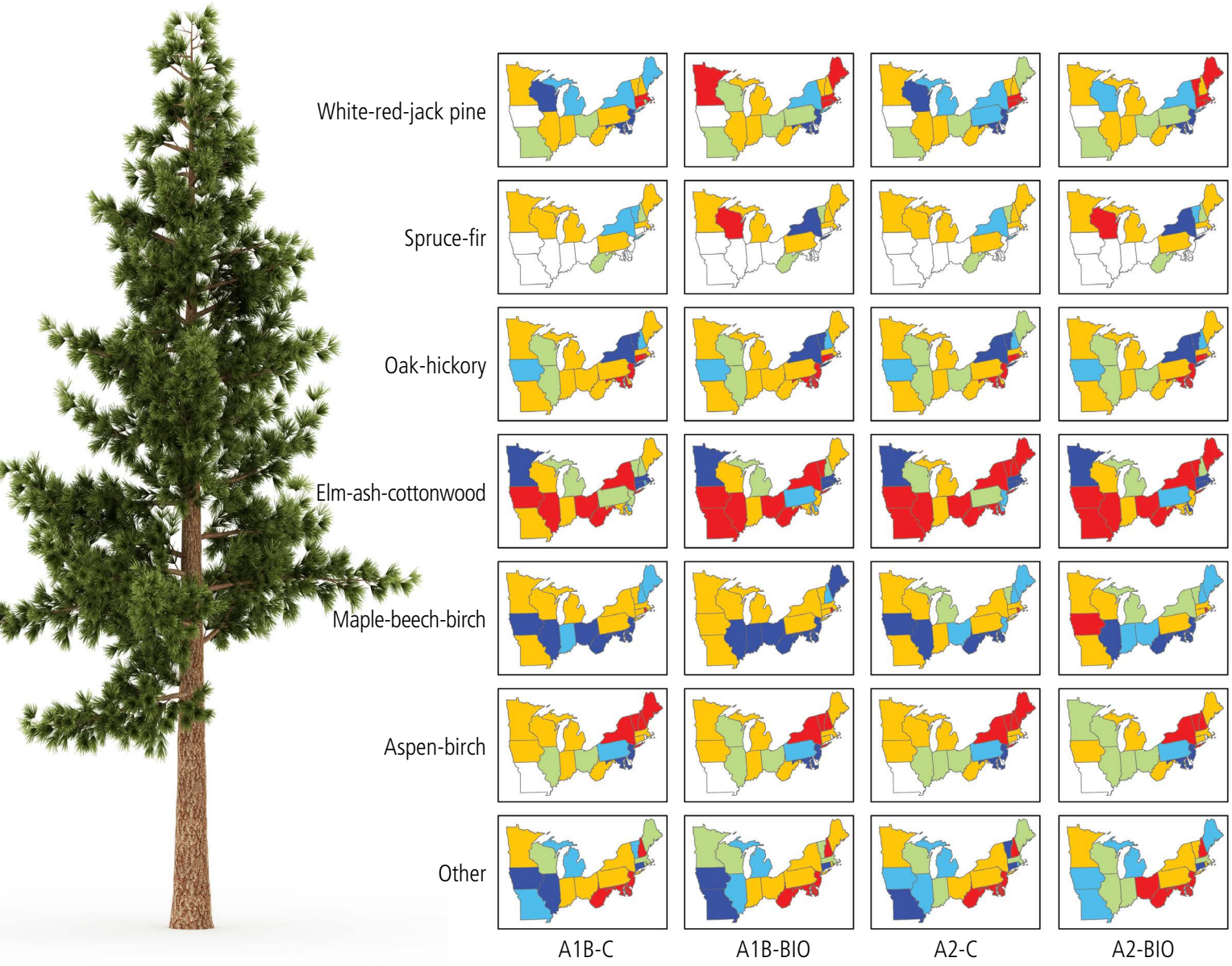


FIGURE 3.4

Projected change in northern forest area by forest-type group, 2010 to 2060, under four scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO).

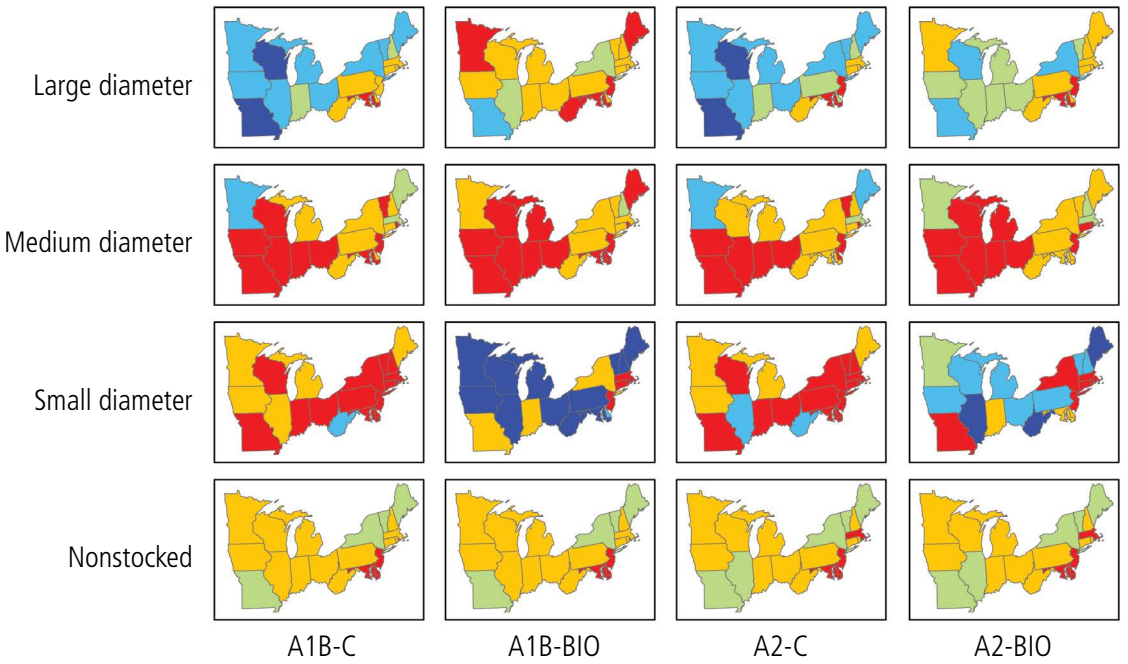


FIGURE 3.5

Projected change in northern forest area by stand-size class, 2010 to 2060, under four scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Small diameter class <5 inches d.b.h.; medium diameter class ≥5 inches d.b.h. and smaller than the large diameter class; large diameter class ≥11 inches d.b.h. (hardwoods) or ≥9 inches d.b.h. (softwoods).

THREATS TO BIODIVERSITY IN PROTECTED AREAS

The Convention on Biological Diversity defines a protected area as "…a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives" (UNEP 1992). Protected areas are classified under a system used by the International Union for Conservation of Nature (2012) and include (from most to least protected): strict nature reserves, wilderness areas, national parks, natural monuments or features, habitat and species management areas, protected landscapes, and managed resource protection areas.

Protected areas differ in their permanence and level of protection. For example, federally established wilderness areas are unlikely to experience high levels of resource extraction, but lands voluntarily enrolled in conservation programs (such as the Conservation Reserve Program) may only be temporarily protected. Forest land that is withdrawn from harvesting through statute, administrative regulation, or designation without regard to productive status is labeled "reserved forest," which is usually publicly owned (Bechtold and Patterson 2005). Of the 174 million acres of northern forests, <6.4 million acres (3.7 percent) are designated as reserved forest (Fig. 3.6); they align with four of the protected-area classes described above: strict nature preserves, wilderness areas, national parks, and natural monuments or features.

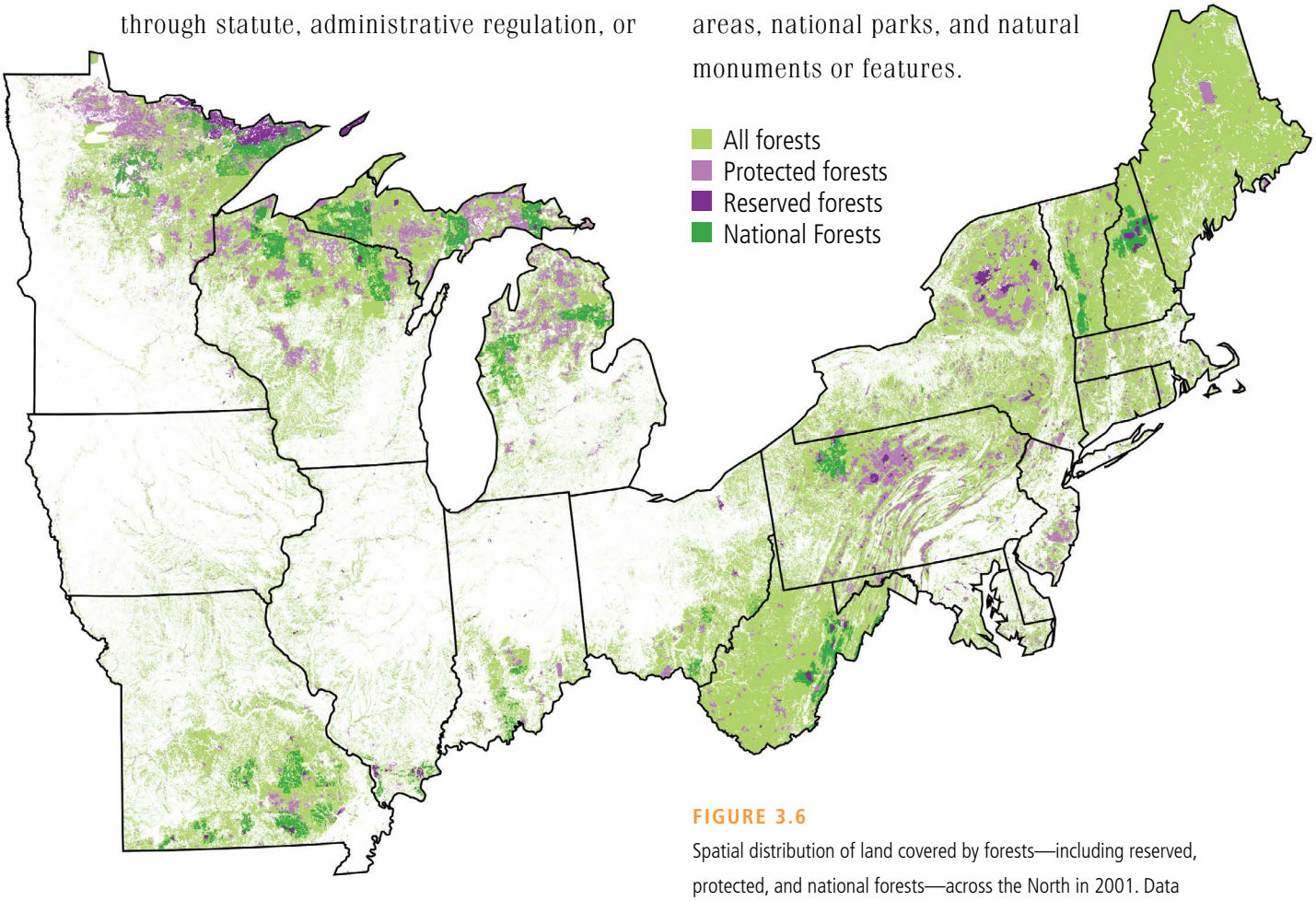


FIGURE 3.6

Spatial distribution of land covered by forests—including reserved, protected, and national forests—across the North in 2001. Data sources: ForestOwn_v1 geospatial database (Nelson et al. 2010); and Protected Area Database (CBI 2012).

Much of the public land base (including most national forests) does not meet the strict definition for protected areas. But these lands do provide protection through long-term stability in both ownership and land use (Chapter 6). In this report, projections of land-use change excluded Federal land because it is assumed that forested Federal land (such as national forests and national parks) will remain forested and in Federal ownership (Chapter 2).

Protected areas can act as important refuges for biodiversity by excluding or controlling factors (such as habitat loss or invasive species) that cause loss of biodiversity outside their boundaries. Forest biodiversity in protected areas can be an important source of ecosystem services, or benefits, especially in landscapes where land cover is predominantly nonforest. These benefits include erosion control, carbon sequestration, recreation, and economic returns from tourism and other rural enterprises.

Changing climate and land-use patterns may threaten the ability of protected areas to effectively conserve biodiversity (Hannah 2008, Radeloff et al. 2010, Stein et al. 2007). Although many protected areas are geographically fixed, distributions of forest ecosystems and species are dynamic and depend partly on climate conditions and the conditions in surrounding landscapes. For example, some species could disappear from protected areas that lose suitable conditions, but these losses could be offset if species are able to take advantage of an increase in suitable climate conditions in other protected areas (Hannah 2008). For other species, distributions could expand if the overall area with suitable climate and land-use conditions increases. The ability of forest-associated plants and animals to move with changing climate conditions would be reduced in landscapes with isolated protected forests that border nonforested areas, lack connectivity to other forested acres, or are subject to interspersed urbanization (Hannah 2008, Opdam and Wascher 2004). This is not likely to be an issue in landscapes with relatively contiguous forest cover, such as northern Minnesota. If changing climate conditions cause one species to be an overall gainer or loser of territory, the result could be a change in species representation, which is the proportion of range in protected areas that each species commands (Hannah 2008). Some proposed management strategies to maintain species representation include creating additional protected areas, increasing connectivity of protected areas, assisting migration by relocating species to new areas (Hannah 2008), and reducing human/urban pressures on remaining areas to increase their resiliency and ability to recover from disturbances (Giordano and Boccone 2010, Zipperer 2002).

Across the North, housing densities in and around protected areas are expected to increase at the expense of forest and other land uses (Radeloff et al. 2012, Radeloff et al. 2010, Stein et al. 2007, Theobald 2010).

The natural amenities offered by protected areas attract people who want to live in relatively undeveloped areas and are willing to commute long distances or can take advantage of telecommuting (Radeloff et al. 2010). Purchasers of seasonal homes and an increasing number of retirees are also contributing to housing growth in and around protected areas. In 2000, 35 million housing units were located within 31 miles of national forests, and this number is projected to increase by 16 million units by 2030. And within national forests, the number of housing units on private inholdings was projected to increase from 1.8 million in 2000 to 1.9 million by 2030 (Radeloff et al. 2010).

FOREST FRAGMENTATION

The value of forest habitats depends not only on attributes of composition and structure but also on the size and arrangement of forest fragments within the larger landscape. Growth of residential development and other land-use changes can threaten forest biodiversity (Radeloff et al. 2010, Stein et al. 2007) by reducing habitat abundance, increasing fragmentation, changing ecological processes (e.g., suppressing wildfires), and altering biotic interactions (e.g., introducing nonnative species or predatory pets). Such changes can also isolate forested areas, reducing the ability of species to respond to changing climate. Policies such as promotion of clustered developments and financial mechanisms such as tax benefits offered by land trusts, could help reduce the impact of housing growth on the biodiversity of protected areas (Radeloff et al. 2010).

Various metrics of forest fragmentation offer useful indicators of habitat suitability for species that require large fragments, forest interiors, ecotones (forest edges), proximity to nonforested land covers, or corridors for movement between fragments. Landscape metrics typically are derived from maps of current and projected forest cover that delineate individual fragments of land cover. These maps are needed to assess potential future changes in landscape patterns.

A raster map showing baseline forest cover (distribution and density) of the North in 2009 (Fig. 3.7A) was developed following the methodology of Wilson et al. (2012), having 250-m spatial resolution. The forest cover data set was combined with a model of future nighttime illuminated areas, based on a satellite-image time series recorded over the past decade. For future projections, it was assumed that nighttime illumination is associated with developed areas and that recent trends in the growth of illuminated areas will continue through the projection period. The 2009 forest cover map was adjusted using a map of projected illuminated areas, with the appropriate adjustment factor supplied by projections of forest cover in 2060 under storylines A1B, A2, and B2 from an econometric model developed by Wear (2011). This analysis lacked sufficient resolution to include reversion to forest from pastureland, cropland, or rangeland. Map results for storyline A1B were visually similar to A2, but differed from B2; for simplicity, map results are only portrayed for A1B (Fig. 3.7B), but quantitative results are portrayed for both A1B and B2 (see subsequent figures).

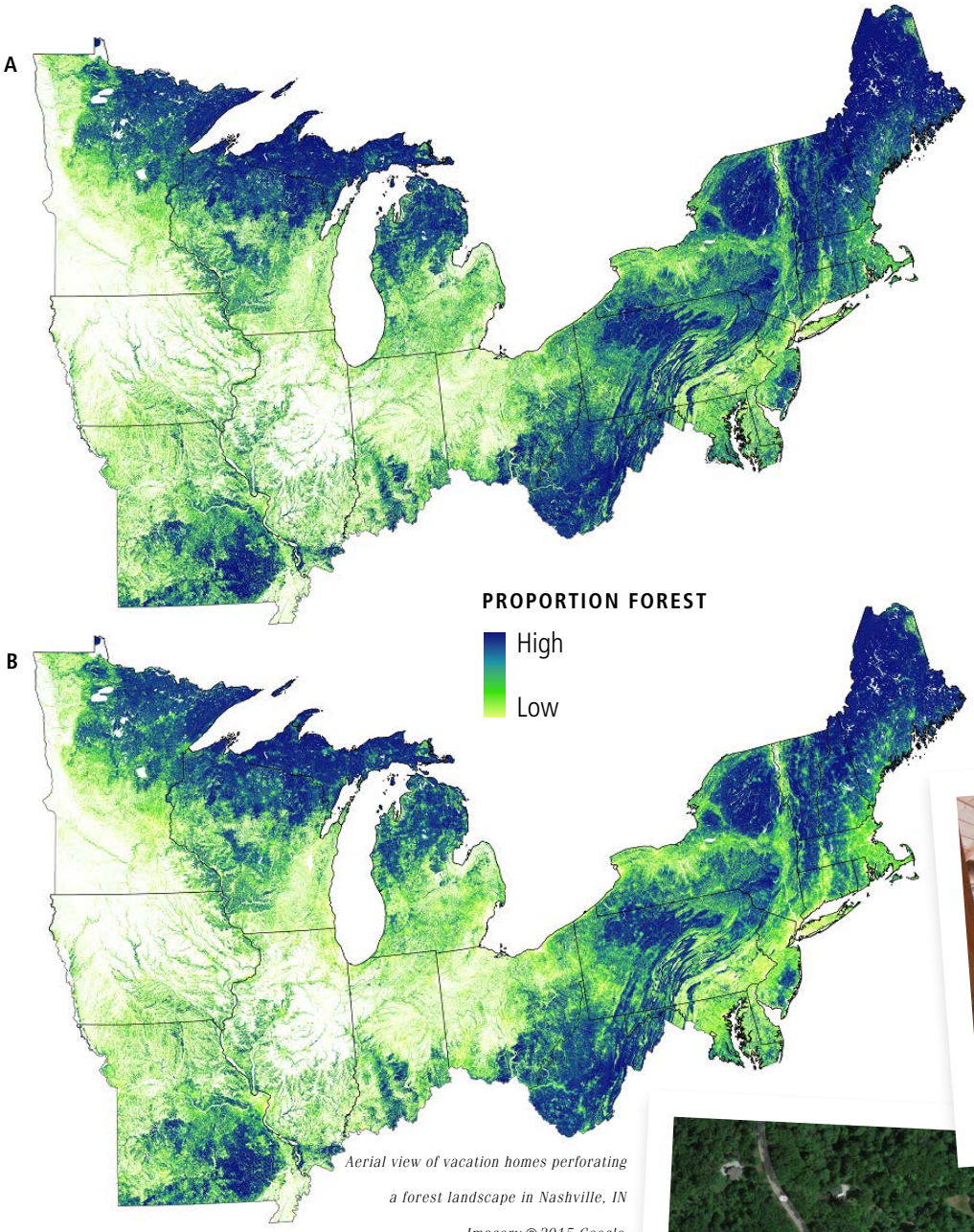


FIGURE 3.7

Spatial distribution and density of northern forests (A) in 2009, and (B) projected for 2060 under storyline A1B that assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio) (IPCC 2007).

Aerial view of vacation homes perforating a forest landscape in Nashville, IN

Imagery ©2015 Google

Projected reductions in forest extent and density are portrayed as differences between the 2009 and 2060 maps (Fig. 3.8). Not surprisingly, given that area of nighttime illumination was used as a proxy for development, forest losses are projected to be concentrated around existing urban and suburban areas and major transportation corridors (Fig. 3.8).

To quantify current and projected future forest fragmentation, a spatial integrity index was adapted that integrates forest patch size, local forest density (which picks up likelihood of edge conditions), and patch connectivity to core forest areas (Kapos et al. 2000).

Because values for the index are calculated from pixels that are labeled or classified as forest, pixels with high forest canopy density were reclassified as forest, and those with low density as nonforest, for current and future conditions, and then spatial analysis was performed to determine spatial integrity values. A value of 10 is defined as core forest, and the lowest values (approaching zero) are defined as highly fragmented forest, with intermediate values representing varying degrees of opportunity for rehabilitating landscapes to connect core forest areas.

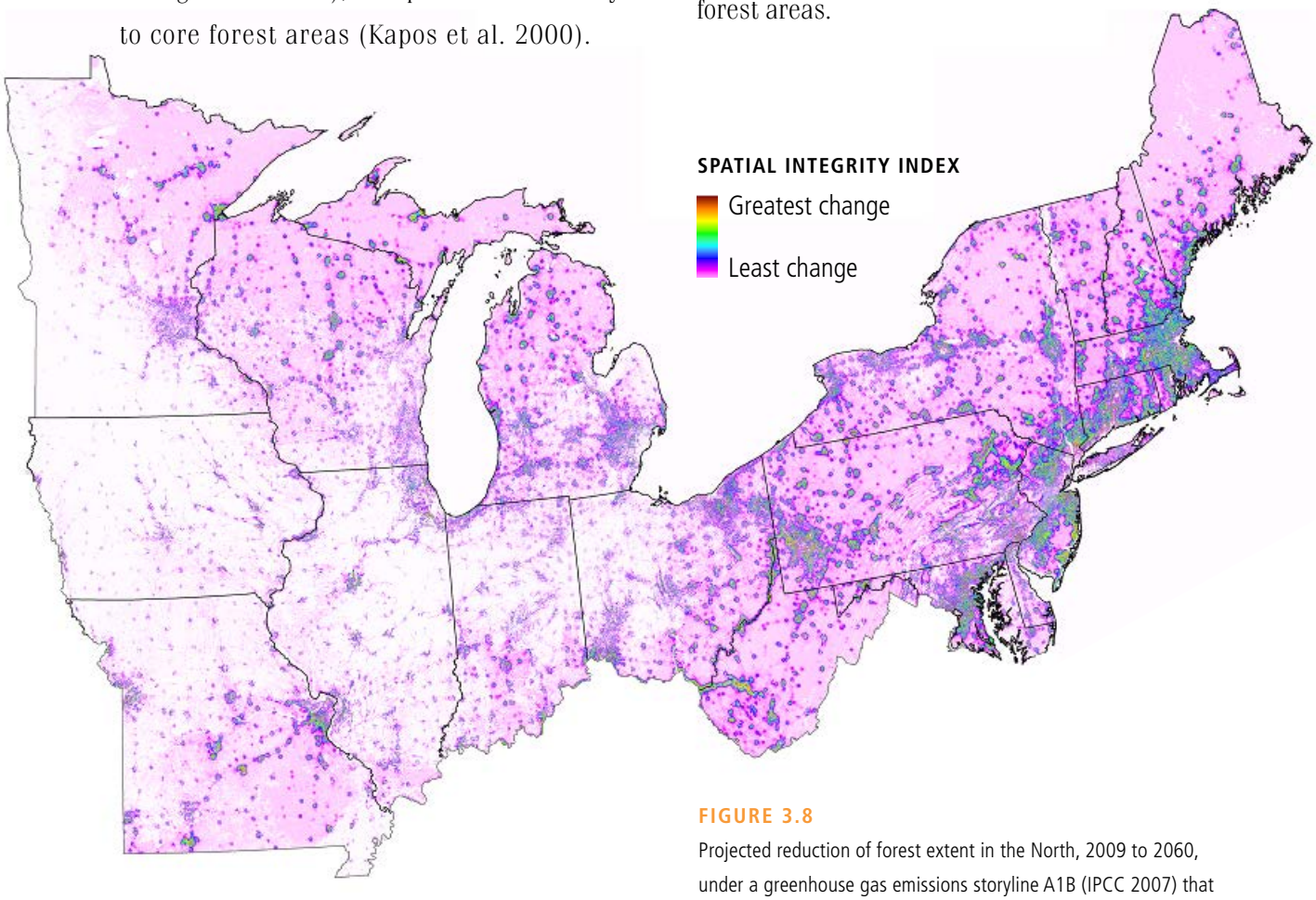


FIGURE 3.8

Projected reduction of forest extent in the North, 2009 to 2060, under a greenhouse gas emissions storyline A1B (IPCC 2007) that assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio).

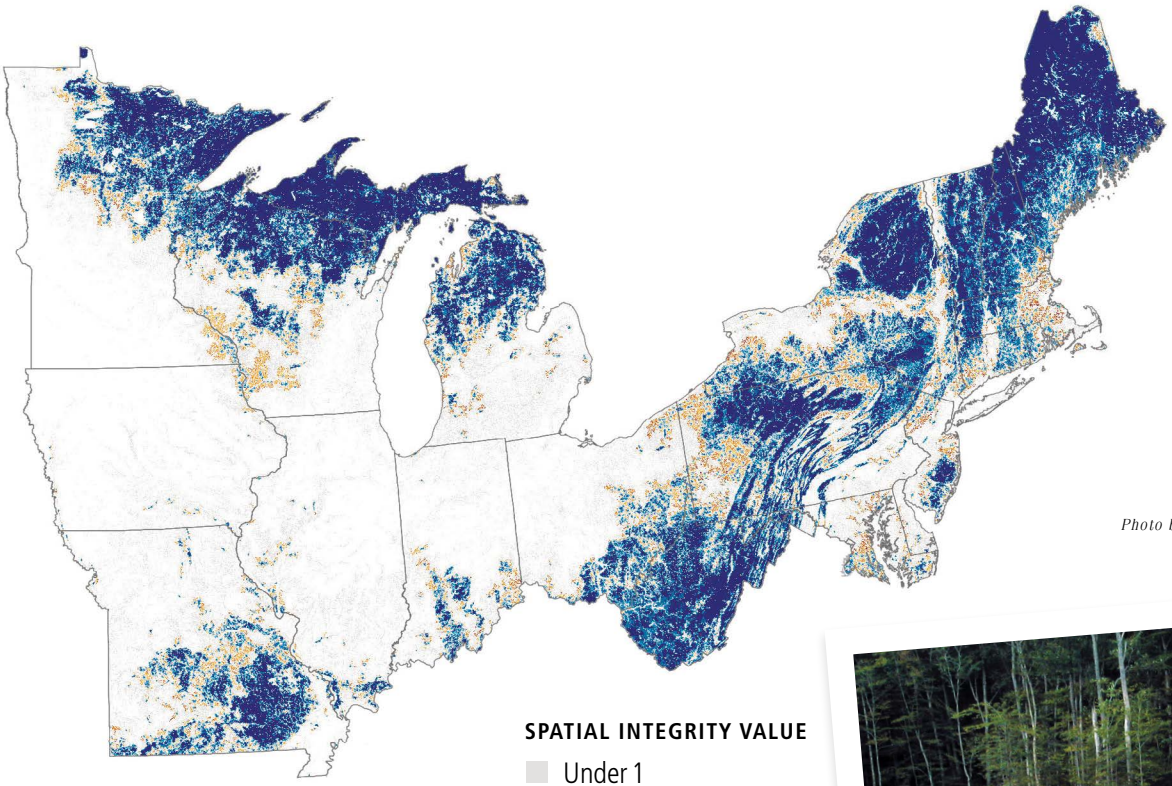


FIGURE 3.9

Forest spatial integrity index values, adjusted for housing densities associated with the wildland-urban interface or urbanized areas, 2009, across the North. Index values range from less than 1 (highly fragmented forest) to 10 (core forest with large patches and high local forest density).

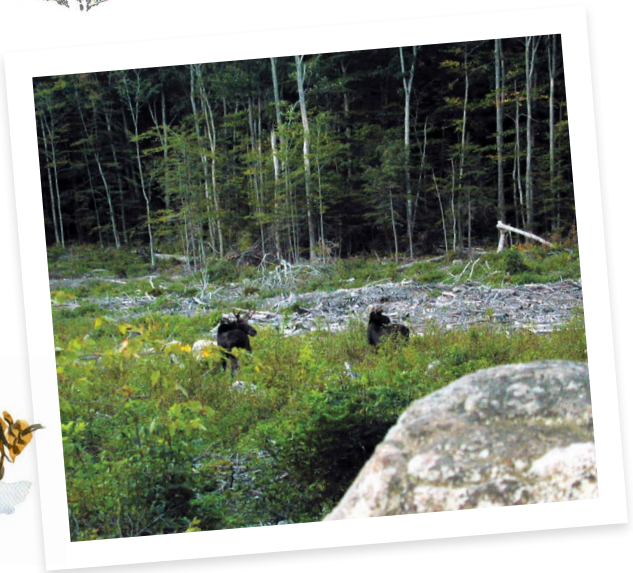


Photo by Mariko Yamasaki, U.S. Forest Service

Pixels having high tree canopy cover (inferred as representing high forest density) can occur in areas that also contain residential urban development. To determine the effects of such development on ecological processes and biotic interactions, two housing density classes were overlaid on the spatial integrity map: (1) forest pixels with a local housing density >15 houses per square mile, which is considered the threshold for the wildland-urban interface; and (2) pixels with >41 houses per square mile, which represent more urbanized areas. Assuming that this level of residential development contributes some characteristics of fragmented land, such as edge conditions and barriers to biotic movement, the spatial integrity value was reduced by two classes for the wildland-urban interface and one class for urbanized areas in the following summary (Fig. 3.9). Following procedures similar to those used for the 2009 spatial integrity index map, but excluding wildland-urban interface data which are not available for future projections, spatial integrity index values were estimated for 2060 and used to estimate the State-level changes in the spatial integrity index discussed later in this chapter.

Areas with the highest level of spatial integrity are characterized by forests with (1) a patch size >1,544 acres; (2) a local forest density of >90 percent in the surrounding 1,213-acre neighborhood; and (3) a housing density of <15 houses per square mile. These forests are thus considered to be core for this scale of analysis, with an index value of 10. An index value of 1 translates into a forest that is highly fragmented, with low or no connectivity to the core, small patch sizes, and ≤10 percent forest density. Values between 1 and 10 correspond to increasing proximity to core forest areas, increasing patch size, and increasing local forest density (Fig. 3.9), with local arrangement and interspersion of spatial integrity values for the wildland-urban interface more easily seen when the map focus is zoomed to a finer scale, as is shown for a subset of the North (Fig. 3.10).

This analysis combined fragmentation estimates from 2009 and housing densities from 2000 to demonstrate future challenges to maintaining biodiversity. This was done for two reasons. First, because fragmentation and urbanization have a delayed impact on forest ecosystems, a phenomenon known as extinction-debt trajectory, their existence portends areas where we can expect future changes in biodiversity that are not yet apparent (Malanson 2002, Tilman et al. 1994). Second, predicting the extent, intensity, location, and very importantly, the spatial distribution of future development depends on many factors, and thus comes with many uncertainties. This, combined with the high sensitivity of most measures of fragmentation to spatial variations in the data sources used, prompted the use of current information.

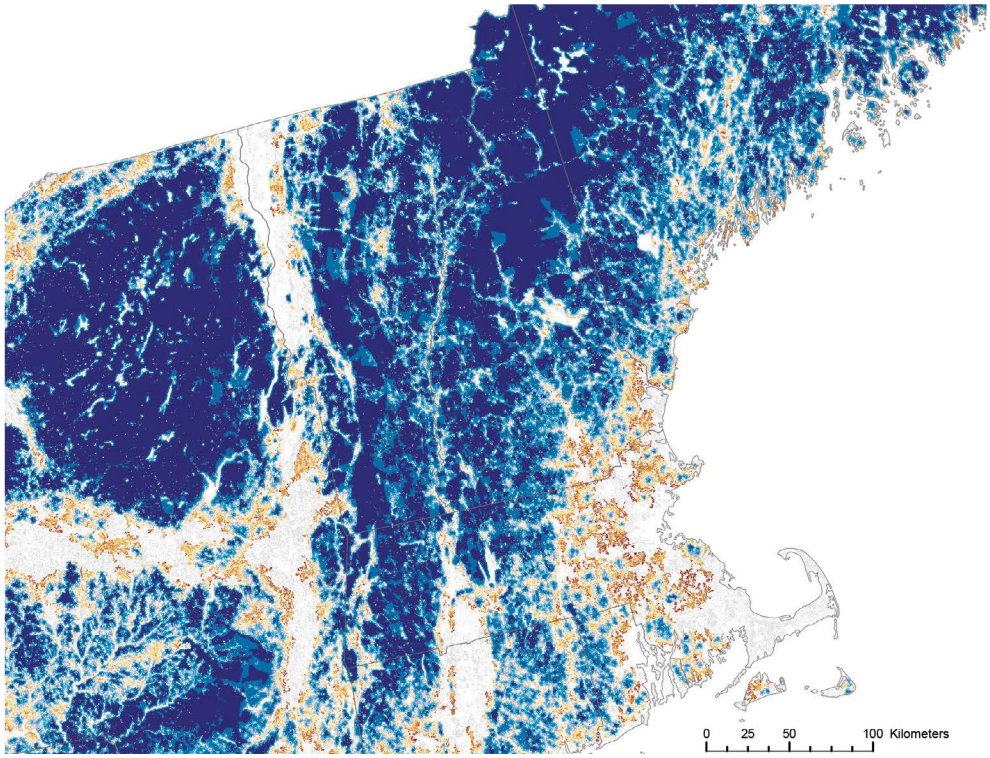


FIGURE 3.10

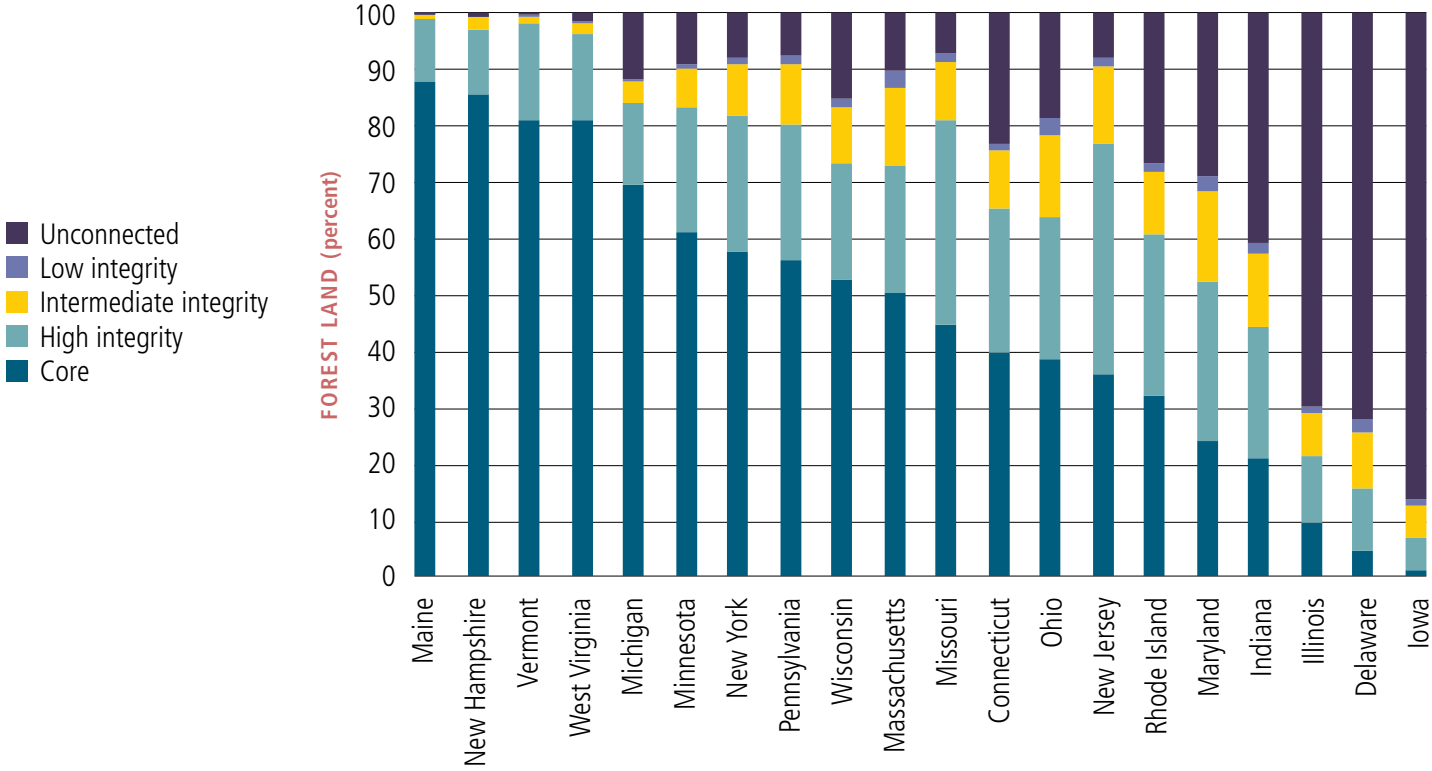
Forest spatial integrity index values, adjusted for housing densities associated with the wildland-urban interface or urbanized areas, 2009, in one area of the North. Index values range from less than 1 (highly fragmented forest) to 10 (core forest with large patches and high local forest density).

Figure 3.11 shows the current distribution of forest spatial integrity categories, adjusted for housing densities associated with the wildland-urban interface or urbanized areas. Maine supports the greatest percentage of core forest (88 percent), and Iowa has the least (1 percent). The pattern is reversed for unconnected forest, with 87 percent for Iowa and less than 1 percent for Maine. The majority of forests (56 percent) in Rhode Island are in neither of these two extreme categories, but are characterized by intermediate categories of low, medium, or high integrity forest.

All States are projected to lose some forest acreage by 2060. Losses outweigh gains, but losses vary by State and are generally larger under storyline A1B than B2 (Fig. 3.12). Under both storylines, some States and spatial integrity class combinations would increase, most of which would occur in unconnected, low integrity, and intermediate integrity forests. Such increases typically are linked to fragmentation of core and high integrity forests, resulting in losses to those classes. In contrast, decreases in unconnected, low integrity, and intermediate integrity forests typically are not balanced by increases in core and high integrity forest, suggesting that acreage would convert to another use. No State is projected to gain forest in the core forest class.

FIGURE 3.11

Forest area by spatial integrity index class in the North, adjusted for housing densities associated with the wildland-urban interface or urbanized areas, 2009.



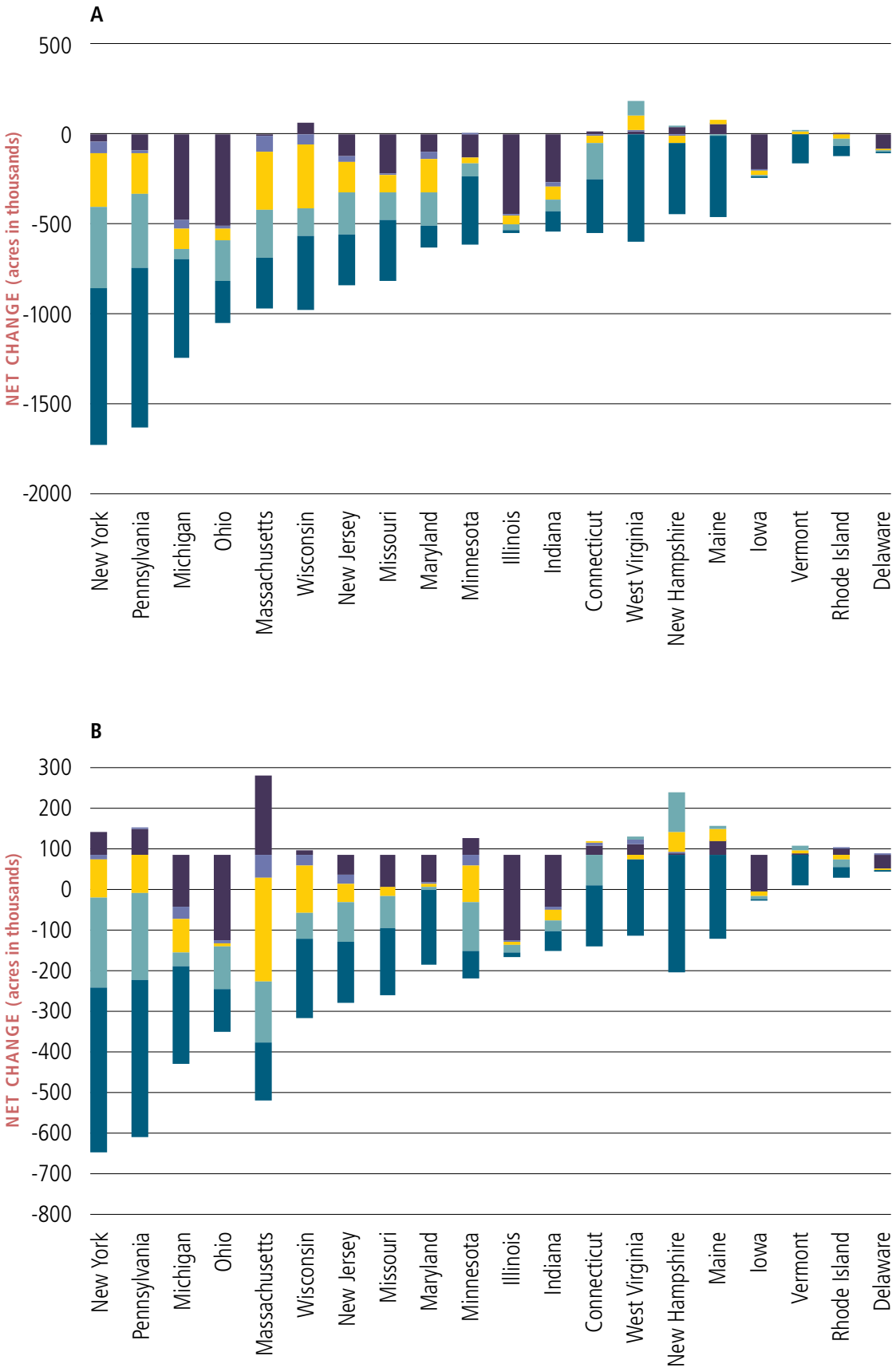


FIGURE 3.12

Projected change in forest area and spatial integrity index class in the North, 2009 to 2060, adjusted for housing densities associated with the wildland-urban interface or urbanized areas, under two greenhouse gas emissions storylines (IPCC 2007): (A) storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); and (B) storyline B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

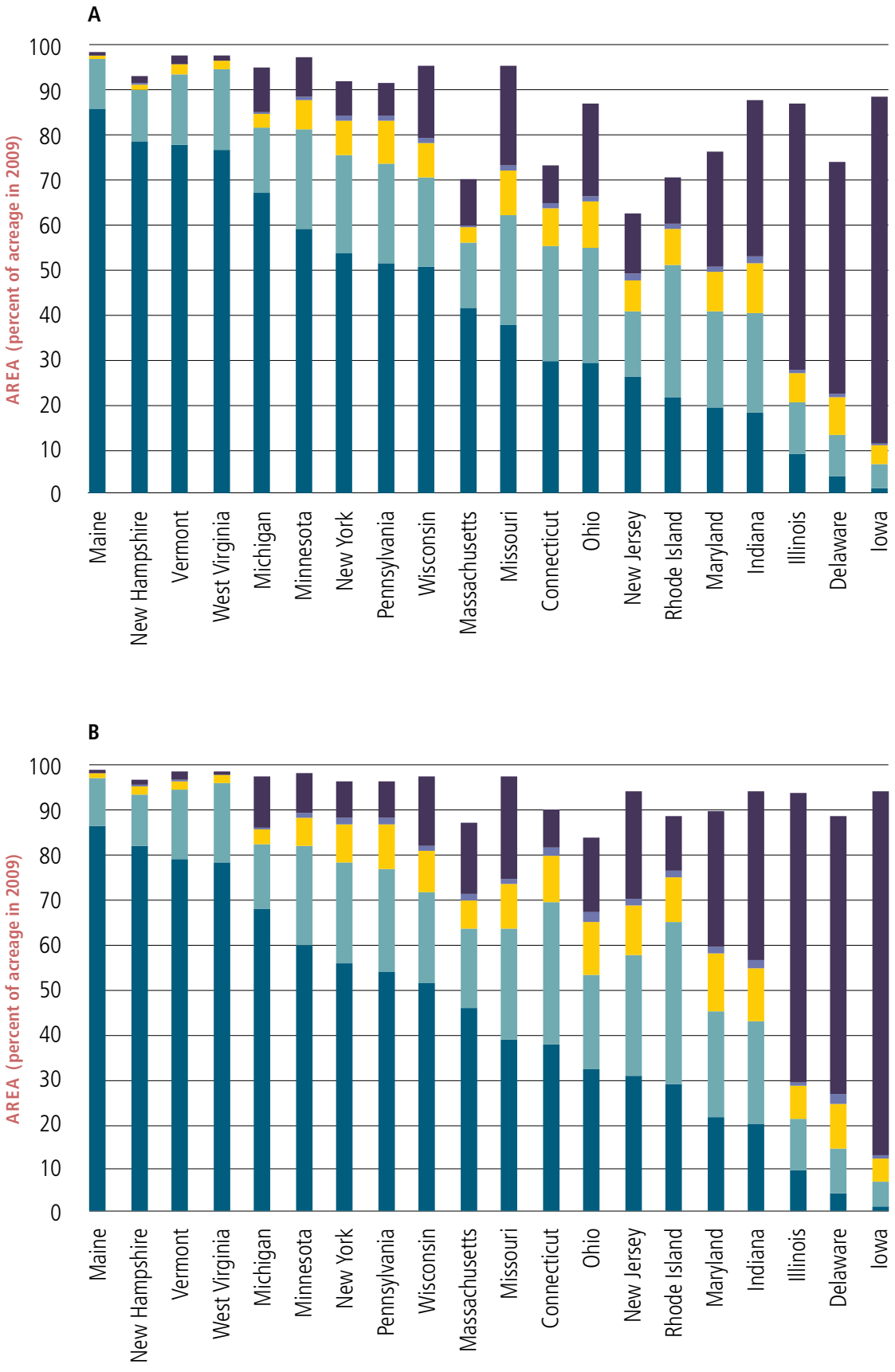


FIGURE 3.13

Projected forest area in the North, 2060, and the spatial integrity index class, adjusted for housing densities associated with the wildland-urban interface or urbanized areas, under two greenhouse gas emissions storylines (IPCC 2007): (A) storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); and (B) storyline B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

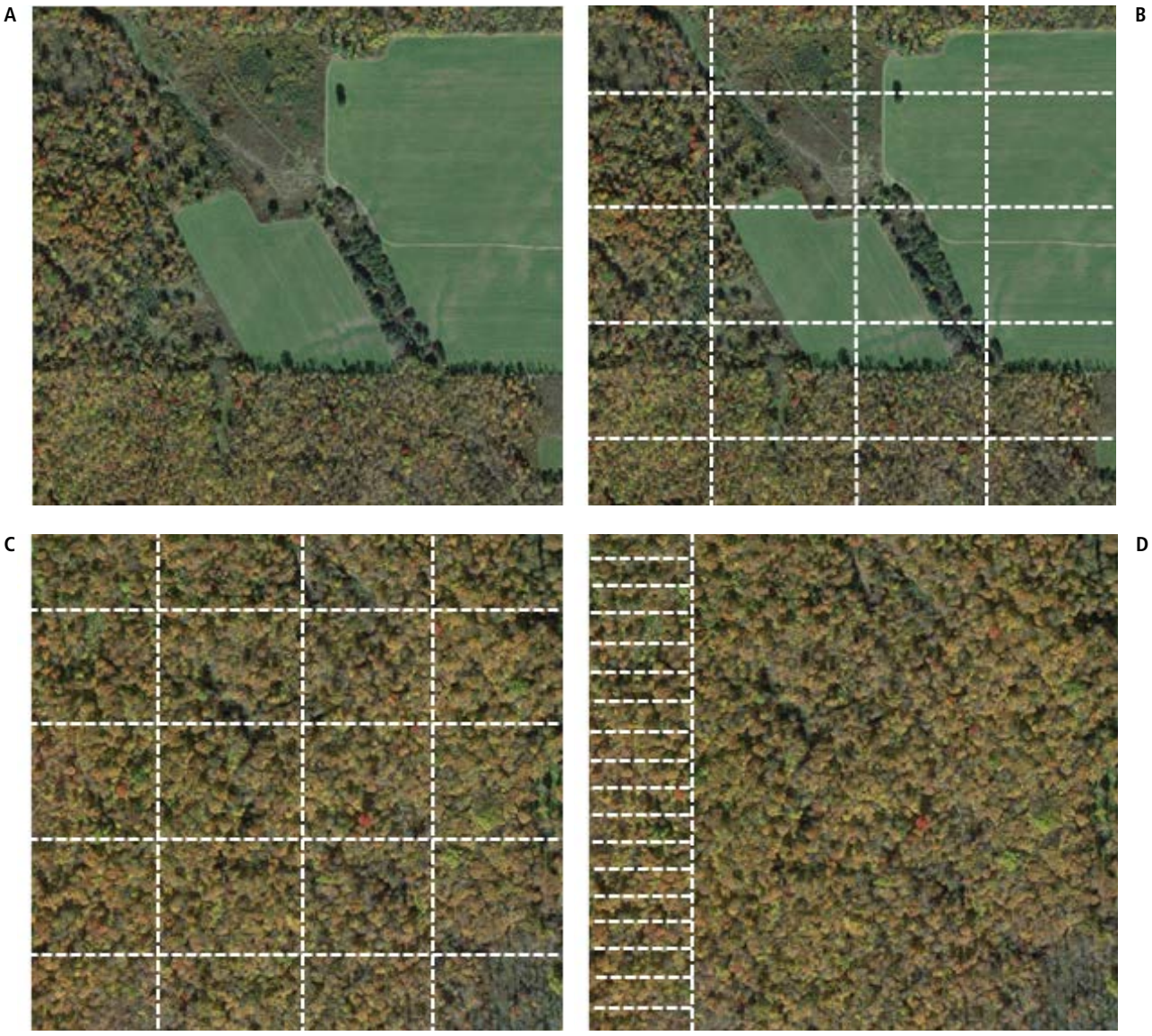
Figure 3.13 shows two projected distributions of future spatial integrity values, calculated as the percentage of the 2009 forest acreage in each spatial integrity category, sorted from highest to lowest percentage of core forest. New Jersey, Massachusetts, Rhode Island, Connecticut, and Delaware are all projected to lose ≥25 percent of forest acreage by 2060 under storyline A1B, but under B2 these five States are projected to lose much less acreage (10 to 16 percent).

FOREST PARCELLATION

One factor affecting forest fragmentation and management is forest parcellation (sometimes called parcelization). Haines et al. (2011) defines parcellation as the division of large landholdings into smaller ones. Parcellation does not necessarily imply that ecological services from affected forests will be lost, but Haines et al. (2011) have shown evidence of a possible relationship between parcellation and fragmentation. Although this relationship has not yet been studied further, it is plausible enough to be of concern, especially because of the growing trend in forest parcellation over the past several decades (DeCoster 1998, Mehmood and Zhang 2001, Zhang et al. 2009).

The distinction between fragmentation and parcellation is shown in Figure 3.14. Two of the landscapes are fragmented—one with all fragments under one ownership and the other divided in multiple ownerships. A third forest landscape does not appear to be fragmented at all; it is a contiguous forest, but one that is divided into 20 different ownerships and so is parcelized. Although a small portion of the fourth forest landscape is divided into many parcels, the biggest portion is not parcelized at all; 80 percent of it is under one ownership. The distinction between the two parcelized forest landscapes demonstrates the potential weakness of using average parcel size as a parcellation measurement. Both landscapes have the same average ownership size (same area and same number of ownerships), but these two forests will most likely face very different sets of development pressures. Nonetheless average ownership size was used as the best proxy for detecting parcellation because it is the only measurement available to use at the scale required by the data set.

Parcellation was correlated with estimated average family forest ownership size using National Woodland Owner Survey data from 2006 (Butler 2008) at the State and county levels. Estimates were based on the average number of forested acres in the State for families that had some holdings in the county of interest. Because respondents indicate how many acres they own, not in a county, but in the State, an ownership may be more than one parcel, with multiple parcels across different counties. We regressed the natural log of those estimates on the log of current (2010) U.S. housing density data as well as several significant State categorical variables (true/false categories). The county-level model has very low explanatory power, with an R^2 of 0.08, but county estimates were retained to illustrate



spatial pattern in cartographic outputs (Fig. 3.15). In contrast, the state-level model has an R^2 of 0.77. These models projected average parcel size for 2060 using U.S. housing density predictions. In all, eight sets of projections were created: the two described above and those based on the county and state-level housing density prediction sets for storylines A1B, A2, and B2.

FIGURE 3.14

Schematic illustrating hypothetical combinations of parcellation and fragmentation: (A) no parcellation on a fragmented landscape; (B) parcellation into uniform ownerships on a fragmented landscape; (C) parcellation into uniform ownerships on a contiguous landscape; and (D) parcellation into ownerships of varying sizes on a contiguous landscape. Hypothetical ownership parcel boundaries are illustrated by dashed lines. Imagery: ©Google 2015.

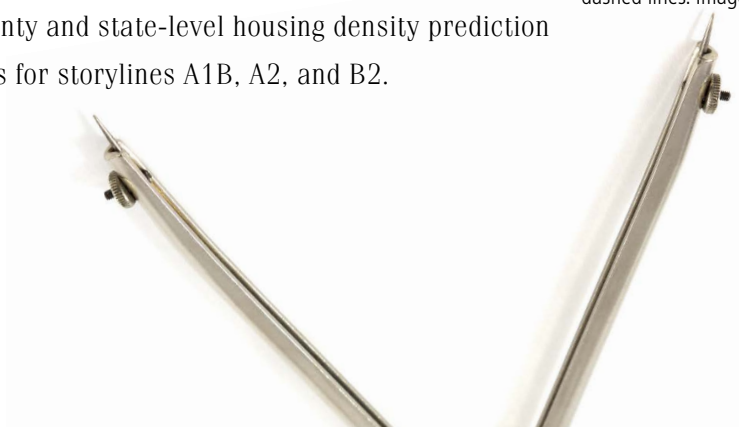


Figure 3.15 shows projected changes in average family forest ownership size at the county level for storyline A1B. Differences in projections across the scenarios are not visually discernible, so the other scenarios are not displayed. Overall, each county and each State is expected to see a reduction in average ownership size, which indicates an increase in parcellation.

The projected changes represent the difference between using fitted or actual current ownership size in projections. The reason the differences shown do not use actual current estimated average ownership size is that the map would be misleadingly noisy. Indeed, some of the projected future sizes are larger than actual current sizes. This is because some actual current sizes are much smaller than the fitted current values. To indicate gains in average ownership size would suggest that the model somehow predicts reverse parcellation in those counties, which is certainly not what is occurring. The map is designed simply to give an understanding of how parcellation is expected to follow increasing housing density predictions.

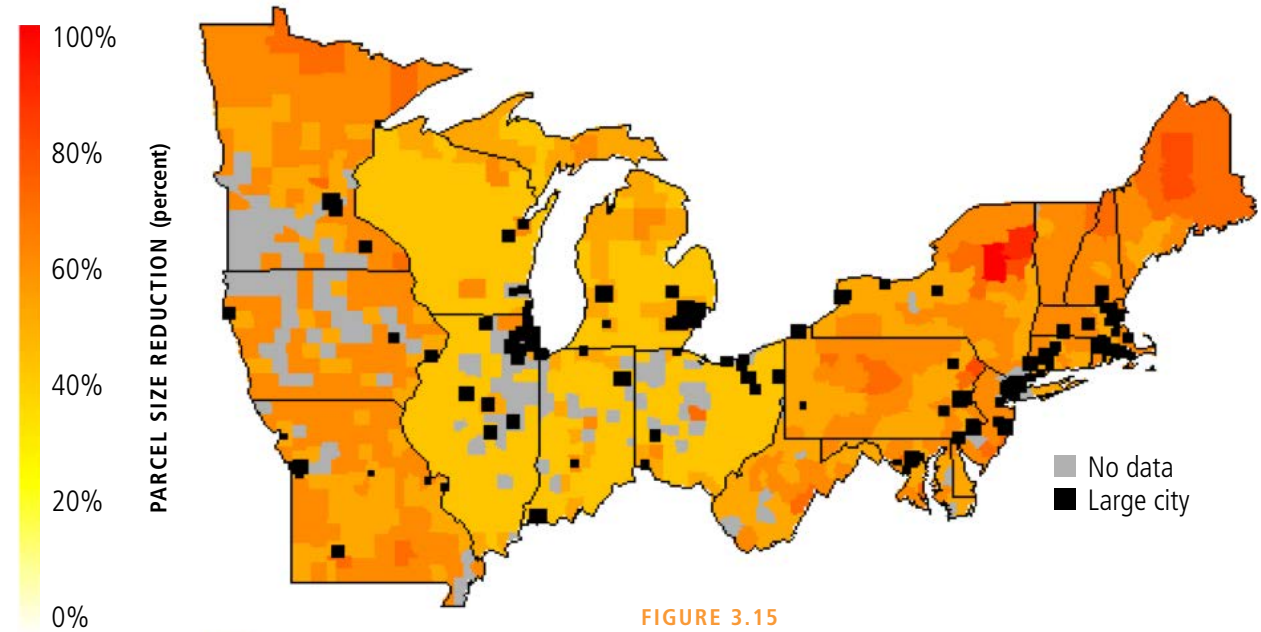


FIGURE 3.15

County-level projected reductions in average family forest parcel size, 2006 to 2060, under greenhouse gas emissions storyline A1 that assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy (Mondal et al. 2013).

Much of the extreme parcellation (>70-percent reduction in average size) is projected to occur far from city centers, most notably in northern Maine, New York, and Minnesota. However, a relatively low proportion of northeastern Minnesota forest acreage is in family forest ownership; in two counties <10 percent of forest acreage is estimated to be held by families. Thus, although parcellation of family forests is projected to be quite severe in that area, it may be less of a concern than in the Adirondacks of New York or in northern Maine.

These projections are simplistic and should be interpreted with caution. They are meant only to offer an idea of the direction of change that can be expected by 2060. With this caveat in mind, we anticipate a much more parcelized family forest landscape, regardless of which of the anticipated scenarios play out. Insofar as forest fragmentation follows this projected parcellation, the forest landscape would be much more fragmented by 2060 as well. With that level of fragmentation, losses in ecological services and socioeconomic benefits can be expected.

TREE SPECIES AND GENETIC DIVERSITY

One of the most basic measures of biological diversity is the total number of species within a given geographic area. This is referred to as species richness. In general, large areas are likely to contain more species than smaller areas. Different measures of diversity are used to account for these differences. Alpha diversity is the number of species observed within a small, homogeneous area; and gamma and epsilon diversity estimate species richness over increasingly larger, heterogeneous areas. Average species richness is reported for trees on survey plots (alpha diversity) established by Forest Inventory and Analysis (FIA), within States (gamma diversity), and across the entire region (epsilon diversity). Numbers of future species are not projected because this report addresses only potential habitat abundance within the region; species distributions also are affected by many nonhabitat factors, including invasive pests, disease, and competition.

Across the 20 Northern States, 160 tree species were recorded on FIA plots during the baseline period (2010). An average of 76 tree species was recorded in each State, ranging from 47 species in Rhode Island to 99 species in West Virginia. The number of species per FIA plot also varied among States and among major species groups (Fig. 3.16).

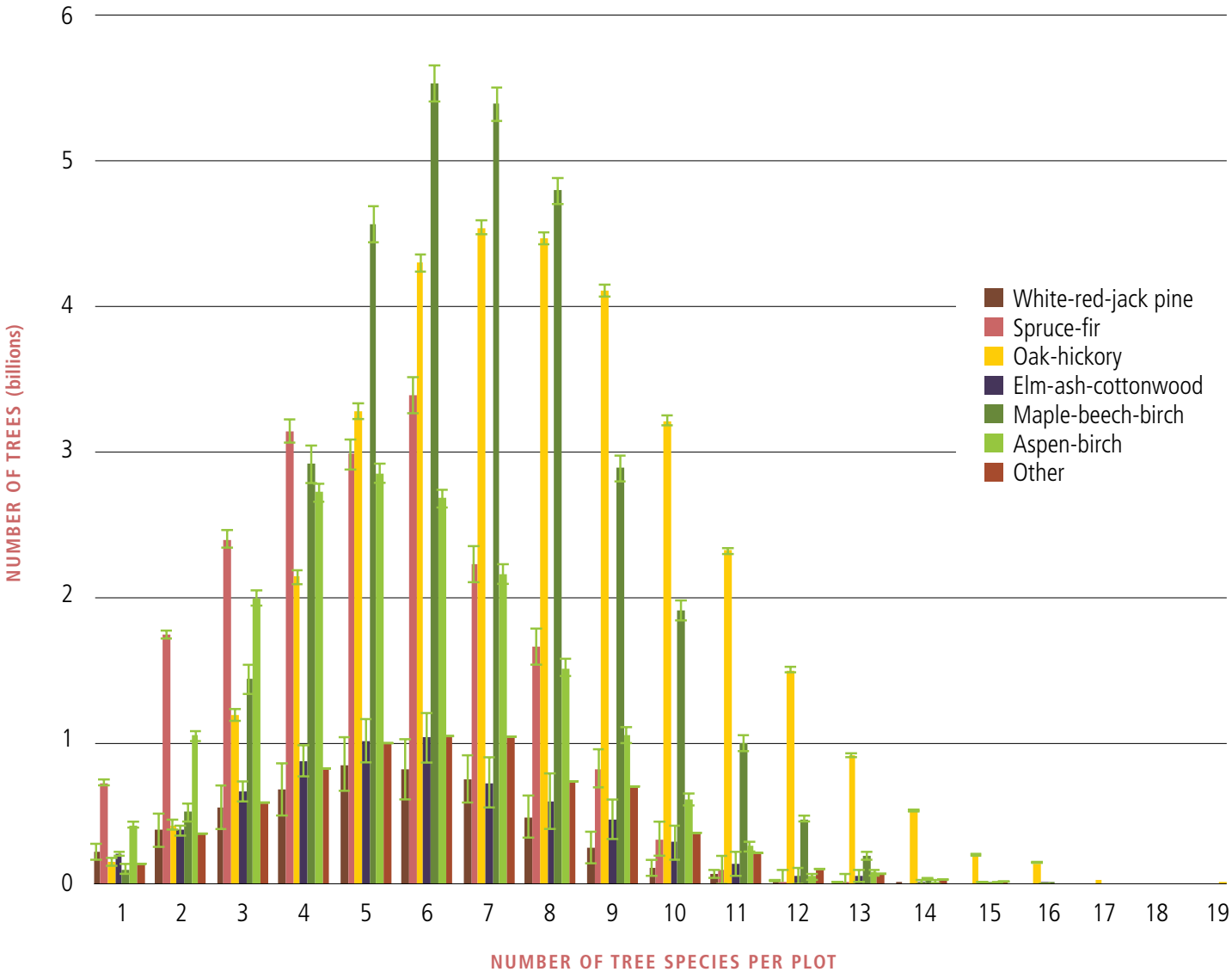
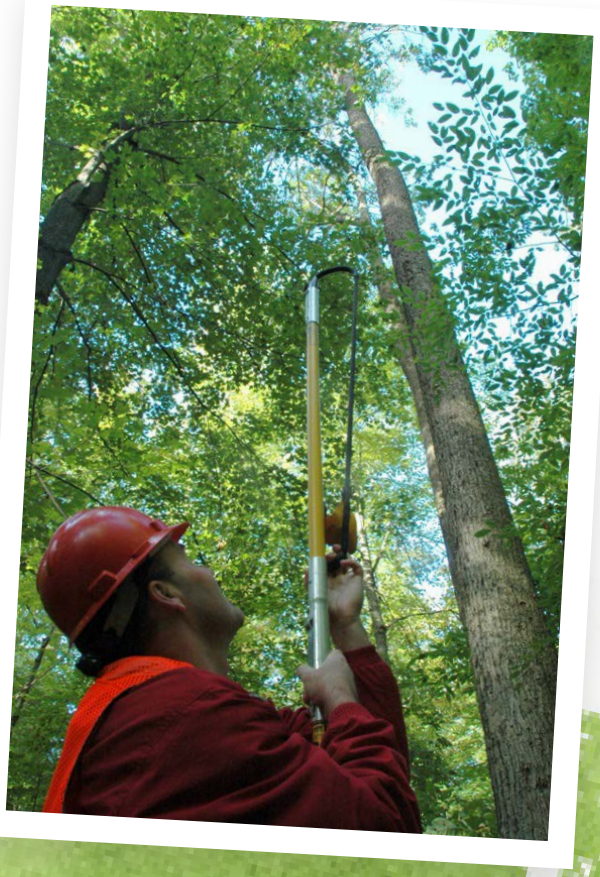


FIGURE 3.16

Number of trees (≥5 inches d.b.h), by forest-type group and tree frequency, 2010, per survey plot in the North; data from FIA. Error bars indicate 68-percent sampling error associated with the estimated number of trees for each column.

Given such a large geographic extent and the high number of FIA plots, it is not surprising that the number of tree species per plot presents such a classically normal distribution. What is notable, however, is the prominent shift to the right (more species per plot) in the maple-beech-birch (the northern hardwoods) and the oak-hickory (*Quercus* spp.–*Carya* spp.) groups. These two groups demonstrate different underlying processes. Maple-beech-birch is

primarily composed of shade-tolerant species and regenerates largely by gap-phase processes. Oak-hickory forests have a more disturbance-mediated origin and so their regeneration and development dynamic reflects a more even-age initiation and release; they can be characterized as the climax forests where disturbance has "reset the clock."



Collecting ash tree seeds

Photo by Tom Arbour, Ohio Department of Natural Resources, used with permission

Genetic Diversity

Biological diversity refers not only to species diversity but also to genetic diversity. To illustrate, consider the variation in characteristics associated within cultivated plants of a single species, like apples (*Malus* spp.). Similarly, genetic diversity within a single tree species results in a variety of traits, resulting in different physical and functional characteristics that help trees adapt to local conditions. A species under threat of rapid, widespread mortality is at risk of losing genetic diversity, even if individual trees persist in some locations.

Such is the concern for ash trees, which are under serious threat from emerald ash borer, a nonnative insect pest that causes rapid mortality in several ash species (Chapter 5). In response, work is underway to preserve germplasm by collecting ash seeds for long-term storage under a combined effort by three U.S. Department of Agriculture agencies (Agricultural Research Service, Forest Service, and Natural Resources Conservation Service) the U.S. Department of the Interior's Bureau of Land Management, and more than 50 cooperators.

The goal of this effort is to preserve seeds from many individual trees of each ash species, evenly spaced across the range. To date, samples have been collected from more than 3,000 individual ash trees, including white (*Fraxinus americana*), green (*Fraxinus pennsylvanica*), black (*Fraxinus nigra*), blue (*Fraxinus quadrangulata*), and pumpkin (*Fraxinus profunda*) ash species. Collection priority is given to portions of the range that are under current infestation. Working collections of seeds (samples made available to researchers and breeders) are held at national seed laboratories with duplicate samples held as a security backup at alternate locations (Karrfalt and Carstens 2013).

The implications for biodiversity are several. The disturbance patterns that initiated many oak-hickory forests—such as land clearing (and subsequent reforestation), large fires, and even-age forest management—are declining in extent and intensity. Furthermore, oak-hickory forests, being primarily located in the southern reaches of the region, are more likely to adjoin major metropolitan areas and thus more likely to lose acreage to urban and suburban encroachment. Oak-hickory is the largest group by area (Chapter 4, Appendix 4) and is projected to lose the most acreage; on a relative basis, elm-ash-cottonwood is projected to be the biggest loser (Chapter 4). Maple-beech-birch and white-red-jack pine are projected to gain acreage. The implication of this projected trend is that overall, tree species diversity would decline through 2060, primarily because of the decrease in acreage of oak-hickory, a group that benefits from some forms of canopy disturbance.

FORECASTS OF CHANGES IN HABITAT AND AT-RISK WILDLIFE SPECIES

Some species require forest habitats that can have unique characteristics such as the species composition, age, and size of trees (Patton 2011). For example, Canada warblers (*Cardellina canadensis*) breed in young forests (6 to 20 years) whereas Acadian flycatchers (*Empidonax virescens*) breed in areas dominated by mature forests. Conservation and management of species with divergent habitat requirements cannot be successful unless they are based on a landscape approach that focuses on simultaneously providing different types of habitats and successional stages in separate areas (Hamel et al. 2005) and managing changes in habitat as forests grow and are subjected to disturbances. Efforts to conserve diverse groups of wildlife can benefit from assessments of habitat responses to changes in climate and land-use change. This report considered species richness and projected changes in area for six forest habitat classes—closed-canopy and open-canopy hardwoods, conifers, and mixed forests—using a NatureServe (2011) data set to project habitat classes, species richness, and species-habitat class associations.

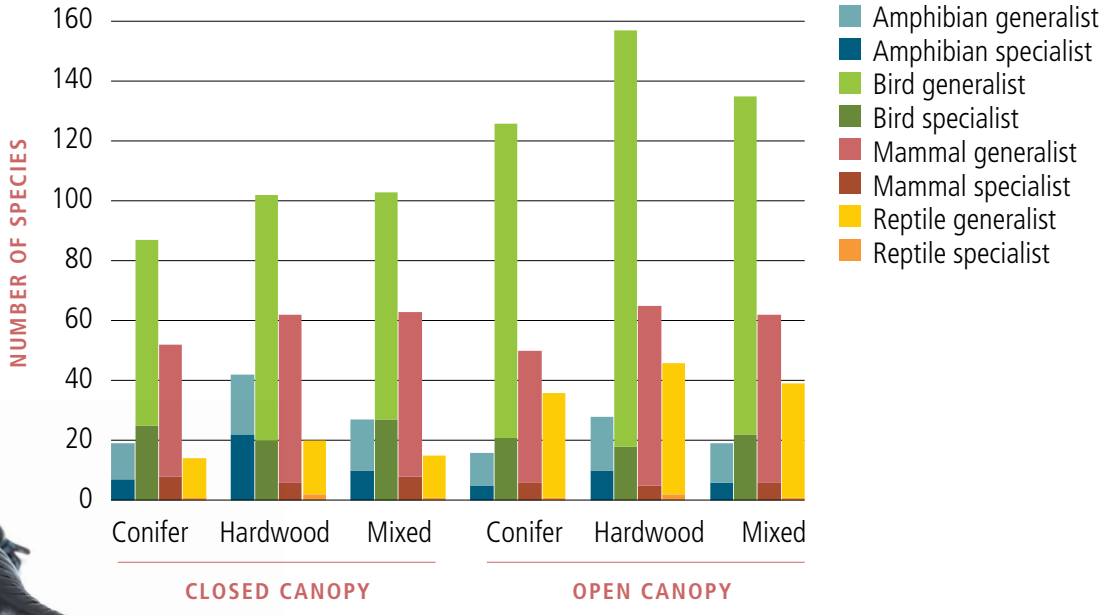
Northern forests provide habitat for 363 terrestrial vertebrate wildlife species, including mammals, reptiles, amphibians, and birds. Many of these species—such as the coyote (*Canis latrans*), American crow (*Corvus brachyrhynchos*), common garter snake (*Thamnophis sirtalis*), and American toad (*Anaxyrus americanus*)—are common generalists, meaning that they inhabit a wide variety of habitats (not necessarily forested), do not depend on any one type of habitat for their survival, and are mostly plentiful across their geographic range. Many other species are more specialized and spend their entire lives within forests; they include the northern hawk owl (*Surnia ulula*), hoary bat (*Lasiurus cinereus*), fisher (*Martes pennanti*), wood frog (*Lithobates sylvaticus*), and coal skink (*Plestiodon anthracinus*).

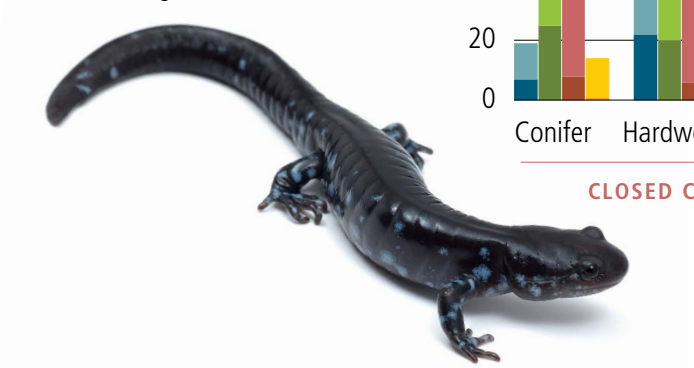
A few species are even more specialized and depend on a specific forest habitat for their survival, such as the open canopies of mixed pine and oak-pine barrens required by the treefrog (*Hyla andersonii*) or the closed-canopy hardwood forests required by the streamside salamander (*Ambystoma barbouri*). Other species may frequent numerous nonforest habitat types but rely on northern forests for critical life stages. An example is the wood duck (*Aix sponsa*), which spends most of its life on water but selects tree cavities for nesting sites. For other species, primarily migratory birds, northern forests make up only part of their geographic range, either as a seasonal destination as with Kirtland's warbler (*Dendroica kirtlandii*) and the northern shrike (*Lanius excubitor*), or as a stop along a migratory route as with the gray-cheeked thrush (*Catharus minimus*). Northern forests are also home to two known endemic species of salamander, the Cheat Mountain salamander (*Plethodon nettingi*), and the blue-spotted salamander (*Ambystoma laterale*), which can be found nowhere else on earth.

Abundance of terrestrial vertebrate wildlife species varied among habitat classes and among major taxa (Fig. 3.17). Species richness is highest in open-canopy forests and hardwood habitats. Bird species accounted for the highest richness, with mammals second in all forests. Bird species numbered >150 species in open-canopy hardwoods, the greatest richness for any taxon-habitat combination. Amphibians were the least rich taxon in open-canopy habitats, and reptiles were the least rich in closed-canopy habitats. Species that limit their habitats to forests (defined as specialists) were in the minority across all habitats except closed-canopy hardwoods, where amphibian specialists were more abundant than amphibian generalists.

FIGURE 3.17

Distribution of terrestrial vertebrate species among closed- and open-canopy conifer, hardwood, and mixed forest habitats across the North in 2010; note that species associated only with forest habitats are termed "specialists" and species associated with both forest and nonforest habitats are termed "generalists."





Forest projection models were used to assess climate and land-use driven changes in forest habitat classes under the assumption that current harvesting levels will continue without the influence of increased bioenergy demands (scenarios A1B-C, A2-C, and B2-C). Results showed that total forest habitat area is expected to decrease from a 2010 value of 173 million acres to 162 million acres for A1B-C, 164 million acres for A2-C, and 168 million acres for B2-C. Across all scenarios, closed-canopy habitat classes would gain acreage but open-canopy classes would lose (Fig. 3.18, Table 3.1). We also projected the potential influence of intensive biomass harvesting rates for bioenergy (scenarios A1B-BIO, A2-BIO, and B2-BIO) (Fig. 3.18); most open-canopy classes would lose some acreage and closed-canopy classes would lose even more (Tavernia et al. 2013).

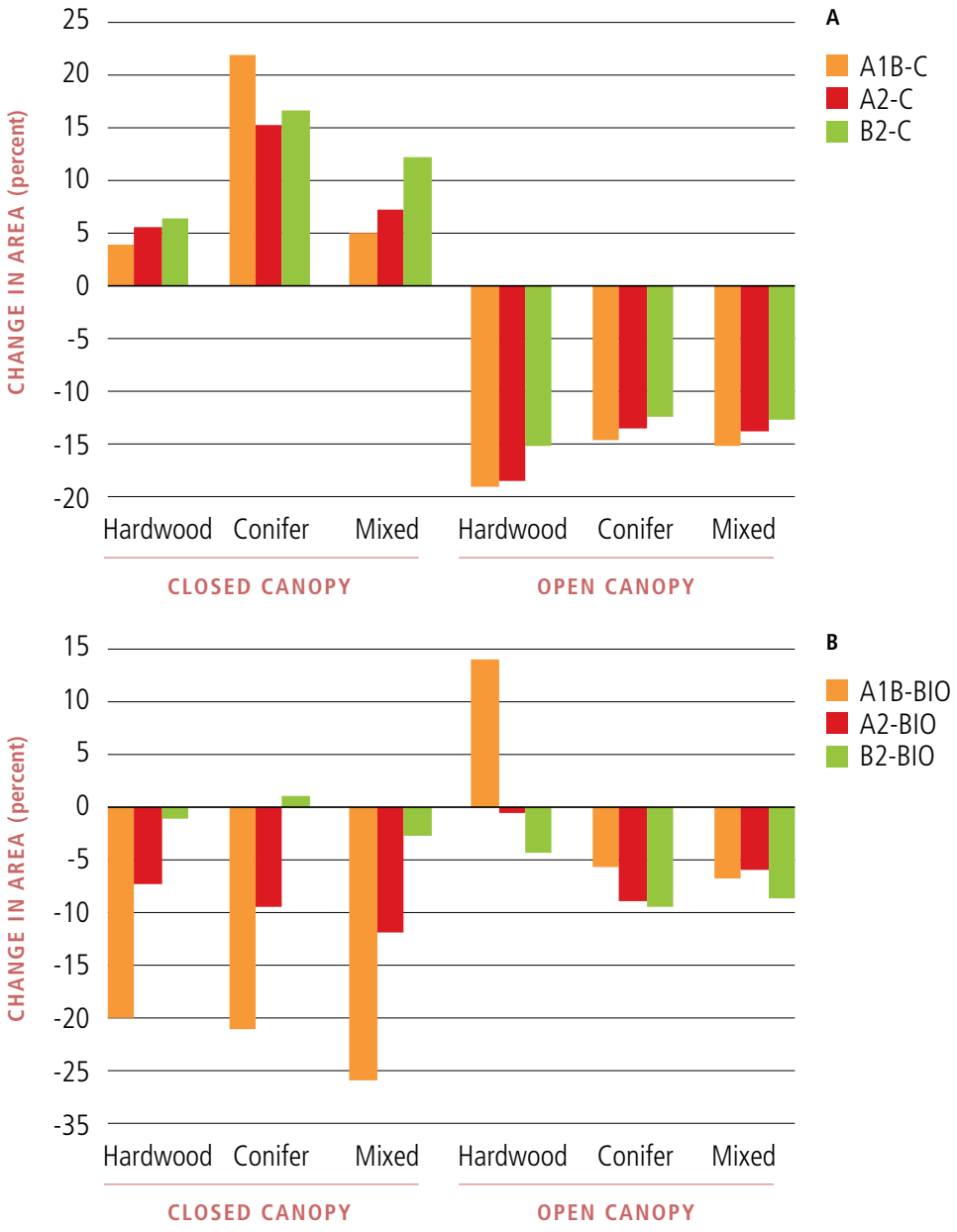


FIGURE 3.18

Projected change in closed- and open-canopy conifer, hardwood, and mixed forest habitats of the North, 2010 to 2060, for six scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Panel A scenario projections assume harvesting will continue at recently observed levels (scenarios labeled –C); panel B scenario projections assume increased harvest for bioenergy production (scenarios labeled –BIO).

Table 3.1—Projected area, 2060, and percent change from the 2010 baseline of closed-canopy and open-canopy forest habitat classes (NatureServe 2011, Tavernia et al. 2013) across the Northern United States under three scenarios; note that changes were driven by projected climate and land-use changes, forest succession, and forest harvesting.

Scenerio	Total habitat	Closed canopy forests			Open canopy forests		
		Hardwood	Conifer	Mixed	Hardwood	Conifer	Mixed
	Million acres (percent change in acreage)						
2010	173.4[a]	70.4	4.3	10.8	59.5	16.7	11.7
A1B-C[b]	162.4 (-6)	73.1 (4)	5.2 (21)	11.4 (6)	48.5 (-19)	14.3 (-14)	9.9 (-15)
A2-C	164.1 (-5)	74.3 (6)	5.0 (16)	11.6 (7)	48.7 (-18)	14.5 (-13)	10.1 (-14)
B2-C	167.5 (-3)	74.9 (6)	5.0 (16)	12.1 (12)	50.6 (-15)	14.6 (-13)	10.2 (-13)

[a]0.6 million acres of the total 174 million acres of forest area could not be associated with habitat classes (Tavernia et al. 2013).

[b]Under the three scenarios, A1B-C assumes moderate levels of greenhouse gas emissions associated with moderate gains in population growth and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2-C assumes high levels of greenhouse gas emissions associated with large gains in population growth and energy consumption with moderate gains in income; and B2-C assumes low levels of greenhouse gas emissions associated moderate gains in population growth, income, and energy consumption.

Early successional forest habitats in the North have experienced decades-long decreases in acreage (Trani et al. 2001). Researchers attribute these decreases to maturation of forests on abandoned farmland, altered forest management practices, forest ownership patterns that discourage harvesting, fire suppression and other disruptions to natural disturbance regimes, and land-use conversion (Askins 2001, Lorimer and White 2003, Trani et al. 2001). Given that young forests characteristically have small diameter trees and relatively open canopies, decreases can be expected to continue under all scenarios.

If so, a broad segment of the wildlife community would be affected. For example, many species that typically inhabit mature, closed-canopy forests relocate to early successional habitat at certain times of the year (Vitz and Rodewald 2006). Wildlife managers can use information about historical habitat conditions and wildlife population dynamics to identify a mix of closed- and open-canopy habitats capable of supporting diverse wildlife communities (Askins 2001, Litvaitis 2003, Lorimer 2001, Thompson and DeGraaf 2001). As illustrated by the intensive harvesting scenarios, policy and management decisions can alter forest habitat conditions and, consequently, help achieve goals for habitat improvement.

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Maintenance of Productive Capacity of Forest Ecosystems

4

W. Keith Moser, Patrick D. Miles, Aimee Stephens, Dale D. Gormanson, Stephen R. Shifley, David N. Wear, Robert J. Huggett, Jr., Ruhong Li

Introduction

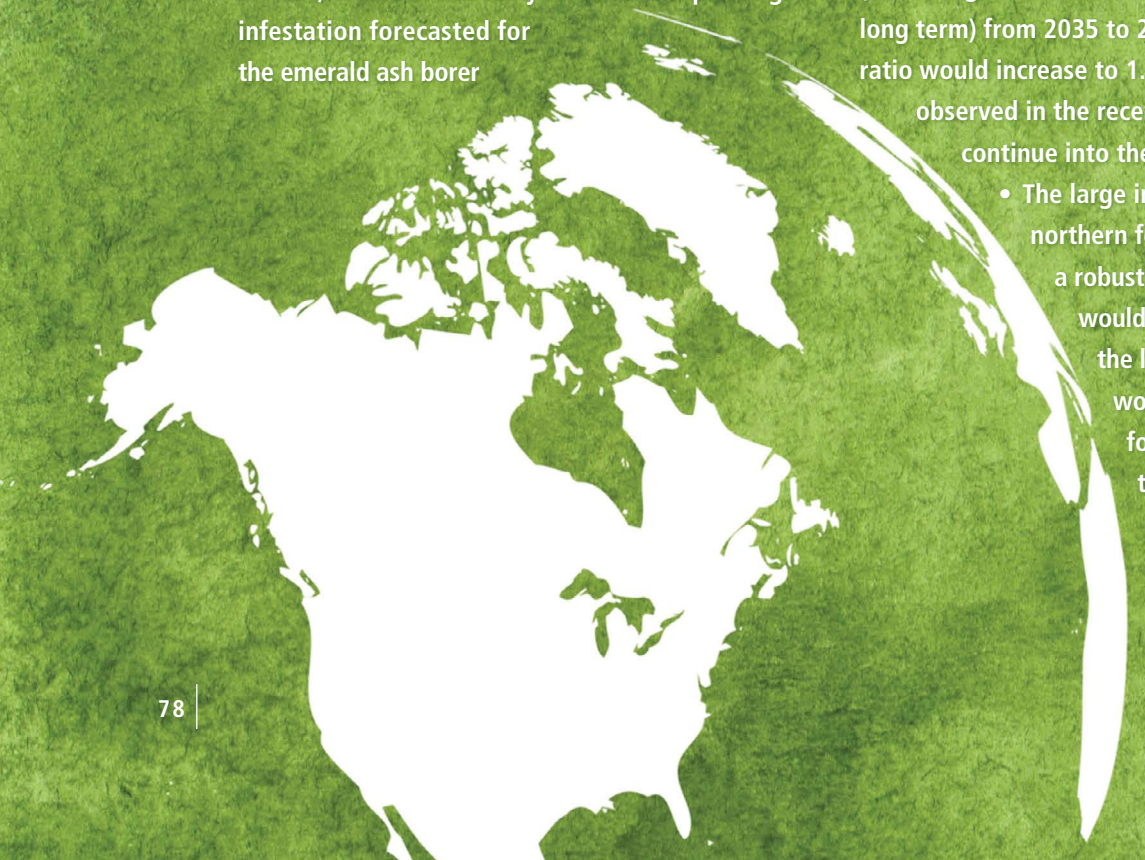
THIS CHAPTER REPORTS projected changes in forest area, age, volume, biomass, number of trees, and removals from 2010 to 2060 for alternative scenarios that bracket a range of possible future socioeconomic and climate conditions in the Northern United States, which consists of 20 central and northeastern States (see Fig. 1.1). As described in Chapter 2, the scenarios incorporate different assumptions about population growth, economic development, land-use change, carbon emissions, and climate change. Changes in forest attributes over time for each scenario were estimated using the Forest Dynamics Model (Wear et al. 2013). The information presented in this chapter, more than any other, is directly derived from projections of changing forest conditions for each scenario as modeled by the Forest Dynamics Model.

Several alternative scenarios were used that cover a range of different assumptions about the economy, population, climate and other driving forces. The assumptions were incorporated into analytical models that estimate how northern forests are likely to change under each alternative scenario. The seven scenarios (A1B-C, A1B-BIO, A2-C, A2-BIO, A2-EAB, B2-C, and B2-BIO) are based on a storyline and storyline variation. They are labeled by their storyline identifier (A1B, A2, or B2) followed by a hyphen and the storyline variation (C, BIO, or EAB).

The storylines were developed by the Intergovernmental Panel on Climate Change (IPCC 2007, Chapter 2): A1B assumes moderate gains in population growth with large gains in income and energy consumption—but with a balanced renewable/fossil fuel portfolio; A2 assumes large gains in population growth and energy consumption with moderate gains in income; and B2 assumes moderate gains in population growth, income, and energy consumption. All projections are estimated using two versions of a single global circulation model, the CGCM 3.1 (Canadian Centre for Climate Modelling and Analysis 2012a) for A1B and A2 and the CGCM 2.0 (Canadian Centre for Climate Modelling and Analysis 2012b) for B2.

Key Findings

- If harvesting rates observed in the recent past continue into the future, differences in projections of forest conditions in the northern region would be small.
- Under all projections, the trend of steadily increasing live wood volume that characterized northern forests in the past century would level off from 2010 to 2050; after 2050, volume is projected to decrease if harvesting increases to satisfy demand for bioenergy.
- The levels of increased biomass harvesting for energy assumed in three scenarios appear to be too large to be sustainable through 2060; lower levels of harvesting for energy or projections that include wood-energy plantations could have different outcomes.
- Forest area by age class is concentrated in the 40- to 80-year age category, resulting in a lack of structural forest diversity that would take decades to alter.
- Under a projection of large gains in population and energy consumption and moderate gains in income, total ash mortality within the expanding infestation forecasted for the emerald ash borer forest conditions would have little effect on total volume, area by species group, or area by age class in northern forests.
- Under all projections for the North, the area of the maple-beech-birch forest-type group would increase and the area of nearly all other forest-type groups would decrease; projections are mixed for the white-red-jack forest-type group.
- For the North as a whole, projected forest removals resulting from land-use changes are likely to average about 13 percent of total removals, with the remainder resulting from harvesting; in populous eastern States—including Massachusetts, Maryland, New Jersey, and Rhode Island—removals resulting from land-use changes would be >50 percent in some decades.
- Under all projections for northern forests, the growth-to-removals ratio would be <1.0 (indicating an unsustainable situation over the long term) from 2035 to 2055; by 2060, the ratio would increase to 1.2 if harvesting rates observed in the recent past (2003 to 2008) continue into the future.
- The large increases in harvesting northern forests required to satisfy a robust demand for bioenergy would not be sustainable over the long term because it would result in decreasing forest volume after 2050; this does not suggest that lower rates of bioenergy harvesting would be unsustainable.



The three storyline variations are as follows:

- C—the standard variation continuing recent removals trends
- BIO—increased harvest and utilization of woody biomass for energy
- EAB—potential impact of continued spread of the emerald ash borer (EAB) (*Agrilus planipennis*) with associated mortality of all ash trees in the affected areas.

A baseline assessment (Shifley et al. 2012) characterized the North as the most densely forested and most densely populated region of the country—a place where people and forests meet and mingle. The past influences of this juxtaposition of people, forests, and associated interactions have culminated in the forests of today, and expectations about future interactions strongly shape projections of forest conditions. Over the next 50 years, population is expected to increase across all three storylines (Chapter 2) resulting in an increase in urban areas at the expense of all other land uses (Chapter 10).

FOREST AREA

Over Time

The anticipated decreases in forest area reverse the long-term trend of increasing forest area in the region (Fig. 4.1). Over the next 50 years, forest land area is projected to decrease from an estimated 174 million acres in 2010 to 163 million acres (-6.4 percent) in 2060 under A1B; to 165 million acres (-5.4 percent) under A2; and to 168 million acres (-3.5 percent) under B2. Although decreasing by about 1 percent per decade across all scenarios, the anticipated losses would still be relatively small compared to the cumulative increase in forest area since the start of the 20th century. However, the anticipated loss paired with the expected increases in population would mean a substantial decrease in forest area per capita (Appendix Chapter 2). Northern forests will have to work harder to meet the needs of a growing population, which is expected to increase by somewhere between 15 and 50 million people from 2010 to 2060 (Chapter 2).

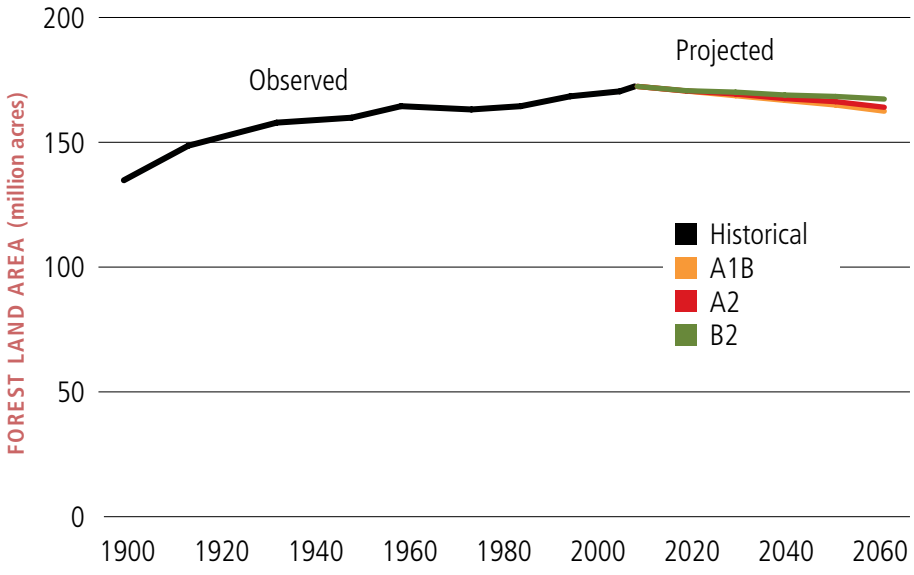


FIGURE 4.1
Forest area in the North under historical conditions (Smith et al. 2009) and projected from 2010 to 2060 under three greenhouse gas storylines (IPCC 2007)—A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Forest area in 1630 has been estimated at about 300 million acres.

Projected population increases are expected to occur in and around existing urban centers (Chapter 2). Consequential losses in forest area are expected to follow a similar pattern (Chapter 3). As a result, forest land losses would be concentrated in the more densely populated States along the Atlantic seaboard (Fig. 4.2). With the loss of forest land and with the clustering of losses around urban areas would come additional concerns about fragmentation and parcellation, the consequences of which could outweigh the relatively small percentage loss in total forest area (Chapter 3).

By Forest-type Group

The current distribution of forest area by forest-type groups is spatially depicted in Figure 4.3 and displayed in Figure 4.4. Under all three scenarios the oak-hickory (*Quercus* spp.–*Carya* spp.) and maple-beech-birch (*Acer* spp.–*Fagus* spp.–*Betula* spp.) groups would continue to dominate through 2060. These two types, which together comprised 62 percent of the total forest area in 2010, are projected to account for about 64 percent of total forest area under all scenarios in 2060 (Appendix Chapter 4).

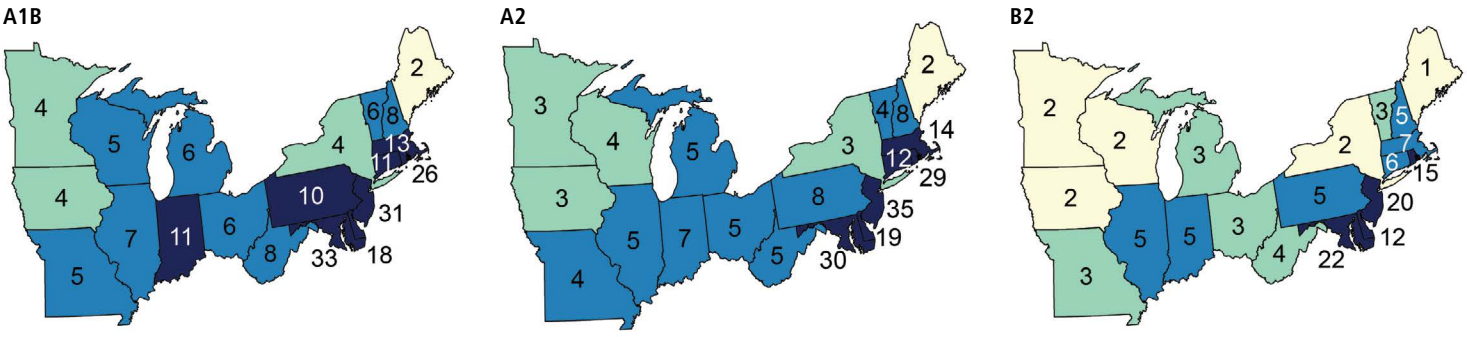


FIGURE 4.2

State-level projected decreases in forest area, 2010 to 2060, under three greenhouse gas emissions storylines: A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption.

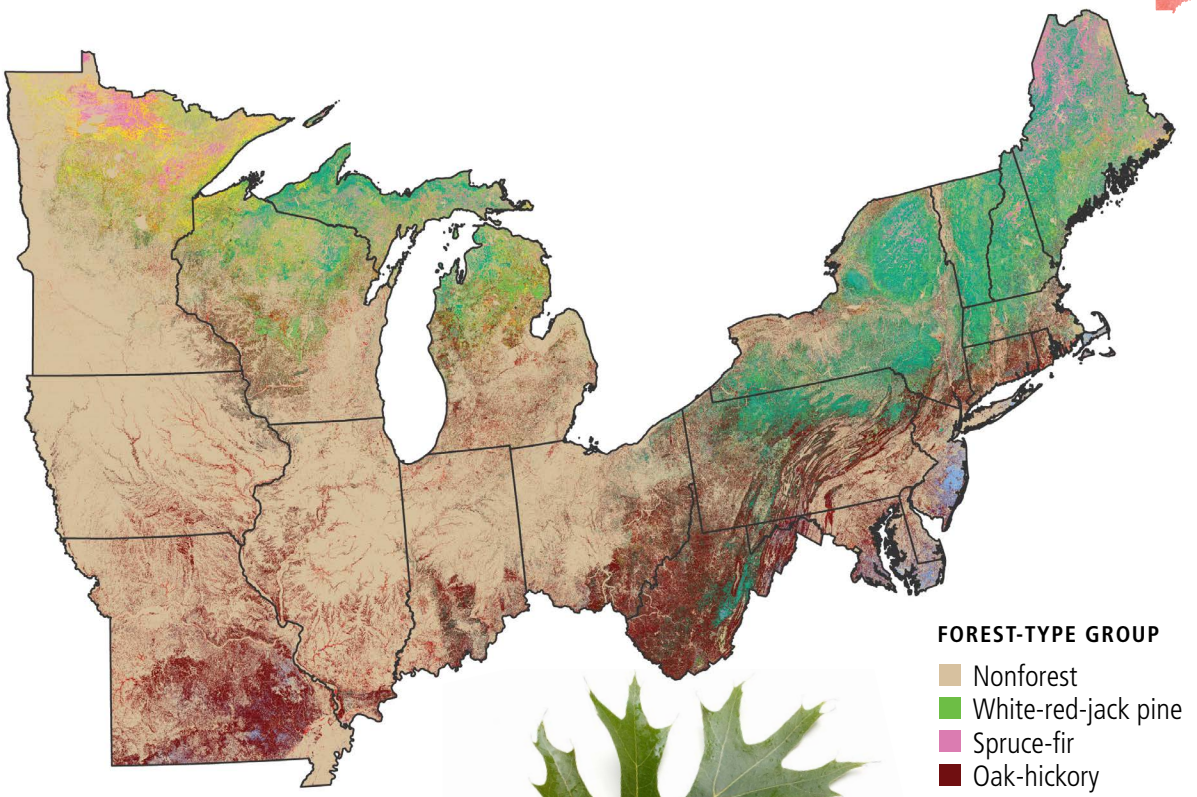


FIGURE 4.3

Forest-type groups in the North (Wilson et al. 2012, Wilson et al. 2013).

Forest area loss will likely be one of the biggest contributors to composition changes in northern forests from 2010 through 2060. Figure 4.5 shows the percent change in forest area by forest-type group. Four of the six groups—spruce-fir (*Picea* spp.—*Abies* spp.), oak-hickory, elm-ash-cottonwood (*Ulmus* spp.–*Fraxinus* spp.–*Populus* spp.), and aspen-birch (*Populus* spp.—*Betula* spp.)— are projected to decrease under all three scenarios. The white-red-jack pine group (*Pinus strobus* – *Pinus resinosa* – *Pinus banksiana*) is expected to increase under some scenarios, and the maple-beech-birch group is expected to increase under all scenarios.

These changes reflect the differential impacts of projected stand development, succession, growth, harvest, and mortality on areas that would remain forested (for example, more maple-beech-birch and less oak-hickory). Also, projected increases in urban areas would affect some groups more than others, in large part reflecting their relative abundance in locations near major population centers.

Only 52 percent of forest area is projected to be in the same forest-type group in 2060 as it was in 2010 (Fig. 4.6), with changes stemming from a variety of causes including succession, harvesting, and diversion to nonforest land uses. For example, only 40 percent of the land that was in the white-red-jack pine group in 2010 is projected to remain in that group in 2060; 21 percent is projected to be converted to the late successional maple-beech-birch group; and 5 percent to nonforest uses (Fig. 4.6). Conversion to nonforest land uses is projected to be highest in the "other" forest-type group (10 percent) and the oak-hickory group (9 percent), both of which are often located in close proximity to urban areas. Conversions to nonforest would be lowest (2 percent) for the spruce-fir group, which is usually located far from large urban areas. The elm-ash-cottonwood group—especially under the emerald ash borer scenario—and the aspen-birch groups would experience the largest percentage decrease (Fig. 4.5).

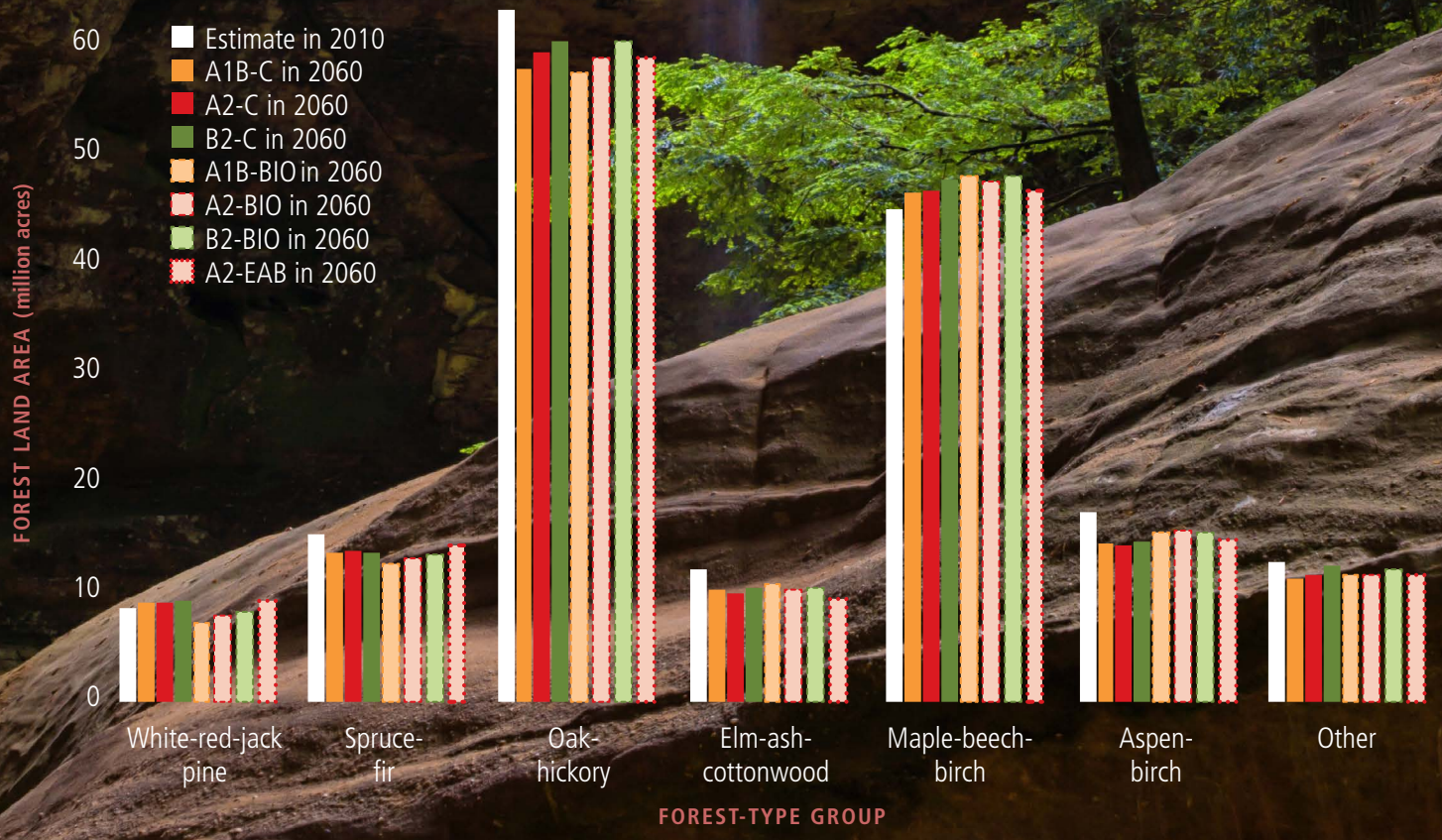
By Age Class

Because of past patterns of natural and human disturbance that occurred in the first half of the 20th century, northern forests are predominantly "middle aged," with over half of current acres between 40 and 80 years and relatively few acres <20 years or >100 years (Pan et al. 2011) (Fig 4.7). This lack of age-class diversity has implications for biodiversity and wildlife habitat suitability now and into the future (Chapter 3).

In forests undergoing normal patterns of succession without large disturbances, the age-class distribution naturally shifts toward older forests. Certain harvesting practices or severe insect, disease, or fire effects will regenerate forest area and move it to the youngest age class. Over the past five decades, however, rates of forest regeneration have been relatively low, and northern forests have aged.

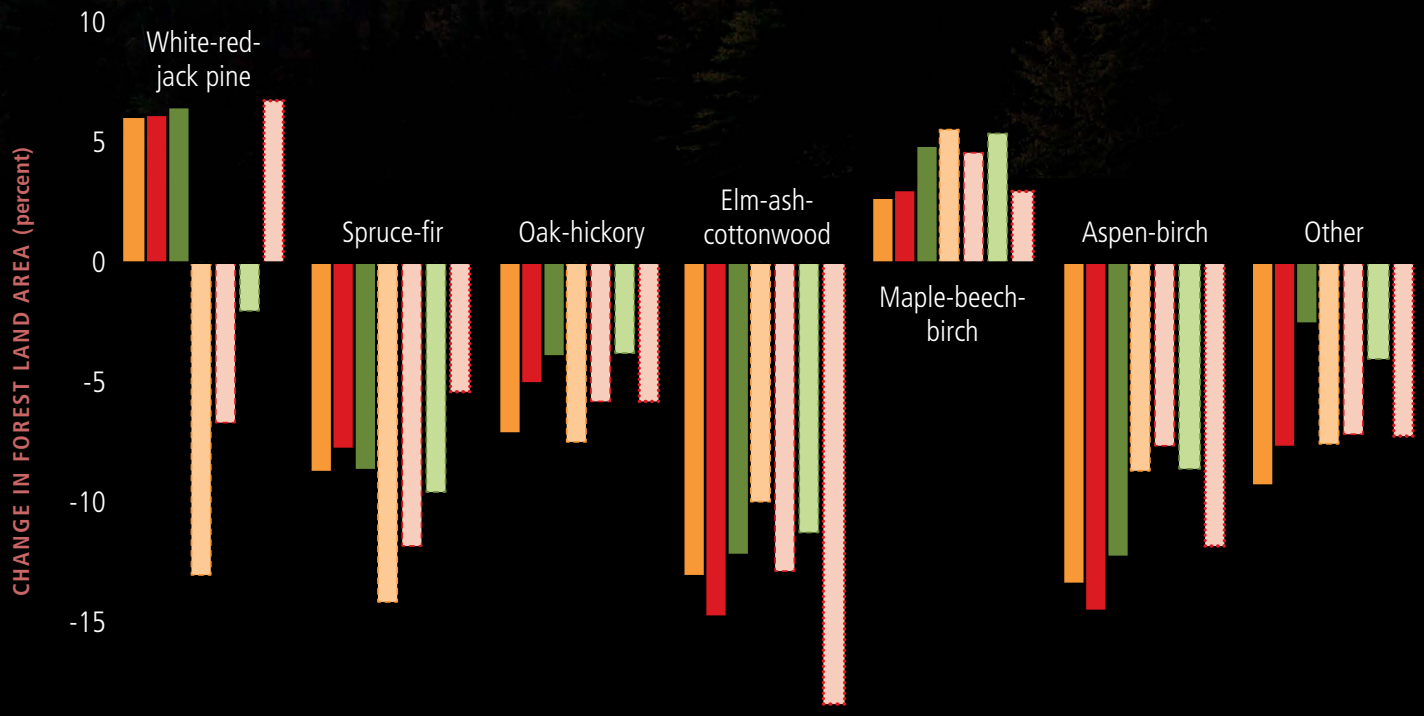
Three of the scenarios (A2-C, A1B-C, and B2-C) assume continuation of the levels of forest harvesting, regeneration, and disturbance that have contributed to the current compressed age-class distribution. As a result, northern forests would continue to age, with the bulk of acres shifting into the 60- to 100-year classes over the next 50 years (Fig 4.7). Chapter 3 reports decreasing potential habitat for species that depend on early successional forest ecosystems, primarily because of changes in forest succession and conversion of forests to nonforest uses. Under A2-EAB, a similar shift in the age-class distribution would occur, despite the assumed loss of ash species to the continued spread of emerald ash borer. For all of these scenarios, forest maturation over the next five decades is expected to decrease the area of forest land <60 years and increase area for older forests (Fig. 4.8). Longer projection periods would likely exacerbate this trend.

FIGURE 4.4



Area of forest land in the North by forest-type group, 2010 and 2060 (projected), for seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will eventually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

FIGURE 4.5



Projected decrease in forest area by forest-type group in the North, 2010 and 2060 (projected), for seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will eventually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

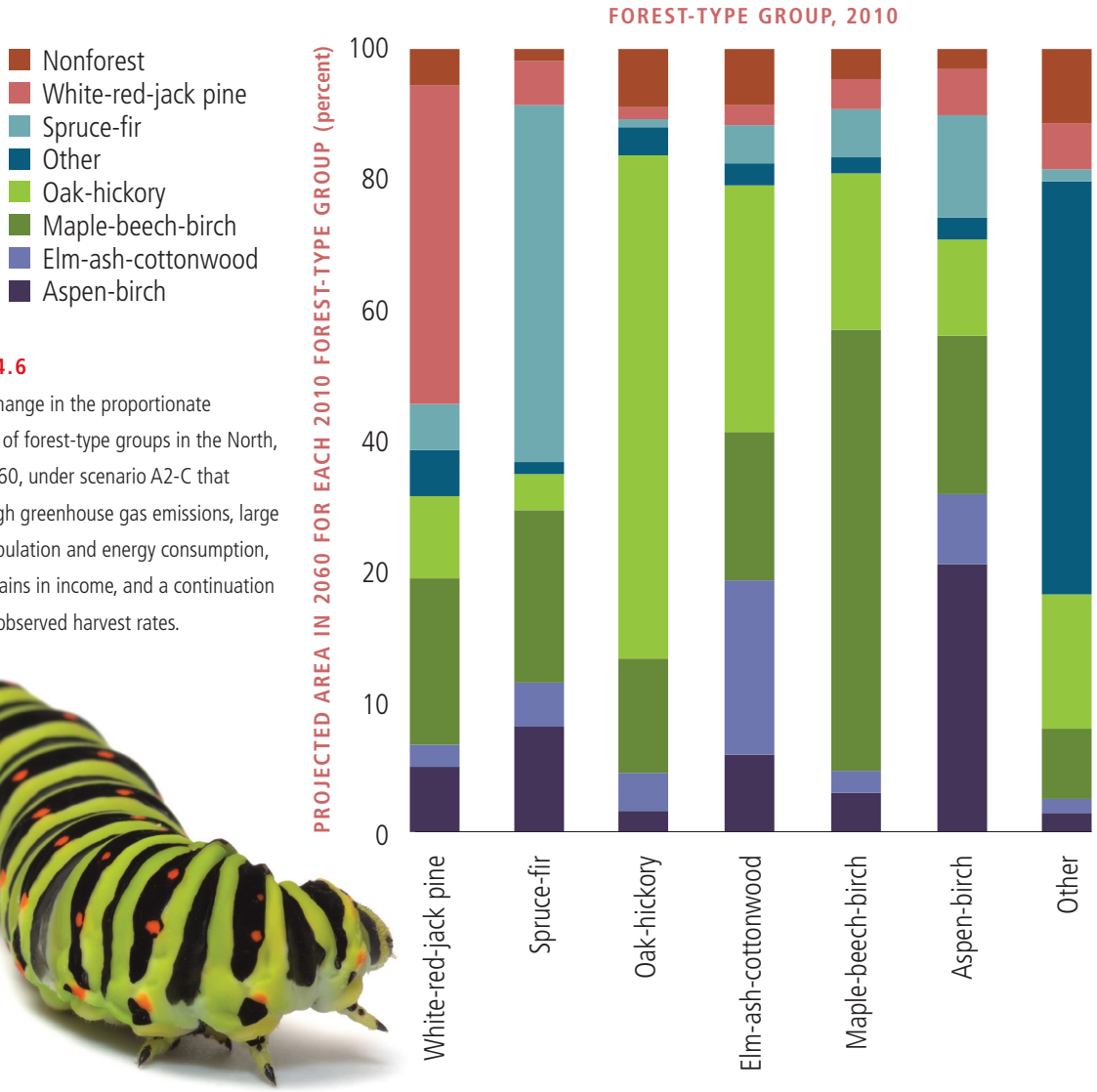


FIGURE 4.6

Projected change in the proportionate distribution of forest-type groups in the North, 2010 to 2060, under scenario A2-C that assumes high greenhouse gas emissions, large gains in population and energy consumption, moderate gains in income, and a continuation of recently observed harvest rates.

The pattern of age-class changes for A2-EAB, which assumes expanding zones of ash mortality, would mirror that of the A2-C scenario. Because ash species are rarely the majority component of forest stands, the loss would not have an effect on the stand age of affected forest acres.

Scenarios with enhanced removals to meet the demand for bioenergy (A1B-BIO, A2-BIO, and B2-BIO) are projected to have the largest impacts on the age structure of northern forests. All three scenarios assume an increase in harvesting that results in regenerated stands. The projected total forest area would be the same for a paired set of scenarios (for example, A2-C versus A2-BIO), but the proportion of forest area in younger age classes would increase under the one that assumes increased harvesting for bioenergy. The result would be an increase in young (early successional) forests and a shift in distribution toward the younger age classes (Fig. 4.7). Under all scenarios with increased harvesting for bioenergy, forest area in the youngest age class (<20 years) would increase.

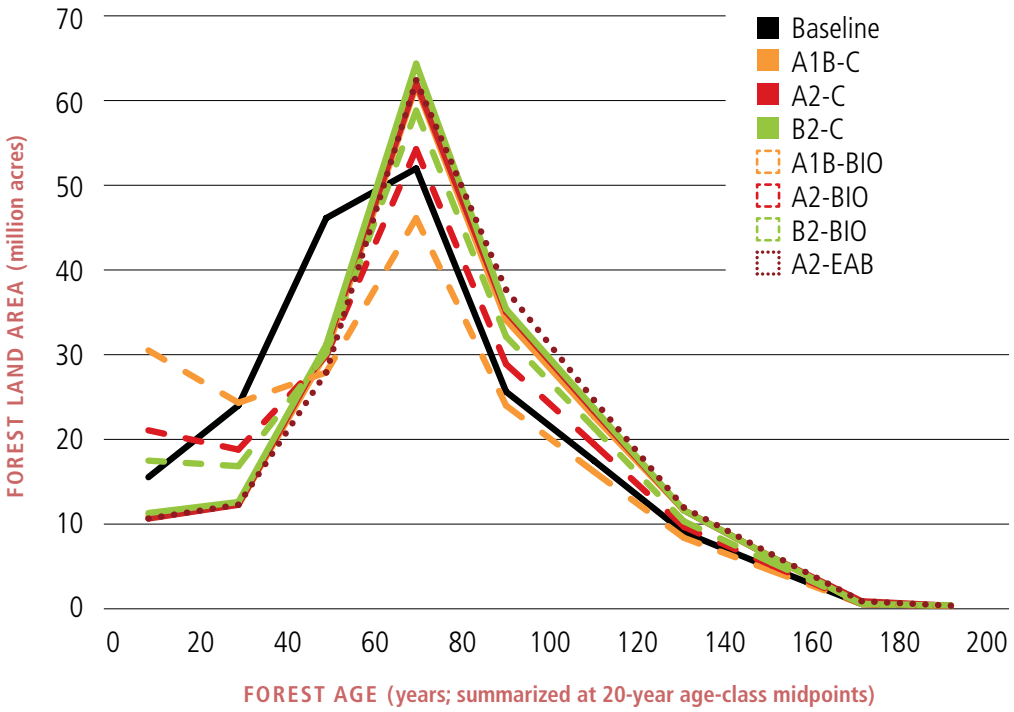


FIGURE 4.7

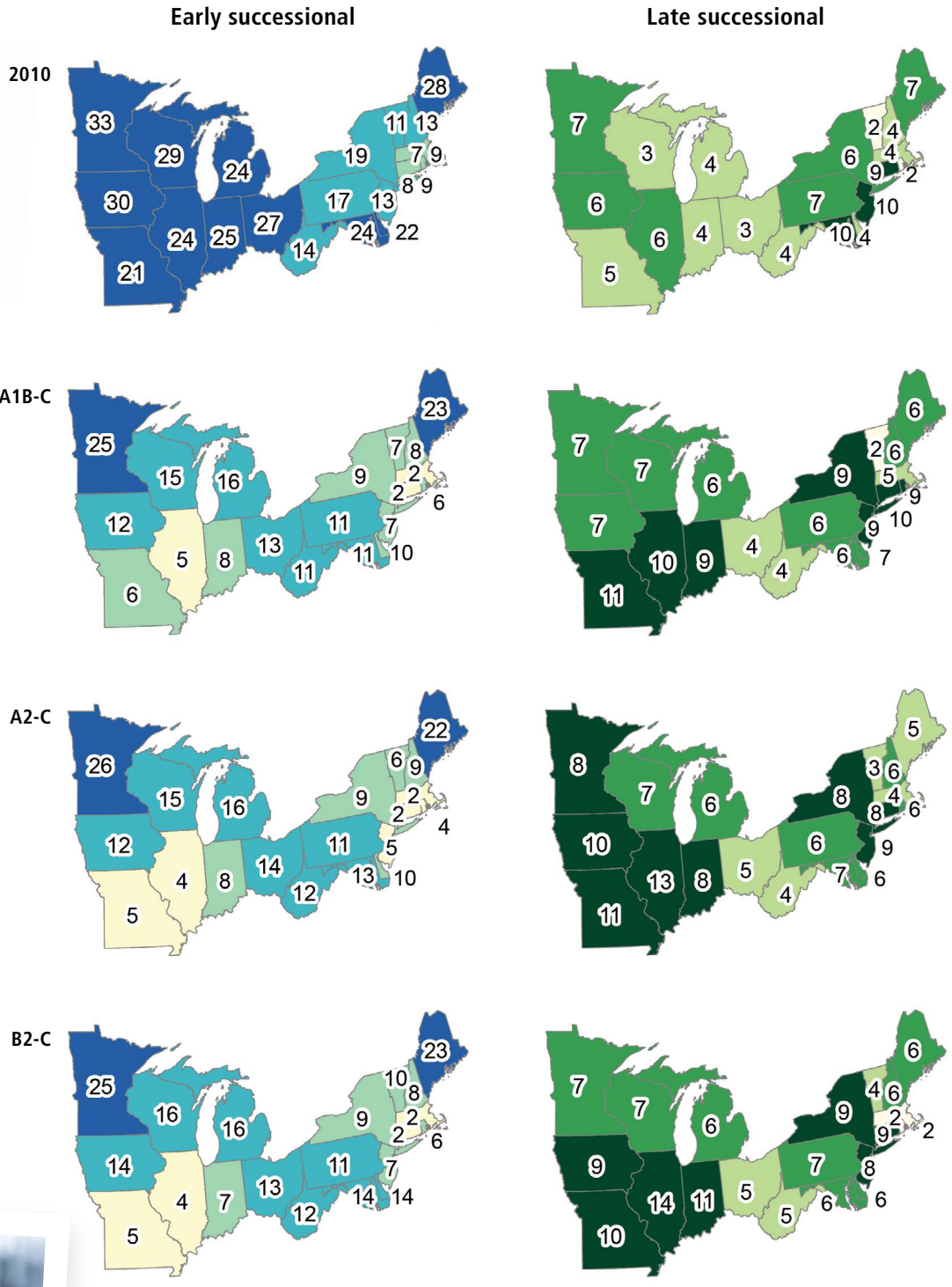
Forest land area by age class in the North is estimated for 2010 and projected for 2060 under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

Scenario A1B-BIO would result in double the area of young forests by 2060 while also reducing forest area in the 40- to 100-year classes. With increased harvesting, fewer acres would progress into older age classes. Thus, the projected increases for age classes >60 years would be smaller for scenarios with increased biomass harvesting than for no increase in harvesting (Figs. 4.7, 4.8).

All three scenarios with increased harvesting are expected to result in a more even distribution of forest area by age class, most notably for forests <80 years, which would improve both landscape-scale forest structural diversity and habitat diversity (Hunter and Schmiegelow 2011). However, as discussed in later sections of this chapter and in Chapter 5, the rate of harvesting associated with scenarios A1B-BIO, A2-BIO, and B2-BIO has other, less desirable, ramifications.

FIGURE 4.8

Proportionate area of early successional forest (aged 40 years or younger) and late successional forest (aged more than 100 years) in the North in 2010 and 2060 (projected) under three scenarios that assume a continuation of recently observed harvest levels. Furthermore, A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption (IPCC 2007).



Many northern forests currently classified as >100 years will experience gap-phase regeneration and gradually move into an uneven-age structure with multiple age cohorts. Although uneven-aged stands do not fall neatly into a single age class or size class, these forests generally retain a cohort of mature, dominant overstory trees. Consequently, from a biodiversity perspective, uneven-aged stands are considered to be mature forests that are in the understory reinitiation stage of stand development—or as Oliver and Larson (1990) reported, in the old-growth stage of development.

NUMBER OF TREES

The number of trees in the region is projected to decrease by 12 to 20 billion, or roughly 10 to 17 percent, from 2010 to 2060 (Fig. 4.9). As forests age, fewer but larger trees are the expected outcome. The largest decrease would occur under the A2-EAB scenario, in which the emerald ash borer infestation would permanently reduce the total number of ash trees. The growing space released by dying ash trees is presumed to be captured by adjacent trees of other species rather than by new reproduction. This projected outcome—the long-lasting reduction in the total number of trees—is one of the most notable results from the A2-EAB scenario.

VOLUME

Live Tree Volume

The total volume of all live trees is a measure of historical productivity because it represents the wood volume that has accumulated up to the year of measurement. It is a function of site factors (productivity of the soil and availability of soil moisture), climatic factors (growing season length, averages and variations in temperature and rainfall), ecological factors (competing species and disturbances), and stand history (forest age, past management actions, and past disturbances). The estimates of all live volume include the volume from cull trees and noncommercial tree species, which are excluded in estimates of growing-stock volume discussed in the next section. Typically, estimates of all live volume are highly correlated with aboveground tree biomass, even though they exclude tree stumps, tops, branches, and bark, all considered part of the aboveground biomass pool.

The projected total live tree volume for the northern forests is somewhat similar across all scenarios until 2050 (Appendix Chapter 2, Fig. 4.10). The scenarios with increased biomass harvesting (A1B-BIO, A2-BIO, and B2-BIO) or increased mortality attributed to emerald ash borer (A2-EAB) would have less volume than those assuming no changes in harvesting (A1B-C, A2-C, and B2-C), but the trends for all scenarios would follow a similar pattern.

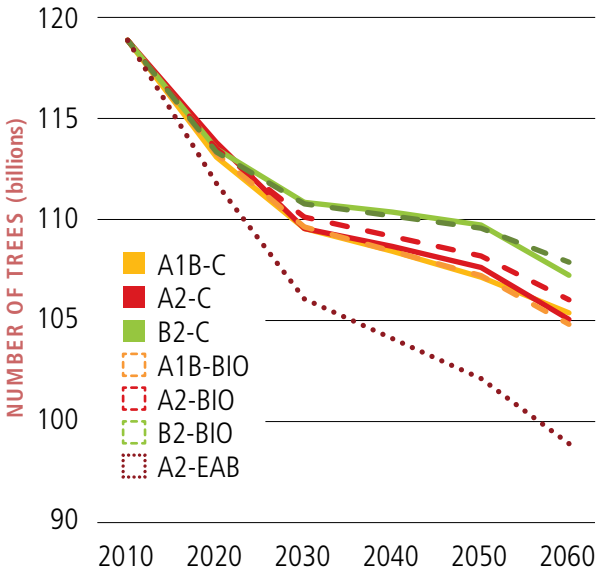


FIGURE 4.9

Projected number of trees in forests of the North, 2010 to 2060, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime.

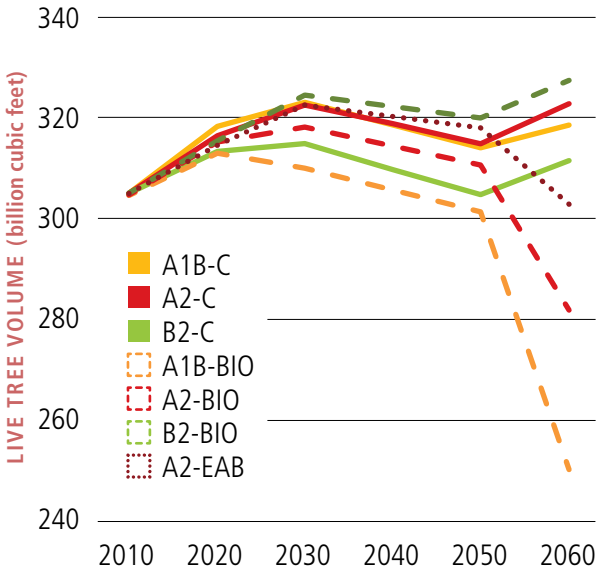


FIGURE 4.10

Projected live tree volume in forests of the North, 2010 to 2060, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime.

Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

Starting in 2050, however, biomass removals would increase rapidly under scenarios A1B-BIO, A2-BIO, and B2-BIO with a corresponding decrease in volume. For those scenarios, bioenergy demand would exceed what can be provided by alternative sources such as residues from wood production and agriculture, and require that harvesting increase dramatically (Ince et al. 2011a,b; Chapter 2).

Only scenarios with increased biomass harvesting (A1B-BIO and A2-BIO and B2-BIO) projected a net decrease in live tree volume from 2010 to 2060. But as illustrated in the following section on growing-stock volume, even the scenarios that project volume increases estimate that the rate of increase would be lower than the rate observed over the previous five decades.

Live tree volume projections are markedly different across the region, with most of the States in western areas increasing in volume and most of the States farther east experiencing smaller increases or even decreases (Fig. 4.11). Many of the eastern States that are expected to experience losses are the same States expected to lose forest area to urbanization. Projected differences vary greatly by State under A1B-C, A2-C, and B2-C (based on historical removals by product class from 2003 to 2008) versus scenarios with increased biomass utilization. Examples are Minnesota and Wisconsin, both heavily forested and both expected to experience significant volume decreases under the biomass scenarios, particularly A1B-BIO, and increases under the other scenarios. Under all enhanced biomass scenarios, heavily forested States where current harvesting rates are high are projected to supply most of the additional biomass. This outcome is in part due to model assumptions about future biomass harvesting that are based on historical rates of harvest removals and land use. A simple scaling function is used to increase removals under the biomass scenarios (Chapter 2).

Differences in projected volume among forest-type groups are illustrated by comparing A2-C with corresponding scenarios that assume enhanced biomass utilization (A2-BIO) and expanding emerald ash borer impact (A2-EAB).

Volume differences among these scenarios were generally <10 percent by 2060 (Fig. 4.12) and proportional to volumes in 2010. As expected, scenarios with increased biomass harvesting or increased ash mortality predict less live volume than A2-C.

Further comparisons by major species group indicated that under A2-EAB, ash trees would essentially disappear from northern forests by 2040 (Fig. 4.13), but the loss of ash volume would be partially offset by volume increases in other species (Chapter 5).

Growing-stock Volume on Timberland

In the North, 95 percent of forest land is classified as timberland (forest land that maintains a minimum potential for growth of 20 cubic feet per acre per year and is not restricted from active forest management by statute or regulation); and 92 percent of the timber on timberland is classified as growing stock (merchantable timber volume, or all live volume reduced by defect and nonmerchantable species). Consequently, patterns and trends observed for growing-stock volume on timberland are usually similar to corresponding measures of total volume of all live trees, albeit with lower volume totals.

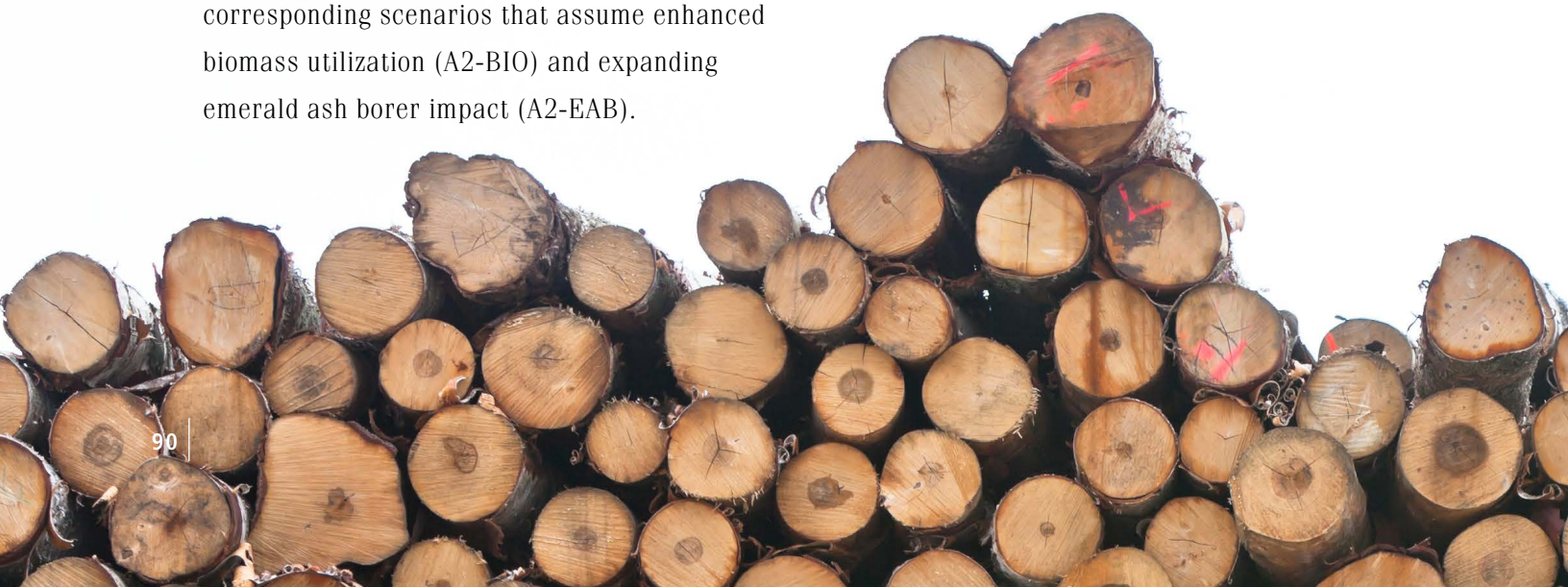
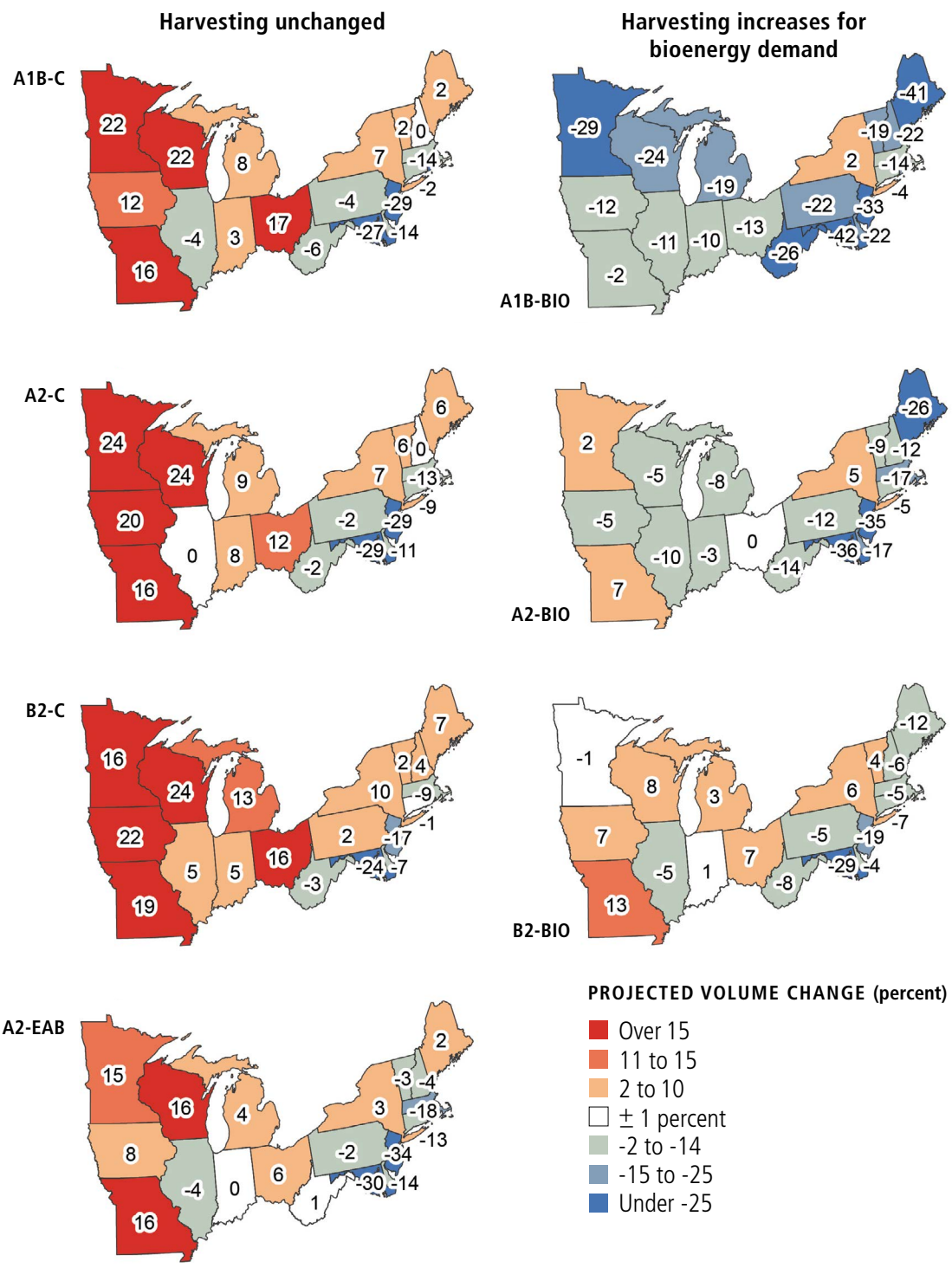


FIGURE 4.11

Projected change in live tree volume in forests of the North, 2010 to 2060, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.



Trends and projections of volume—Historical data from Smith et al. (2009) show that volume increases of growing stock have been steady, doubling from about 125 billion cubic feet in the early 1960s to current levels of 263 billion cubic feet. This trend is projected to level off by 2050 (Fig. 4.14), when differences in assumptions would result in decreases under the scenarios with accelerated biomass harvesting and modest increases under the other scenarios. Even under the scenarios that project the largest increases in growing-stock volume, the rate of increase would be much smaller than that observed in previous decades. Projected growing-stock volume in 2060 would be 6 percent larger than the 2010 estimate under A1B-C, 7 percent larger under A2-C, and 9 percent larger under B2-C. Decreases in growing stock volume from 2010 to 2060 under scenarios that assume accelerated biomass removals would be 0.2 percent (B2-BIO), 8 percent (A2-BIO) and 19 percent (A1B-BIO); clearly A2-BIO and A1B-BIO would be unsustainable in the long run.

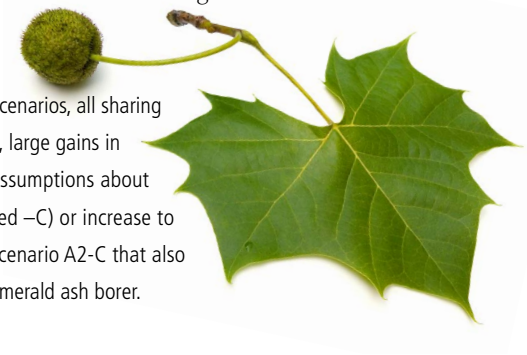
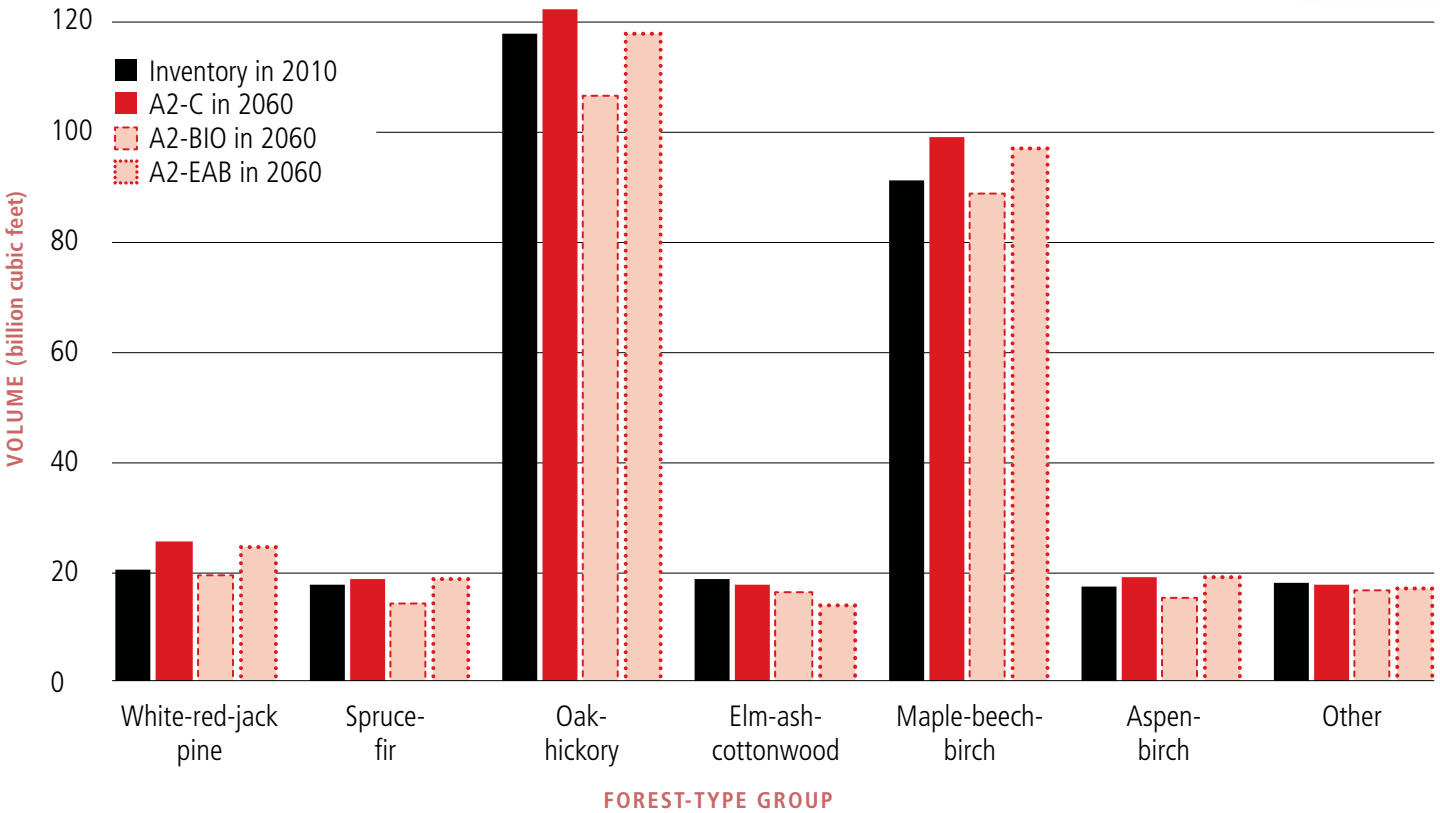


FIGURE 4.12

Live tree volume on forests in the North estimated for 2010 and projected through 2060 under three scenarios, all sharing one greenhouse gas emission storyline, A2, that assumes large increases in greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income (IPCC 2007), but with varying assumptions about future removals. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.



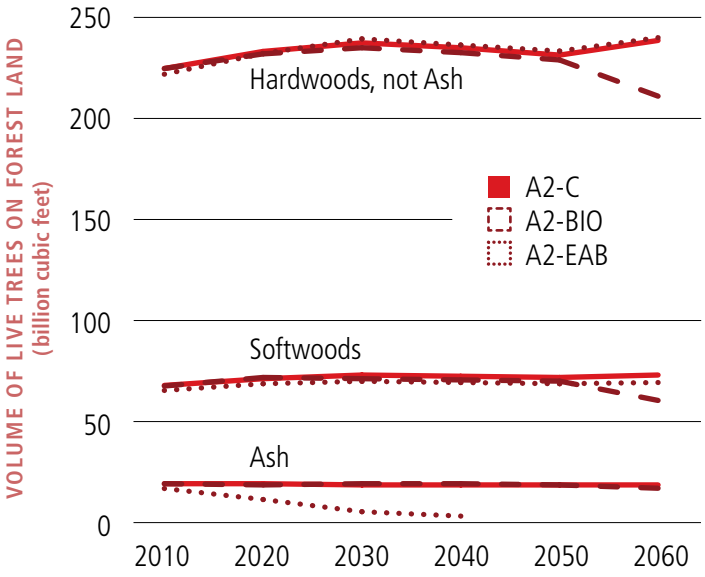


FIGURE 4.13

Projected change in live tree volume of ash, other hardwoods, and softwoods in the North under three scenarios, all sharing one greenhouse gas emission storyline, A2, that assumes large increases in greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income (IPCC 2007); but with varying assumptions about future removals. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

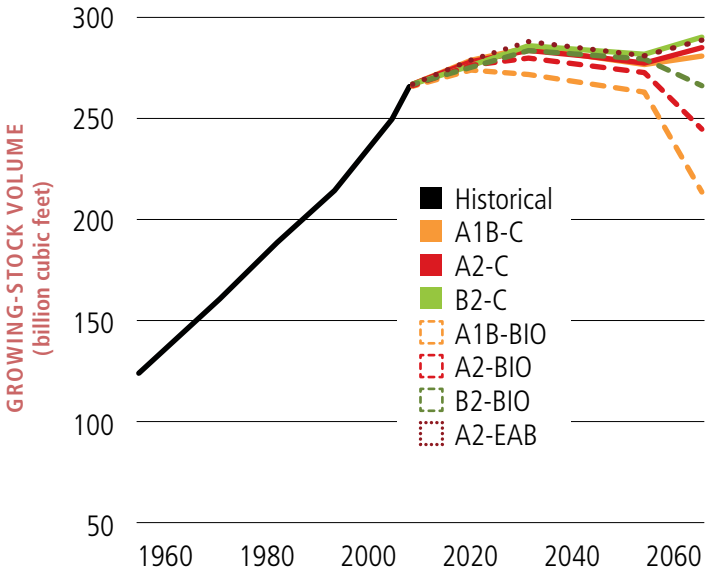


FIGURE 4.14

Net volume of growing stock on timberland in the North, both historical (back to 1963) and projected through 2060 under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

Despite the expected impact of emerald ash borer upon ash species, regional growing-stock volumes in 2060 projected under A2-EAB would increase by 8 percent over the 2010 estimates and would mirror projections for A2-C.

The change from a historical trend of rapidly increasing growing-stock volume to a projected trend of nearly constant growing-stock volume can be attributed to the combined effects of (1) an aging forest resource with a normal decrease in the annual rate of volume growth; and (2) an accelerated conversion of forest to urban land with a corresponding loss of timberland area and associated losses in timberland volume.

Net volume growth predictions—Collectively, the annual rates of volume growth, mortality, and removals determine the net change in total growing-stock volume as illustrated in Figure 4.14. When net growing-stock volume (gross growth less mortality) exceeds growing-stock removals, the result is an overall increase in growing-stock volume. Likewise, a high rate of mortality or of removals can result in a decrease in total volume, for example, under A1B-BIO (Fig.4.15).

This section reports net growth of growing-stock volume, which has been adjusted to exclude volume losses not associated with harvesting or land-use removals (harvesting and land-use removals are addressed in subsequent sections). Net growth is usually a positive value; a negative value would indicate abnormally high mortality attributed to insect infestations, disease outbreaks, weather events, wildfire, or other severe disturbances.

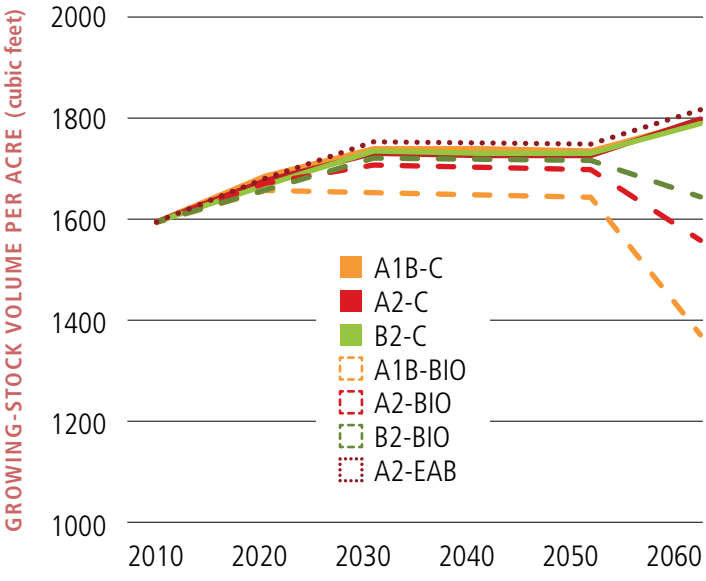


FIGURE 4.15

Projected change in per-acre growing stock in the North, 2010 to 2060, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

Predicted net annual volume growth for growing stock on timberland would be essentially the same under A1B-C, A2-C, B2-C, and A2-EAB (Fig. 4.16) for the entire projection period. Conversely, the scenarios with increased biomass harvesting (A1B-BIO, A2-BIO, B2-BIO) projected much higher increases in volume growth from 2030 to 2060, primarily because increased harvesting intensity regenerates new, young forest areas that typically have more trees,

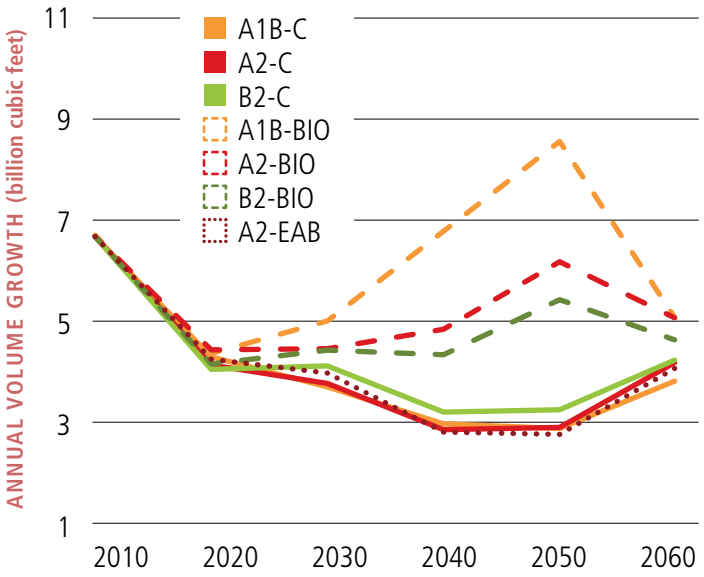


FIGURE 4.16

Projected average annual increase in growing-stock volume for the North, 2010 to 2060, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

smaller trees, and less volume per acre—but a faster rate of volume increase—than the mature forest they replace. Thus, the enhanced biomass scenarios would create a temporary bubble of growth related to the intensity of the harvesting removals. As shown in subsequent sections, much of this accelerated growth would be offset by the accelerated removals, resulting in little net change in volume.

REMOVALS

Volume removals occur when trees are harvested or when land is converted to urban or other uses. In the northern forests, partial harvesting of the overstory can accelerate the growth of the remaining trees. Harvesting that removes much or all of the forest overstory usually regnerates land back to young forest. Thus, harvesting mature forest can sometimes stimulate increased rates of volume growth in the residual or replacement forests. However, land that is converted to urban use is almost always permanently lost from the forest resource base, and its associated wood volume no longer contributes to the timberland volume total. In contrast, land-use conversions between timberland and agricultural land are more likely to be bidirectional; for example, abandoned agricultural land in one location often reverts to timberland through natural succession at the same time that forests are cleared for agriculture elsewhere.

Removals, whether by harvesting or by conversion of forests to another use, were modeled in 5-year intervals and then summarized by decade from 2020 to 2060 (Appendix Chapter 4). As described in Chapter 2, removals predictions were based on assumptions that the patterns of harvesting removals observed in the recent past will continue into the future (A1B-C, A2-C, B2-C, A2-EAB) or will increase to meet bioenergy demand (A1B-BIO, A2-BIO, B2-BIO).

Procedurally, the volume of removals attributable to land-use change for a given period was calculated as acreage converted to nonforest use multiplied by average volume per acre. Removals attributable to harvesting were then calculated by subtracting estimated land-use removals from the total removals projected by the Forest Dynamics Model (Chapter 2). The following sections separately discuss the projected volume changes for both types of removals.

Harvesting

Annual removals in northern forests are projected to double or triple from 2010 to 2060 under the enhanced biomass utilization scenarios, with increases ranging from 2.9 to 6.8 billion cubic feet (Appendix Chapter 4, Fig. 4.17).

In contrast, annual removals would be essentially flat and nearly identical under the other four scenarios, rising slightly from 3.09 billion cubic feet in 2010 to 3.33 billion cubic feet under A1B-C, 3.39 billion cubic feet under A2-C, 3.12 billion cubic feet under B2-C, and 3.58 billion cubic feet under A2-EAB by 2060.

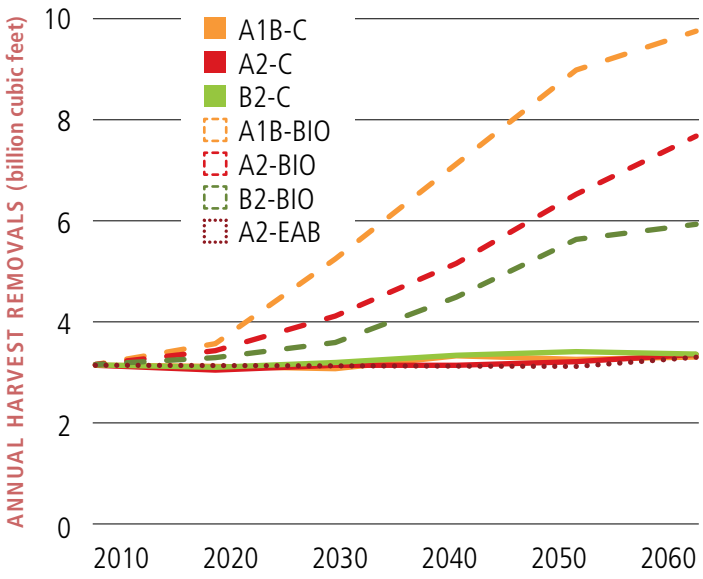


FIGURE 4.17

Annual harvest volumes for the North for 2010 and projected through 2060, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

With the exception of the densely populated areas on the Atlantic seaboard, projected removals are expected to increase or stay relatively constant at the State level, as shown for A2-C in Figure 4.18. An example is Maine, which had the highest projected removals of any Northern State based on removals that increased by <5 percent from 2010 to 2060. The other heavily forested States of Michigan, Minnesota, and Wisconsin also are projected to have increases, as is the less heavily forested Indiana, and Pennsylvania is expected to remain about the same. With the exception of Rhode Island, decreases in volume harvested are projected for the States along the Atlantic seaboard.

Modeling the extent of salvage harvesting that would accompany ash mortality was beyond the scope of this chapter; doing so would likely have produced noticeable increases in projected removals under the A2-EAB scenario.

Conversion to Nonforest Land Uses

Land-use change removals are those volume losses solely attributable to a decrease in forest area when forest land is converted to urban or agricultural uses. The woody material on converted lands may or may not be harvested, but the assumption is that the entire volume is lost from the forest inventory. Projections of land-use removals were driven by assumptions about loss of forest land under the greenhouse gas emissions storylines; scenarios with accelerated biomass harvesting or expanding emerald ash borer mortality were very similar to the analogous scenarios that projected a continuation of past harvesting rates (Appendix Chapter 4, Fig. 4.19). The only appreciable exception is A1B-BIO/A1B comparison: the volumes removed under the enhanced biomass removal assumptions would be so large that they would reduce the metric—average standing volume per acre—used to calculate land-use change removals.

Land-use removals are projected to increase for all variations of the A1B and A2 scenarios and are projected to decrease for the B2-C and B2-BIO scenarios (Fig. 4.19). Removals would primarily come from hardwood stands, reflecting the composition of forests in the counties that would be most impacted by the loss of forest land.

For the northern forests as a whole, removals resulting from land-use change would be a small component (about 12 percent in 2010) of total removals (Fig. 4.20); the exception would be six States along the Atlantic seaboard (Fig. 4.21) where land-use change would be a large—or even the largest—source of removals. Compared to the midwestern States, most of the States farther east would have higher percentages of total removals resulting from land-use change (examples include New Hampshire, Massachusetts, and Pennsylvania but not Maine) with the highest among them being the small States along the Atlantic seaboard. Situated along the Interstate-95 corridor, this highly urbanized area is more likely to lose forest land to population growth and associated development; harvesting is expected to be comparatively minimal because ownerships are small and the value of ecosystem services from forests is relatively high. In Iowa and Illinois, land-use removals are predicted to be high in the first decade of the projection period, but then decrease rapidly in subsequent decades.

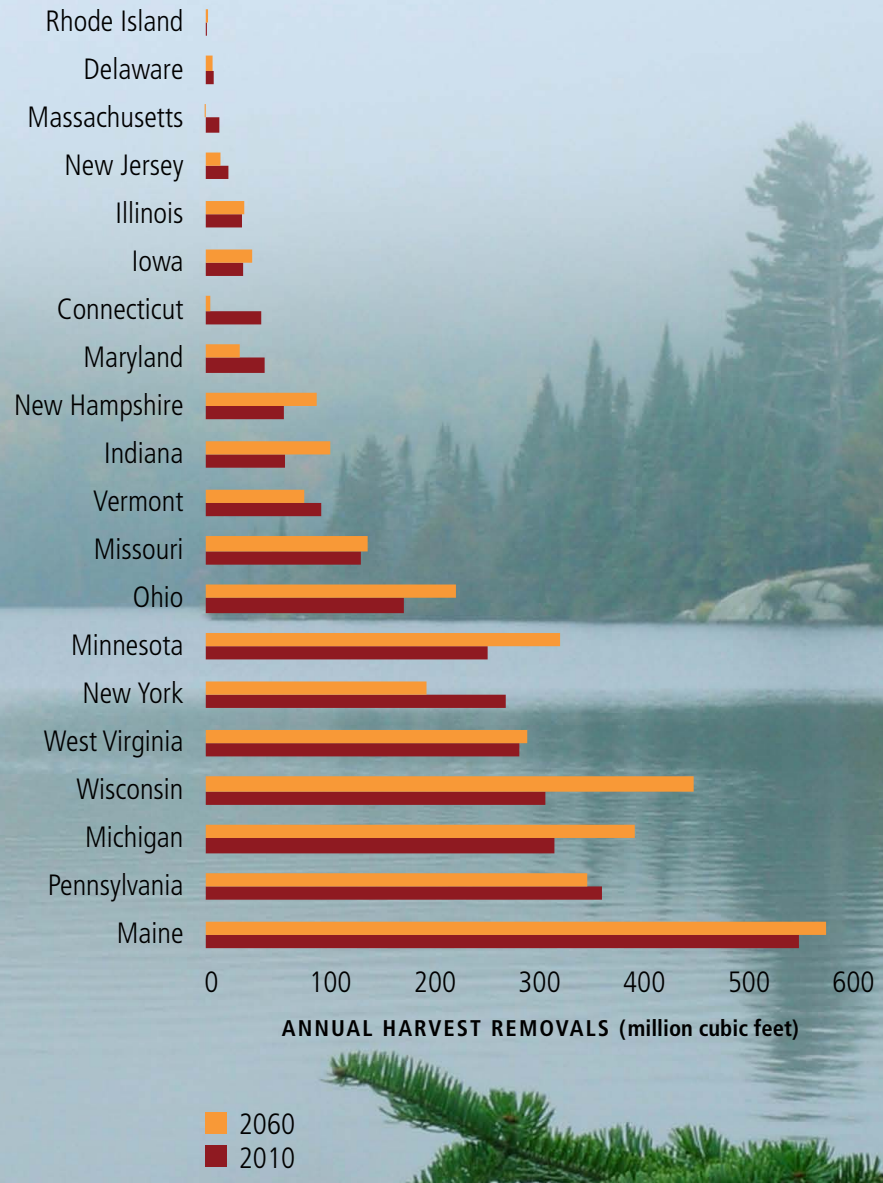


FIGURE 4.18

State-level harvest volume in forests of the North in 2010 and projected for 2060 under scenario A2-C that assumes high greenhouse gas emissions, large gains in population and energy consumption, moderate gains in income, and a continuation of recently observed harvest rates.

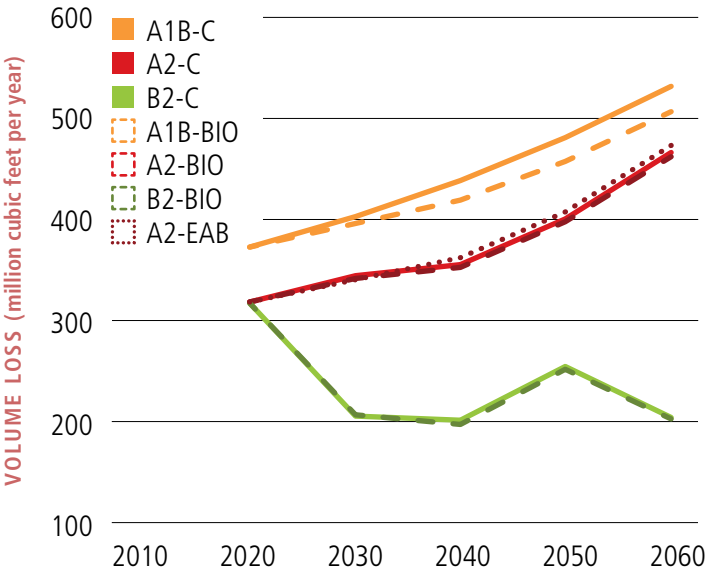


FIGURE 4.19

Projected annual volume losses resulting from land-use changes in forests of the North, 2010 to 2060, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

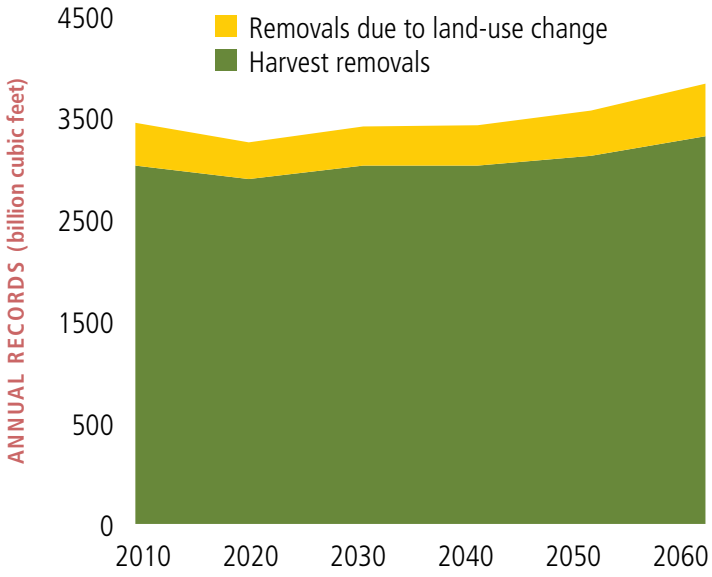
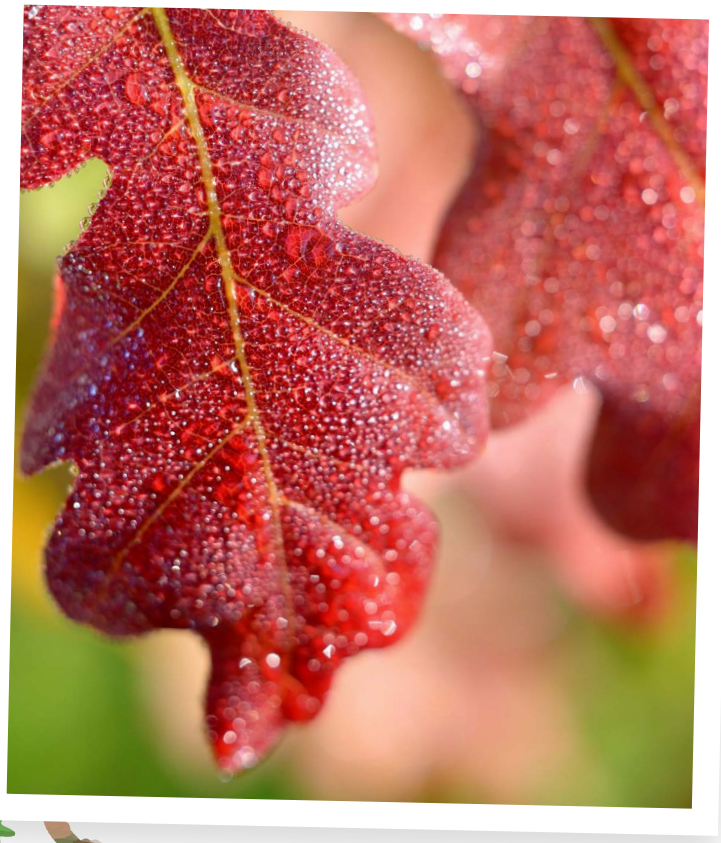
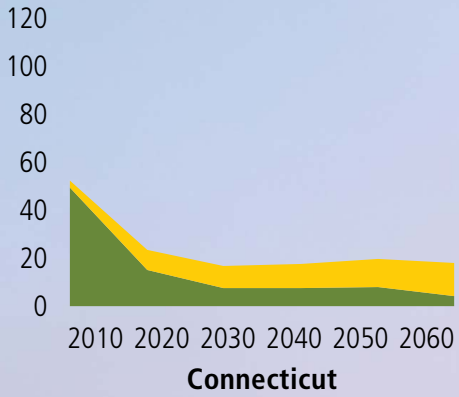


FIGURE 4.20

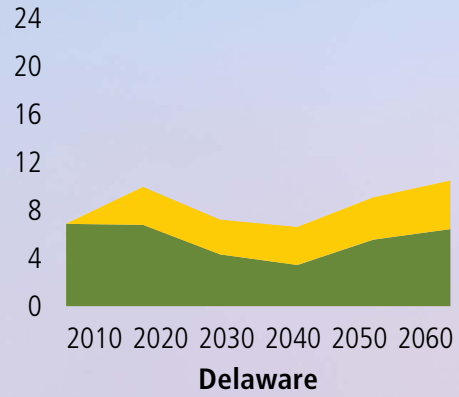
Comparison of projected volume losses resulting from harvesting and land-use changes in the North, 2010 to 2060, under scenario A2-C that assumes high greenhouse gas emissions, large gains in population and energy consumption, moderate gains in income, and a continuation of recently observed harvest rates.



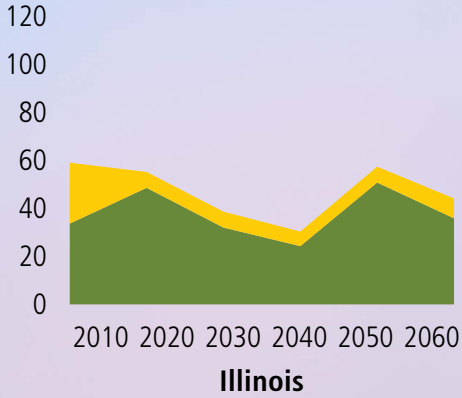
REMOVALS (million cubic feet per year)



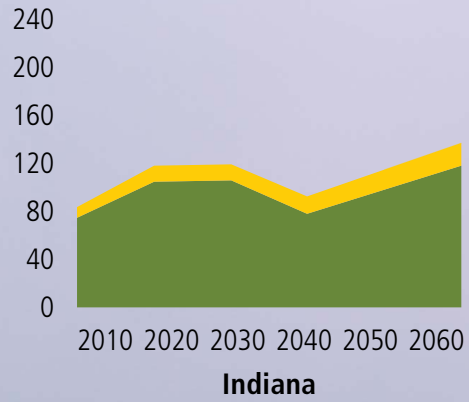
Connecticut



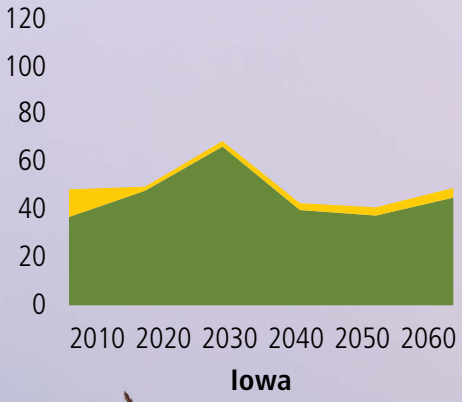
Delaware



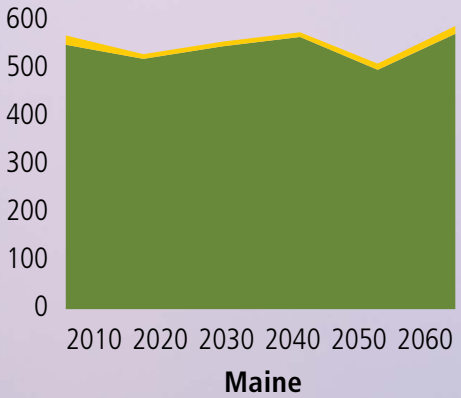
Illinois



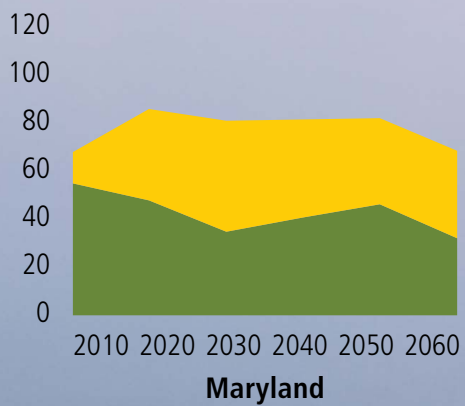
Indiana



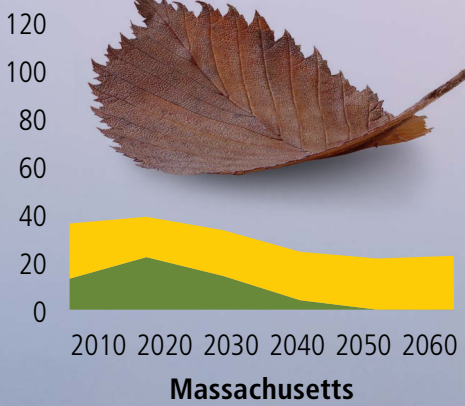
Iowa



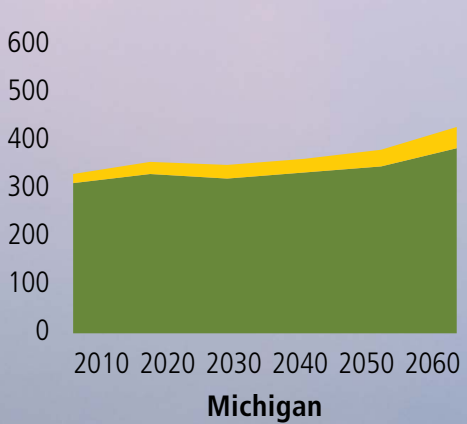
Maine



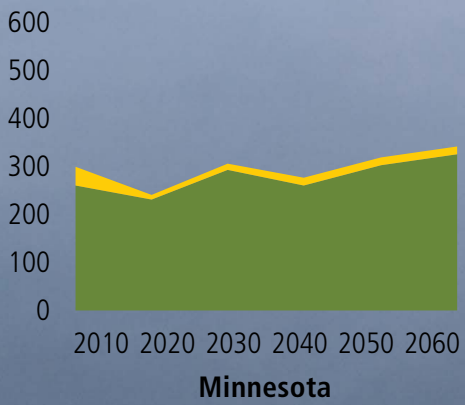
Maryland



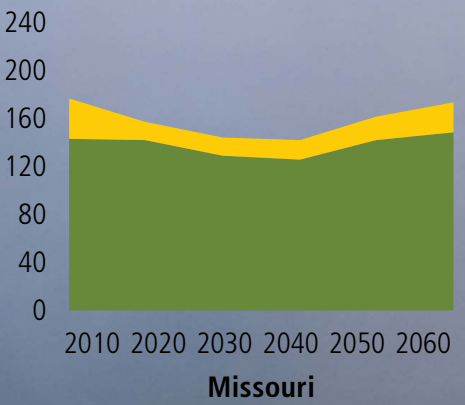
Massachusetts



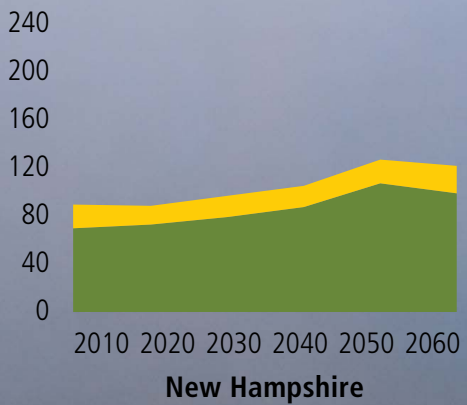
Michigan



Minnesota



Missouri



New Hampshire

FIGURE 4.21

Removals due to land-use change
Harvest removals

State-level comparison of projected volume losses resulting from harvesting and land-use changes in the North, 2010 to 2060, under scenario A2-C that assumes high greenhouse gas emissions, large gains in population and energy consumption, moderate gains in income, and a continuation of recently observed harvest rates.

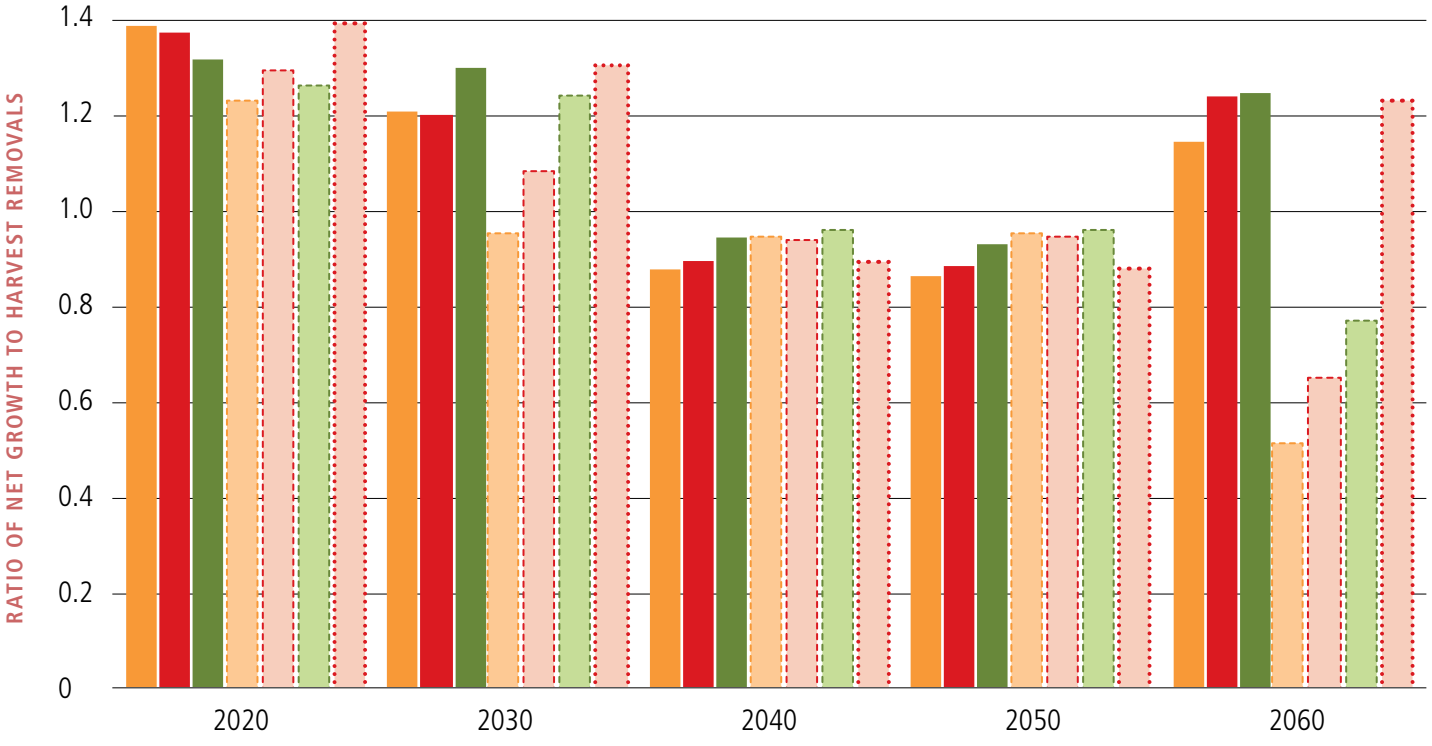
RATIO OF NET GROWTH TO REMOVALS

The ratio of net volume growth to harvest removals is an important indicator of forest sustainability (Fig. 4.22). For periods when the ratio is >1.0, wood volume is accumulating faster than it is being harvested, and total live volume on timberland is increasing. Ratios <1.0 indicate periods when harvest removals exceed net growth and total live volume on timberland is being depleted; over the long run, such ratios are not sustainable.

Figure 4.22 shows ratios predicted for harvesting removals but excludes removals that would result from the land-use changes discussed above. Thus, in some situations where the ratio of growth to harvest removals is >1.0 and volume per acre is increasing, total volume for a State or region could still decrease if large areas of forest are converted to urban or agricultural uses and the trees on the converted land no longer contribute to estimates of total volume.

FIGURE 4.22

Ratio comparing projected average annual net cubic foot volume growth to harvest, by decade, under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.



Total volume is projected to increase from 2010 to 2030, decrease slightly until 2050, and then increase from 2050 to 2060 under A1B-C, A2-C, B2-C, and A2-EAB (Fig. 4.14). The decrease is attributable in part to conversion of forest land to other uses and in part to a reduced rate of growth associated with an aging forest resource. As forests age, the annual rate of volume growth typically decreases even though total volume per acre may increase gradually. When coupled with constant or increasing harvesting (Fig. 4.17), the outcome would be a decreasing growth-to-removals ratio from 2020 to 2040 (Fig. 4.22). The projected ratio in 2030 would be <1.0 for all scenarios, with harvesting exceeding growth for a decade or more.

By 2060, the growth-to-removals ratio would increase to about 1.2 under scenarios A1B-C, A2-C, B2-C, and A2-EAB. In contrast, the ratio would continue to decrease for the scenarios with accelerated biomass removals, both for hardwoods and softwoods, with decreases reaching precipitous levels by 2060. These results suggest that the modeled harvesting levels associated with scenarios A1B-BIO, A2-BIO, and B2-BIO are not sustainable over the long term. This is not to suggest that in all situations and at all levels of removal, increased harvesting of biomass for energy is unsustainable, but simply that it is not sustainable at the rate assumed in the modeled scenarios over the long term.

CONCLUSIONS

Differences among projected forest conditions from 2010 to 2060 are small under A1B-C, A2-C, and B2-C. Although these scenarios are based on different assumptions—population growth, land-use change, greenhouse gas emissions, and climate response (see Chapter 2)—their projections of forest area, species composition, volume, volume growth, and removals are most notable for their similarities. The projected outcomes for A2-EAB, which models the elimination of ash species from northern forests as a consequence of the expanding range of emerald ash borer, are similar to those for A2-C in most other respects. Despite the anticipated impacts from conversion of forest land to urban uses, forest land area is projected to decrease by only about 5 percent over the next 50 years.

The models predict that existing forests will get older and removals resulting from harvesting will remain nearly constant under scenarios A1B-C, A2-C, B2-C, and A2-EAB. The consequence for the region as a whole is that forest growth and succession rather than climate change or land conversion would be the primary forces driving forest changes. This is not to suggest that stability will prevail in all locales. For example, forests that adjoin urban areas will certainly be impacted more than rural forests, and tree species at the edge of their natural ranges would be the most vulnerable to changes in climate.

Scenarios with accelerated biomass harvesting stand in sharp contrast, because the greatly accelerated rates of harvesting would dominate projected future changes in volume, volume growth, and age-class diversity.

Two other highly consequential outcomes emerge from these projections. First, the normal aging of northern forests over the next 30 to 40 years will likely end the rapid increase in standing volume that has characterized the past 50 years. As forests mature, the rate of volume increase slows. When this dynamic is coupled with small but persistent losses of forest land to land-use changes, the result would be wood volumes that remain relatively constant from 2010 to 2050. This appears to be the outcome under all scenarios, although larger distinctions among alternative scenarios would emerge after 2050. The potential consequences of this trend are far reaching, and they are discussed further in Chapter 11.

The second consequence, as illustrated by the scenarios with accelerated biomass harvesting, is potential for human intervention—through harvesting—to transform future outcomes over the long run. Changes in harvesting rates could take decades to alter the northern forest landscape; but eventually as new patterns of disturbance (increased biomass harvesting) accumulate over time, they can create substantial shifts in standing volume, volume growth rates, and the regional age-class structure. Thus, the future condition that is deemed desirable for northern forests may well require intensive management intervention over many decades to markedly alter the trajectories of change from the status quo. Implicit in the scenario projections are opportunities for improving forest vitality and diversity, supplying large quantities of wood to forest industries, and still sustaining a stable volume of wood.

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Maintenance of Forest Ecosystem Health and Vitality

5

Ryan D. DeSantis and W. Keith Moser

Introduction

FOREST HEALTH WILL likely be threatened by a number of factors—including fragmentation, fire regime alteration, and a variety of diseases, insects, and invasive plants—along with global climate change (Krist et al. 2007, Tkacz et al. 2008). By itself, global climate change could dramatically and rapidly alter forest composition and structure (Allen and Breshears 1998, Allen et al. 2010). In conjunction with other threats, global climate change poses unique challenges to forest management by influencing forest dynamics at virtually all levels: disturbance regimes in forest ecosystems; rates of resource availability and utilization; canopy gap formation and woody debris dynamics; fire regimes; community composition; and forest distribution, structure, biodiversity, and biogeochemistry. Global climate change and other threats, in turn, could favor the establishment of invasive species. The following pages discuss effects of the most pertinent threats to the future health of forests in the Northern United States.

OVERVIEW OF THREATS

The major biotic threats affecting northern forests (USDA FS, n.d.a) include:

- Oak decline
- Asian longhorned beetle (*Anoplophora glabripennis*)
- Gypsy moth (*Lymantria dispar*)
- Emerald ash borer (*Agrilus planipennis*)
- Hemlock woolly adelgid (*Adelges tsugae*)
- Beech bark disease
- Sirex woodwasp (*Sirex noctilio*)
- Spruce budworm (*Choristoneura fumiferana*)
- Winter moth (*Operophtera brumata*)

The threats vary considerably in the amount of forest area they affect and in their rate of spread, but collectively the North surpasses other regions of the country in the number of invasive forest pests per county (Liebhold et al. 2013). Some threats are not yet broadly established but pose serious concern for future forests nonetheless (Tables 5.1, 5.2). Although some have been successfully mitigated, contained, controlled, or even eradicated, others continue to spread unimpeded throughout northern forests (Fig. 5.1).

Key Findings

- Forest threats like emerald ash borer, hemlock woolly adelgid, beech bark disease, and gypsy moth are causing major changes to forests.
- Insects such as the Asian longhorned beetle, spruce budworm, Sirex woodwasp, and winter moth have exhibited the potential to decimate a variety of tree species and could become more formidable to forests in urban and rural areas.
- Emerald ash borer could decimate the entire U.S. population of ash, which is culturally significant to Native American populations, valuable for specialty products, and valued in urban landscapes.
- Decline-disease complexes such as oak decline are causing negative ecological and economic effects.
- Fire regime changes have substantially decreased the abundance of fire-tolerant and fire-adapted vegetation like oaks and have contributed to invasion by fire-intolerant mesic species.
- Invasive plants are contributing to habitat loss, ecosystem degradation, and decreasing species diversity.
- Other threats such as deforestation and fragmentation contribute to worsening forest health conditions, which provide increased opportunities for invasions to spread.
- Although forest threats have always existed, present-day challenges to forest ecosystem health, diversity, and resilience are unprecedented.

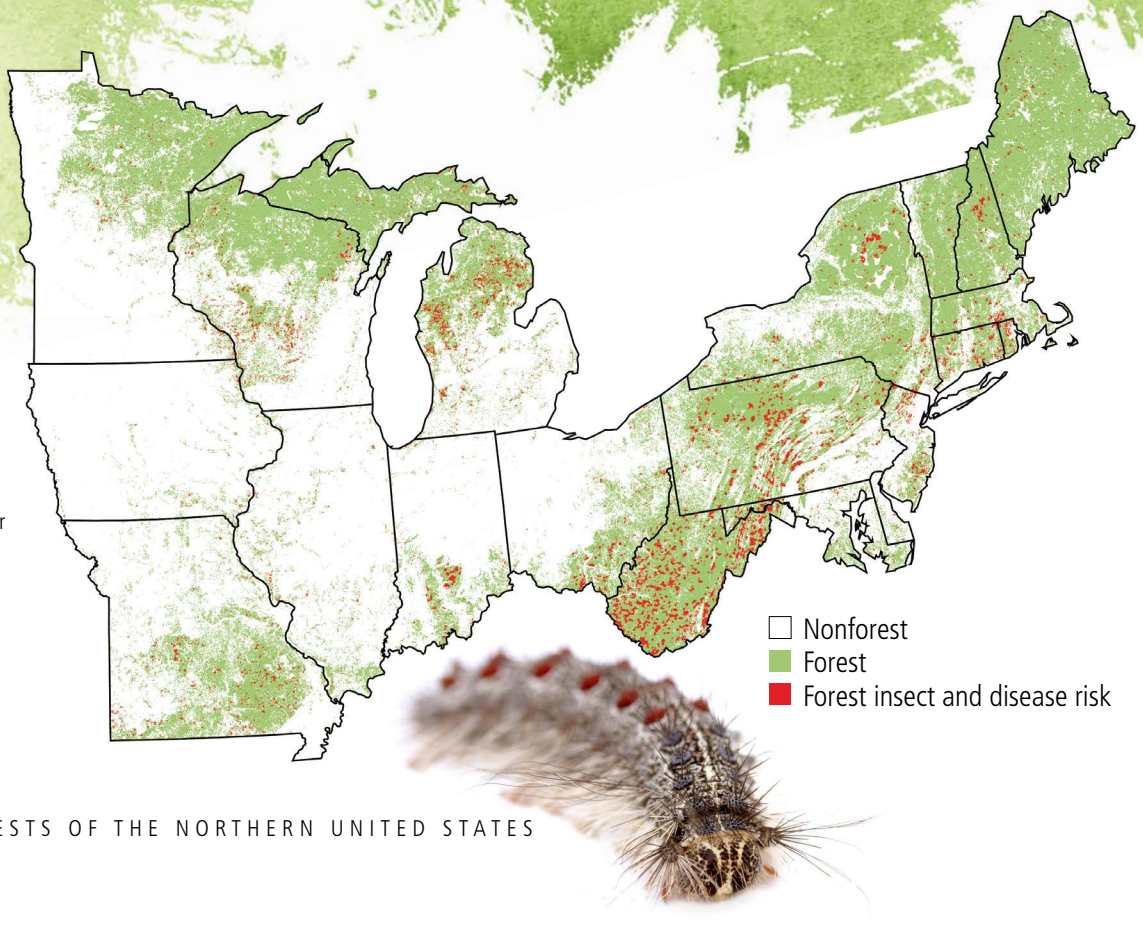


FIGURE 5.1

Areas in the North predicted to have ≥25-percent mortality risk from oak decline, southern pine beetle, gypsy moth, pine engraver beetle, or hardwood decline by 2030 (USDA FS, n.d.e).

Table 5.1—Occurrence of the major invasive insect and disease threats affecting forests in the North

State	Threat (X indicates presence)								
	Oak decline	Asian longhorned beetle[a]	Gypsy moth[b]	Emerald ash borer[c]	Hemlock woolly adelgid[a]	Beech bark disease[a]	Sirex woodwasp[d]	Spruce budworm[a]	Winter moth[a]
Connecticut	X		X	X	X	X	X		X
Delaware	X		X		X				
Illinois	X		X	X					
Indiana	X		X	X					
Iowa	X		X	X					
Maine	X		X		X	X		X	X
Maryland	X		X	X	X	X			
Massachusetts	X	X	X	X	X	X			X
Michigan	X		X	X		X	X	X	
Minnesota	X		X	X				X	
Missouri	X			X					
New Hampshire	X		X	X	X	X		X	X
New Jersey	X	X	X	X	X	X	X		
New York	X	X	X	X	X	X	X	X	X
Ohio	X	X	X	X		X	X		
Pennsylvania	X		X	X	X	X	X		
Rhode Island	X		X		X	X			X
Vermont	X		X		X	X	X	X	
West Virginia	X		X	X	X	X			
Wisconsin	X		X	X		X		X	

[a]*USDA FS, n.d.a.*

[b]*Slow the Spread Project, n.d.a.*

[c]*USDA 2014*

[d]*Purdue University, n.d.*

Table 5.2—Major invasive insect and disease threats affecting forests of the Northern United States (Purdue University, n.d.; USDA FS, n.d.a.)

Threat	Type	Counties (out of 1037) where severe outbreaks occurred					Characteristics
		2009	2010	2011	2012	2013	
Oak decline	Native decline complex	NA	NA	NA	NA	NA	Combination of tree and site factors, drought, fungi, and insects. Periodic widespread mortality is triggered when all factors occur on sites with a high proportion of mature trees in the red oak group.
Asian longhorned beetle	Nonnative invasive insect	9	10	11	11	11	Currently infests a very small area, but has the potential to cause substantial regionwide damage. Feeds on a variety of species but prefers maples.
Gypsy moth	Nonnative invasive insect	122	123	54	36	89	Currently found in 19 of 20 States, gradually spreading west from eastern Massachusetts. Feeds on a variety of species but prefers oaks.
Emerald ash borer	Nonnative invasive insect	187	228	282	330	403	Currently found in 16 of 20 States, spreading at approximately 12 miles per year from southeastern Michigan. Infests ash (*Fraxinus* spp.) exclusively.
Hemlock woolly adelgid	Nonnative invasive insect	181	202	204	217	228	Currently found in 13 of 20 States, spreading northeast and southwest from Virginia. Infests eastern and Carolina hemlocks.
Beech bark disease	Nonnative decline complex	246	254	254	257	261	Currently found in 14 of 20 States and infects >90 percent of American beech trees >6 inches d.b.h. Affects American beech exclusively.
Sirex woodwasp	Nonnative invasive insect	1	6	2	1	5	Currently infests a very small area, but has the potential to cause substantial regionwide damage. Feeds on a variety of species but prefers pines.
Spruce budworm	Native invasive insect	23	38	29	33	24	Biggest defoliator of spruce and fir in eastern forests of North America. Periodic outbreaks are part of natural cycle in spruce-fir forests, but fire suppression and other anthropogenic disturbances increase the likelihood of outbreaks.
Winter moth	Nonnative invasive insect	8	13	13	14	17	Currently found in 6 of 20 States. Feeds on a variety of species.

DECLINE-DISEASE COMPLEXES

Oak Decline

Oak decline is a disease complex recognized in North America since the middle of the 19th century (Hopkins 1902, Oak et al. 1996). Characterized by progressive branch dieback (Fig. 5.2) and eventual mortality, oak decline has been described as the combination of predisposing, inciting, and contributing factors primarily affecting trees from the red oak group (Manion 1991, Wargo et al. 1983).

Oak decline could be responsible for the loss of more than 2 billion square feet of oak basal area over the next 15 years, causing substantial economic losses throughout North America (Krist et al. 2007). In addition, considering that oak-hickory (*Quercus* spp. – *Carya* spp.) is the largest species group in the United States and accounts for 35 percent of all land in northern forests (Smith et al. 2009), the consequences of oak decline could be widespread (Fralish 2004).

FIGURE 5.2
Oaks showing symptoms of oak decline. Photo by USDA Forest Service, Forest Health Protection, St. Paul Archive, Bugwood.org.

Although studies have described relatively localized incidences of oak decline and probable primary causes (Fan et al. 2006) and have detected shifts in species composition away from oak (Rogers et al. 2008), broad-scale information on oak decline is lacking. Identifying the controlling factors and extent of oak decline across a broader scale will be critical for the management of oaks throughout northern forests.

A variety of long-term factors related to tree characteristics and growing site conditions predispose forests to oak decline:

- Affected tree species are primarily from the red oak group (Fan et al. 2008, Haavik and Stephen 2010) and include black oak (*Quercus velutina*), red oak (*Q. rubra*) and scarlet oak (*Q. coccinea*).
- The average age of affected trees is >70 years (Oak et al. 1996).
- The size of affected trees is >10 inches d.b.h. (Johnson et al. 2002).
- Growth of affected trees is <0.08 inches per year (Shifley et al. 2006).
- The canopy position of affected trees is classified as intermediate or suppressed crown class (Fan et al. 2006).
- Stand basal area of affected stands is >56 square feet per acre (Fan et al. 2006).
- Affected trees are generally on poor-quality sites characterized by low productivity, shallow and rocky soils, dry ridges or slopes, and southerly aspect (Kabrick et al. 2008).

Short-term factors that increase susceptibility to oak decline (Houston 1987, Staley 1965, Wargo et al. 1983) by increasing tree stress include: drought (Huddle and Pallardy 1996, Jenkins and Pallardy 1995); structural damage from wind and ice (Shirakura et al. 2006); and defoliation by frost, ice, and insects such as gypsy moth and oak leaf roller (*Archips semiferanus*).

A number of factors contribute to the oak decline complex, including: fungal pathogens, such as *Armillaria mellea* and *Hypoxylon* spp. (Wargo et al. 1983), and insects from the family Buprestidae, such as two-lined chestnut borer (*Agrilus bilineatus*) and red oak borer (*Enaphalodes rufulus*) studied by Starkey et al. (2004). Both are opportunistic organisms that inhabit weakened trees. In combination with predisposing and inciting factors, these organisms increase stress and damage to trees, leading to mortality (Manion 1991, Wargo 1996).

Identifying areas that are particularly susceptible to oak decline can help land managers mitigate negative economic and ecological consequences. Although some factors such as drought are beyond the control of land managers, others can help identify conditions presently conducive to oak decline (for example species, age, and stand basal area). This information can help guide management strategies for reducing incidence and impacts of oak decline.

Beech Bark Disease

Beech bark disease, a complex caused by several species of native and nonnative fungi (*Nectria* spp.) that are vectored by a nonnative scale insect (Shigo 1972), has caused 50- to 85-percent mortality of American beech (*Fagus grandifolia*) in the heaviest infected areas (Fig. 5.3) of northern forests (Houston 1994, Houston et al. 1979).

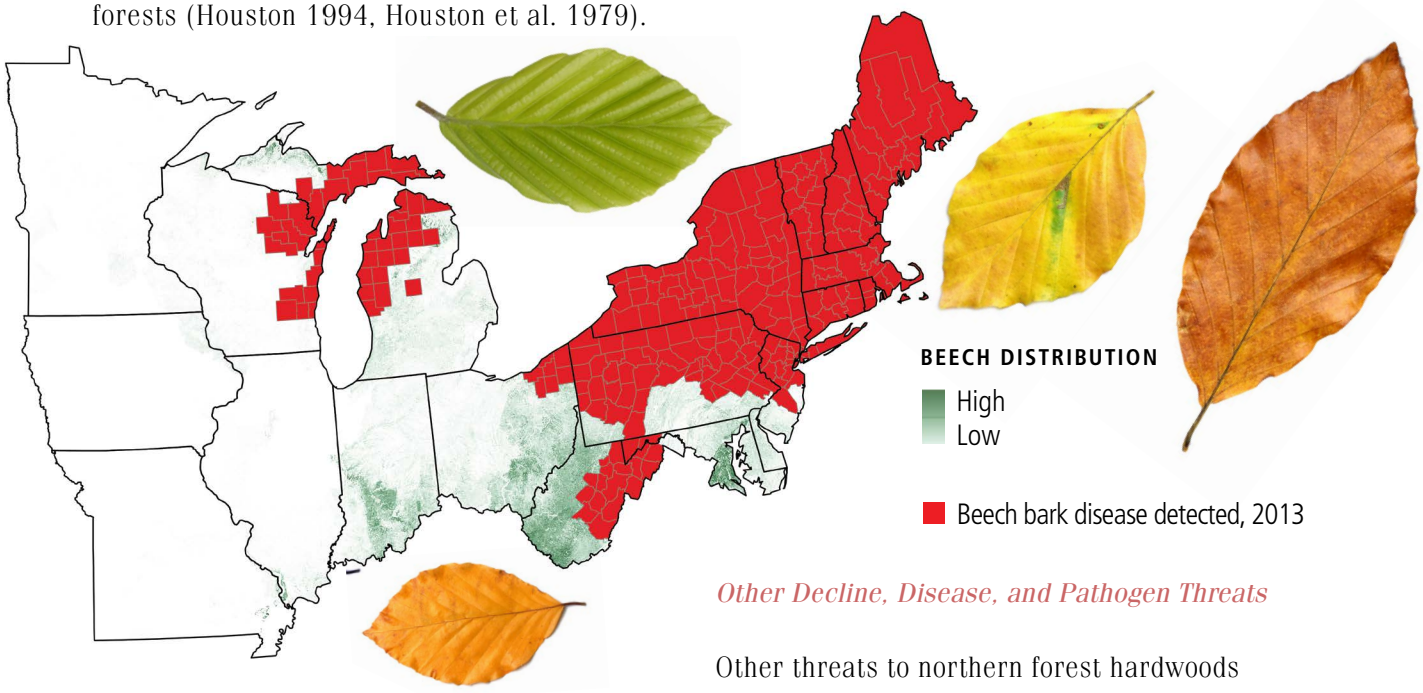


FIGURE 5.3
Range of American beech and counties with beech bark disease in the North (USDA FS, n.d.a; Wilson et al. 2012).

Research suggests that <1 percent of beech trees exhibit genetic resistance to the disease complex and that beech bark disease infects >90 percent of American beech trees >6 inches d.b.h. (Latty et al. 2003, Sage 1996). Although smaller trees have lower susceptibility, beech bark disease has the potential to cause substantial basal-area loss of this species throughout its range. Because American beech is a major component of northern forests, the ecological effects of its demise would be far-reaching and could have negative effects on associated wildlife (Rosemier and Storer 2010).

Other Decline, Disease, and Pathogen Threats

Other threats to northern forest hardwoods include butternut canker (*Sirococcus clavigignenti-juglandacearum*); thousand cankers disease (*Geosmithia morbida*) of walnut (*Juglans* spp.); oak wilt (*Ceratocystis fagacearum*); sudden oak death (*Phytophthora ramorum*); and decline of ash (*Fraxinus* spp.), maple (*Acer* spp.), and basswood (*Tilia americana*). As with oak decline, tree, site and stand conditions, abiotic factors, insects, and pathogens have been implicated as contributing agents (Manion 1991). In addition to decline, ash is susceptible to pathogens that cause chlorosis, witches' brooms, and abundant epicormic branching (PSU CAS 1987).

INVASIVE INSECT SPECIES

Asian Longhorned Beetle

Among the most serious of nonnative insect pests in northern forests is the Asian longhorned beetle. This species is capable of causing extensive damage to many hardwood species (Poland et al. 1998, Solomon 1995). As with emerald ash borer (described in a subsequent section of this chapter), Asian longhorned beetle larvae (Fig. 5.4) cause extensive damage to phloem and xylem in both healthy and declining host trees of all age classes (Haack et al. 1997).

Asian longhorned beetles feed on a variety of species, but they prefer maples (*Acer* spp.), a major concern given the importance of maples in northern forests and urban areas (Haack et al. 2010). An estimated 111 million acres, 64 percent of all northern forest land (Fig. 5.4), are at risk from infestation.

Although quarantines and eradication programs have been somewhat successful since the discovery of Asian longhorned beetle in the mid-1990s, they have come at a high economic cost (Hu et al. 2009).

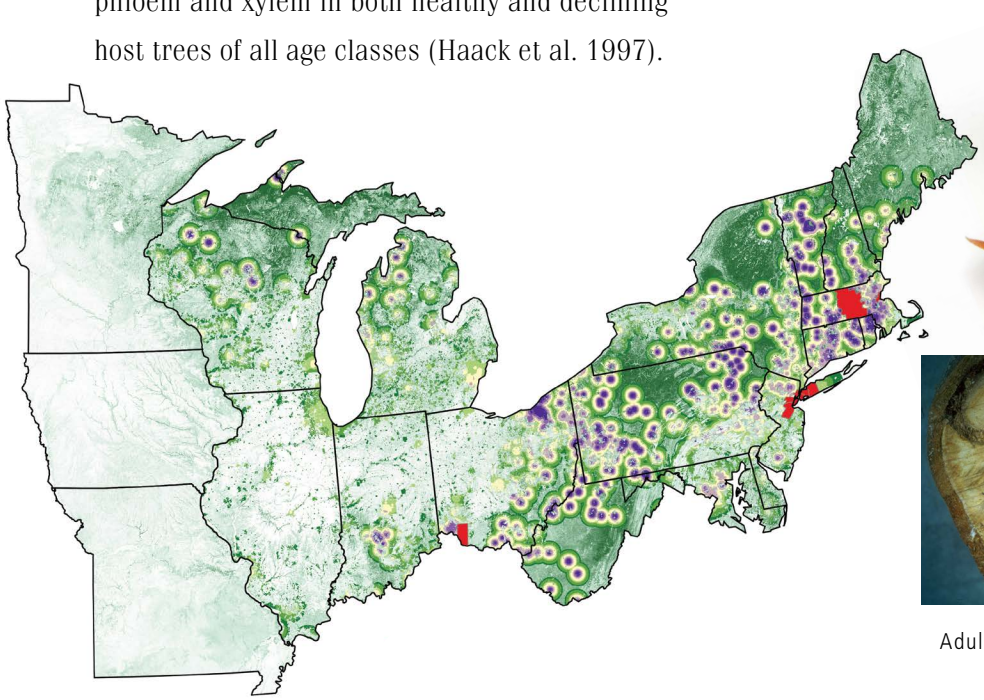


FIGURE 5.4
Spatial distribution of Asian longhorned beetle occurrence and susceptibility in the North; susceptibility is defined as the potential for introduction and establishment of a forest pest within a tree species or group (USDA FS, n.d.a; USDA FS, n.d.b; Wilson et al. 2012).

Adult Asian longhorned beetle on log showing damage.

Photo by E. Richard Hoebeke, Cornell University, Bugwood.org

Asian longhorned beetle larva.

Photo by Kenneth R. Law, USDA APHIS PPQ, Bugwood.org

Consequently, the long-term and broad-scale effectiveness of inspection, interception, and eradication programs is uncertain. As of 2013, Asian longhorned beetle infestations were confined to Massachusetts, New Jersey, New York, and Ohio (Fig. 5.4). Because spread rates and host mortality probabilities have not yet been established, accurately projecting the future range of Asian longhorned beetle is challenging. However, it clearly poses a serious threat to northern forests for two reasons: (1) it can utilize numerous tree species as hosts; and (2) new introductions associated with imported goods are highly likely.

Susceptibility of Host Trees to Nonnative Invasive Insects

Susceptibility is defined as the potential for introduction and establishment, over a 15-year period, of a forest pest within a tree species or species group (USDA FS 2014; USDA FS, n.d.e). Potential for introduction considers the import of commodities (such as bricks, stones, metal, and glass materials) that are shipped with wood packing or pallets from countries where invasive insects are native, as well as the businesses and individuals engaged in importing and handling commodities of concern (represented as polygon ZIP code centroids). Potential for establishment considers the mean basal area for all host trees (Wilson et al. 2012), by ZIP code centroids with 18-mile buffers, to include the potential cumulative spread of the invasive insect over a 15-year period at the rate of 1 mile per year (Bancroft and Smith 2001).

Gypsy Moth

Gypsy moth was brought to North America and accidentally released in 1869. Since then it has continued to spread across northern forests from east to west (Liebhold et al. 1995). Although it prefers white oak (*Q. alba*), host trees can include other oak species as well as aspen (*Populus* spp.), birch (*Betula* spp.), willow (*Salix* spp.), beech, hemlock (*Tsuga* spp.), pine (*Pinus* spp.), and spruce (*Picea* spp.). During population outbreaks, foliage of nearly all forest trees is at least partially consumed (Liebhold et al. 1995). Outbreaks can cause extensive defoliation, reducing tree growth and vigor. Repeated defoliation (Fig. 5.5) can result in mortality, often in conjunction with secondary fungal and insect invaders that attack weakened trees (Liebhold et al. 1995).

A 2005 study suggested that the infested area is only 23 percent of the total area susceptible to the gypsy moth (Morin et al. 2005). Thus far, management consists of slowing the spread of its advancing border (Figs. 5.5, 5.6, 5.7) along a line from central Wisconsin southward and eastward to West Virginia (Tkacz et al. 2008).

Gypsy moth larva feeding on foliage.

Photo by John H. Ghent, USDA Forest Service, Bugwood.org

Foliage consumed by late instar gypsy moth larvae.

Photo by E. Bradford Walker, Vermont Department of Forests, Parks and Recreation, Bugwood.org

Adult male (brown) and female (white) gypsy moths.

Photo by USDA APHIS PPQ Archive, Bugwood.org

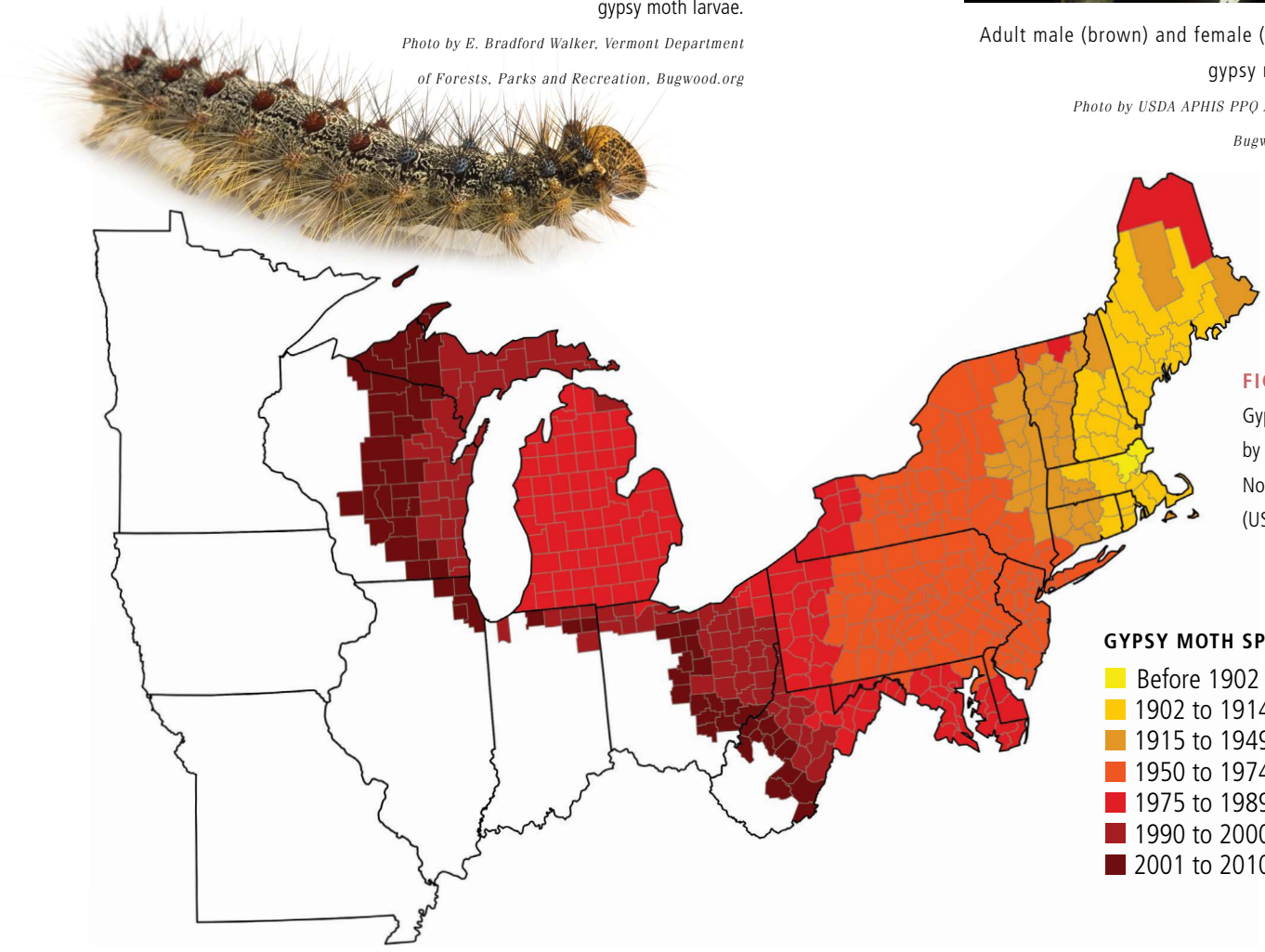


FIGURE 5.5
Gypsy moth spread by year throughout Northern U.S. counties (USDA FS, n.d.a).

Because females (Fig. 5.5) are generally incapable of flight, the rate of gypsy moth spread has been fairly slow (Slow the Spread Project, n.d.b). Given the slow spread rate and the fact that the gypsy moth is a resource generalist, modeling the expansion of the core infested area is important. The Gypsy Moth Slow the Spread Project has monitored the gypsy moth population expansion and has been successful at slowing its spread for more than 20 years; the average spread rate in northern forests since the project's inception is about 3 miles per year (Tobin and Blackburn 2007), a gradual decrease from previous decades. Nevertheless, gypsy moth could occupy most of the northern forest by 2060 based on the current spread rate. This means that the continued success of the Gypsy Moth Slow the Spread Project will likely be crucial for sustaining the health of northern forests over the next 50 years.

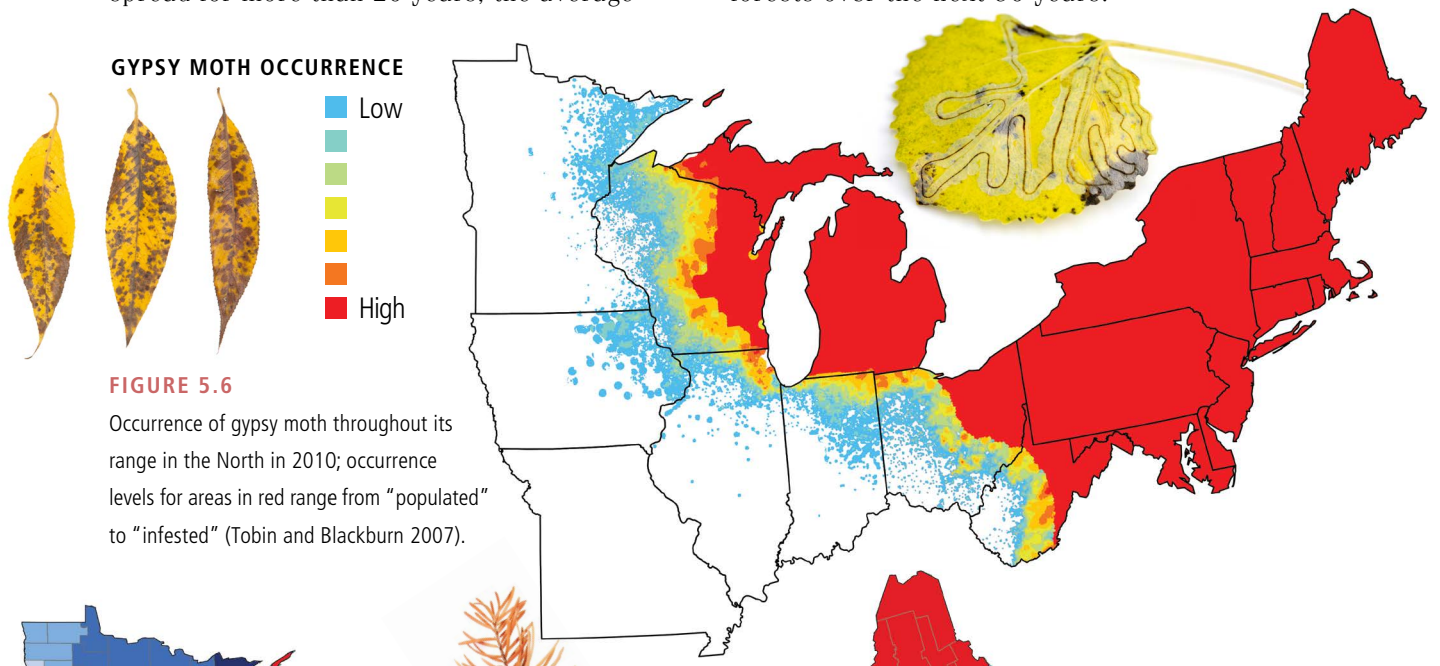


FIGURE 5.6

Occurrence of gypsy moth throughout its range in the North in 2010; occurrence levels for areas in red range from "populated" to "infested" (Tobin and Blackburn 2007).

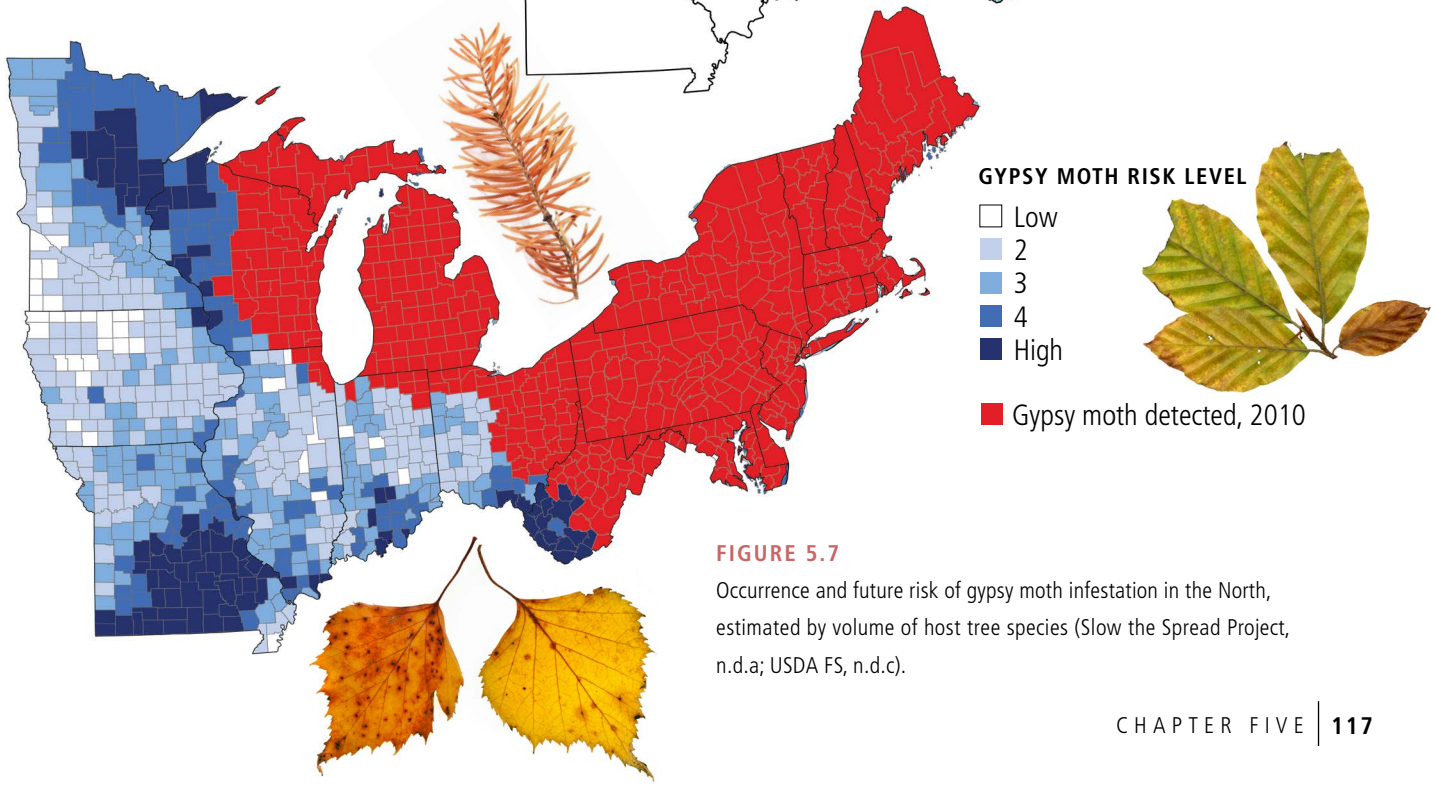


FIGURE 5.7

Occurrence and future risk of gypsy moth infestation in the North, estimated by volume of host tree species (Slow the Spread Project, n.d.a; USDA FS, n.d.c).

Emerald Ash Borer

The nonnative invasive emerald ash borer (EAB) kills trees when damage from larval phloem galleries (Fig. 5.8) and outer sapwood cavities girdles their stems, disrupting water and nutrient transport (Cappaert et al. 2005).

Adult emerald ash borer.

Photo by David Cappaert, Michigan State University, Bugwood.org

Emerald ash borer larva in phloem gallery.

Photo by David Cappaert, Michigan State University, Bugwood.org

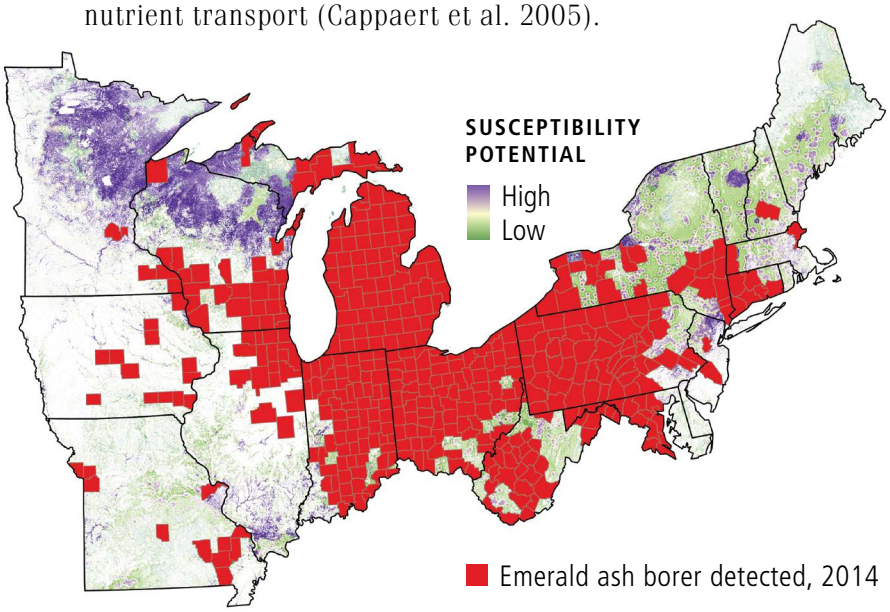


FIGURE 5.8

Spatial distribution of emerald ash borer occurrence and susceptibility as a function of preferred host range, presence of urban ash trees, proximity of urban ash trees to natural forests, and past rates of phloem insect interceptions at U.S. ports of entry; susceptibility is defined as the potential for introduction and establishment of a forest pest within a tree species or group (USDA FS, n.d.b; Wilson et al. 2012).

In Asia, the beetles feed on ash throughout its native range but do not usually cause extensive damage because their hosts have developed defensive mechanisms, including production of volatile compounds (Eyles et al. 2007, Jendek 1994, Rebek et al. 2008). Because North American ash species lack these defenses and are suitable hosts, infestations are usually fatal to affected trees (Poland and McCullough 2006).

Since its introduction to North America in the 1990s, emerald ash borer has spread across 23 percent of the range of ash (Fig. 5.8) and killed millions of ash trees in northern forests (Gandhi and Herms 2010, Haack et al. 2002, Pureswaran and Poland 2009). It is spreading at about 12 miles per year, which suggests that it will occupy the entire range of northern ash (Fig. 5.9) before 2050 (DeSantis et al. 2013b).

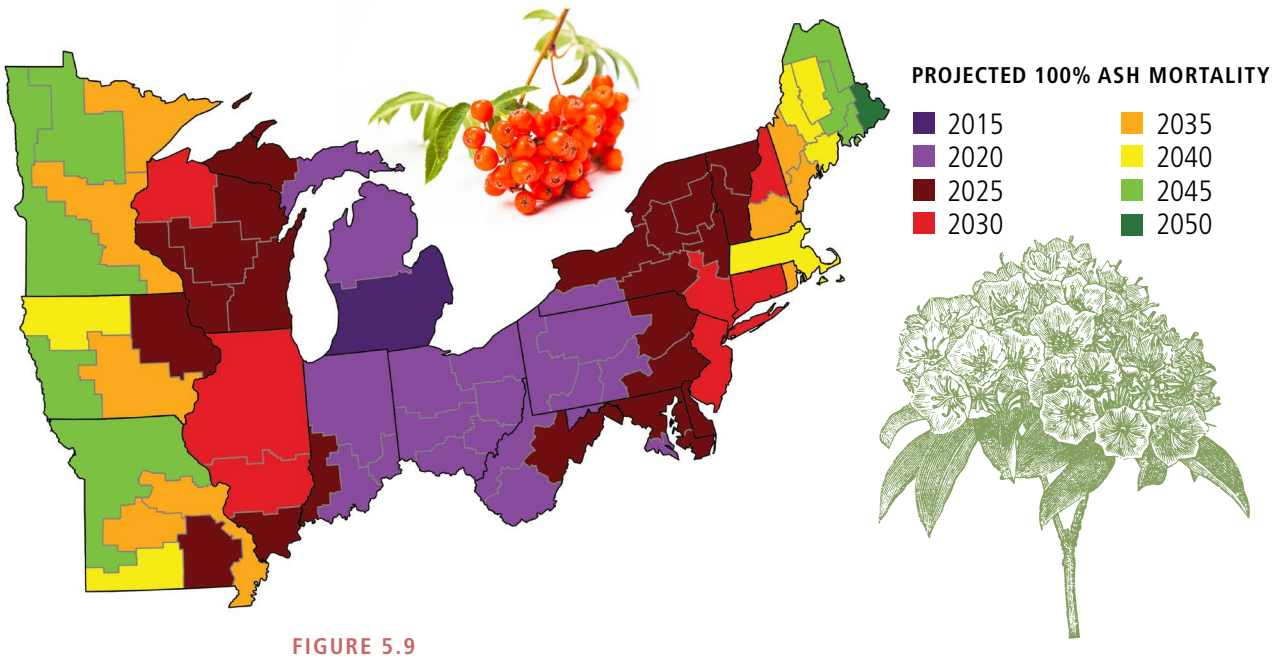


FIGURE 5.9

Projected ash mortality caused by emerald ash borer in forests of the North by survey reporting unit within each State (source: FIA data) and based on the following assumptions: (1) emerald ash borer spread leads to 100-percent ash mortality once the spread subsumes each survey unit, (2) the spread in New York, Vermont, New Hampshire, and Maine will be influenced by present infestations in the Canadian municipalities of Ontario and Québec but not from infestations in other Canadian or U.S. locations, (3) the spread rate is 12 miles per year, with the initial extent of the insect based on detection in U.S. counties and Canadian regional municipalities (CFIA 2014; DeSantis et al. 2013b; Personal communication, 2011, Paul Chaloux, Emerald Ash Borer National Program Manager, U.S. Department of Agriculture, APHIS, Riverdale, MD).

Therefore, given enough time, nearly all ash trees in northern forests will likely be killed (Herms et al. 2010, Prasad et al. 2010).

Modeling results suggest infestations will contribute to a small decrease in the total number of trees and saplings in survey units measured by Forest Inventory and Analysis (FIA) from 2010 to 2060, but also that the effects of ash mortality on the elm-ash-cottonwood (*Ulmus* spp.–*Fraxinus* spp.–*Populus* spp.) group will differ among FIA inventory units. Although the loss of ash trees will alter forest species composition in non-urban forests measured by FIA, modeling results suggest EAB effects will not cause substantial forest-type group changes. In many areas, the impacts of emerald ash borer on ecosystem functioning could be minimal because increases in associated non-ash species may offset the loss of ash trees and their associated volume. Despite the assumption of 100-percent ash mortality, the transition from ash to other species could progress slowly as it is replaced by a variety of associated species. The emerald ash borer infestation could also produce canopy gaps that would facilitate an increase in native and nonnative invasive plant species (Gandhi and Herms 2010).

Because this analysis focused on species groups, the geographic differences in the composition of each group are important including:

- In Maine inventory units, ash is not present in significant amounts in any species groups.
- In Minnesota inventory units, the elm-ash-cottonwood group is mainly composed of green ash (*Fraxinus pennsylvanica*) and black ash (*F. nigra*) whereas white ash (*F. americana*) is a very small component of the oak-hickory forest-type group and is largely absent from the elm-ash-cottonwood forest-type group.
- In most northern inventory units, the ash component of the elm-ash-cottonwood forest-type group is larger than the ash component of the oak-hickory forest-type group.

Furthermore, this modeling was not designed for urban areas not measured by FIA; therefore, urban areas could experience larger impacts because they support an extensive distribution of ash (Chapter 10).

Emerald ash borer infestation will likely have negative economic consequences for the wood products industry, in urban areas where ash has been widely used for landscaping and street trees, and for Native American tribes that value ash as a culturally important forest resource (Cappaert et al. 2005). Infestation could also affect wildlife and ecosystem functioning, especially on wet sites where black ash and pumpkin ash (*F. profunda*) are common (Burns and Honkala 1990b).

Hemlock Woolly Adelgid

Hemlock woolly adelgid was first discovered in North America in the Pacific Northwest in 1924, but the insect was not reported to cause extensive hemlock damage until its 1951 discovery in Virginia (Annand 1924, Gouger 1971, McClure 1987). It has subsequently spread northeast and southwest from the initial Virginia infestation to its present range (Fig. 5.10) and has caused considerable damage to eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliniana*).

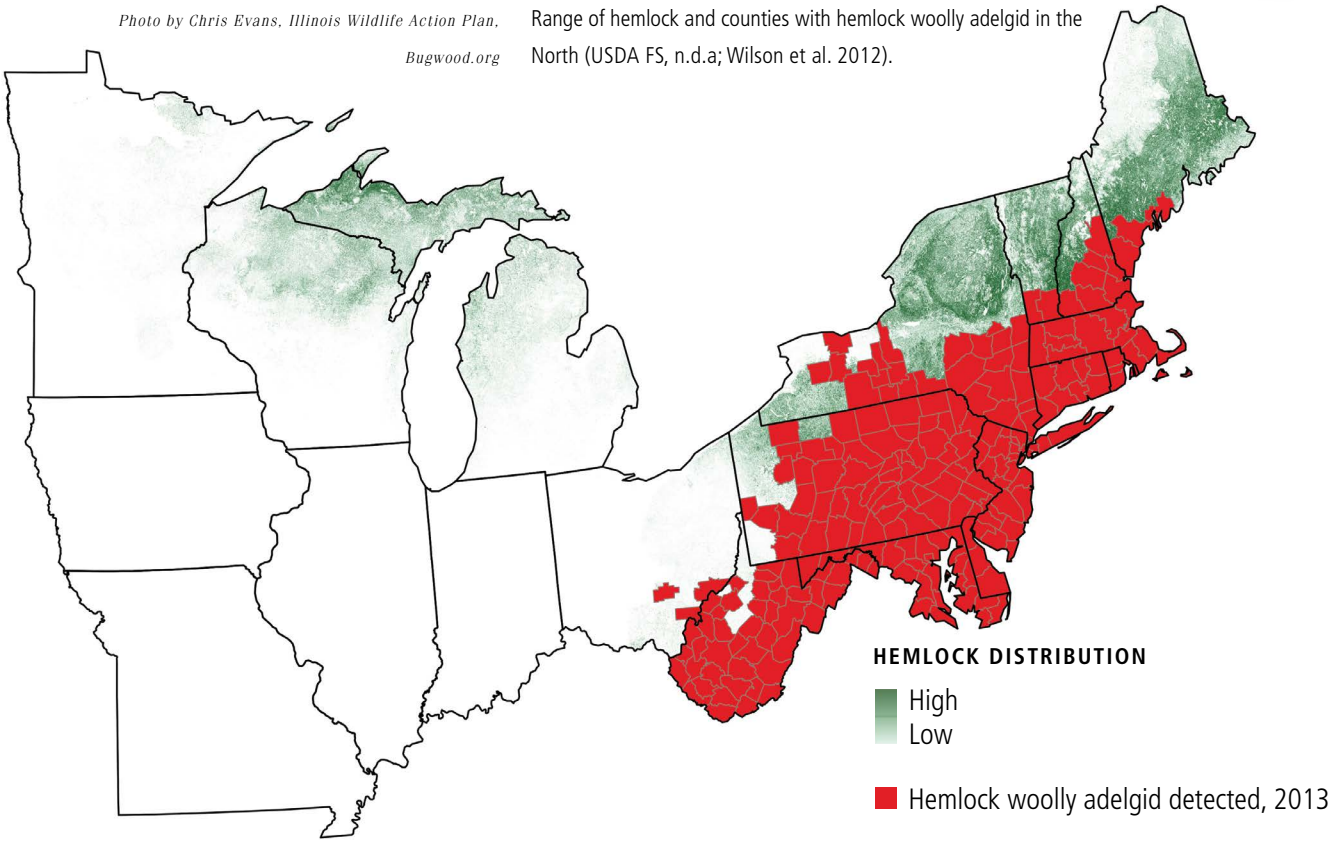
Throughout the native range of hemlock woolly adelgid in Asia, as well as in western areas of North America, hemlocks appear to be resistant (McClure and Cheah 1999). However, mortality in northern forests can be >95 percent of infested hemlock trees, and defoliation of surviving trees can range from 50 to 75 percent. This means that the probability of hemlock mortality in infested stands can eventually reach 100 percent (Orwig and Foster 1998, 2000). Mortality commonly occurs 4 to 10 years after infestation in the northern range of hemlock woolly adelgid, but in its southern range mortality occurs more rapidly (Georgia Forestry Commission, n.d.). Because defoliated hemlock trees lose the ability to produce seed or to sprout, changes in tree species composition are common following infestation (Orwig and Foster 1998, Spaulding and Rieske 2010).

Hemlock woolly adelgid infestation.

Photo by Chris Evans, Illinois Wildlife Action Plan, Bugwood.org

FIGURE 5.10

Range of hemlock and counties with hemlock woolly adelgid in the North (USDA FS, n.d.a; Wilson et al. 2012).



Establishing the spread rate of hemlock woolly adelgid and the probability of hemlock mortality is necessary for the management of hemlock in northern forests. However, this determination is complicated by (1) an asymmetric pattern of adelgid spread that is influenced by host abundance and (2) geographical variation in lethal cold winter temperatures (Parker et al. 2002, Skinner et al. 2003). Although hemlock woolly adelgid can succumb to low winter temperatures, it appears to be more susceptible to extreme low temperature events than to long periods of exposure to typical winter low temperatures. The spread rate ranges from 5 to 18 miles per year, and southwest spread is more rapid than to the northeast (where winter temperatures are lower). Thus, if winter low temperatures rise with climate change, the rate of hemlock woolly adelgid spread could increase across northern landscapes.

Sirex Woodwasp

Sirex woodwasp, which attacks both living and dead trees, was first detected in North America in 2004 and has been increasingly present in solid wood packing materials at U.S. ports of entry (de Groot et al. 2006, Haugen and Hoebeke 2005).

Native to Asia, Europe, and northern Africa, Sirex woodwasp was accidentally introduced to Australia, New Zealand, South Africa, and parts of South America, where it now causes ≤80-percent tree mortality in pine plantations (Haugen and Hoebeke 2005). Although it currently infests a very small area of northern forests, it has the potential to cause substantial regionwide damage (Fig. 5.11).

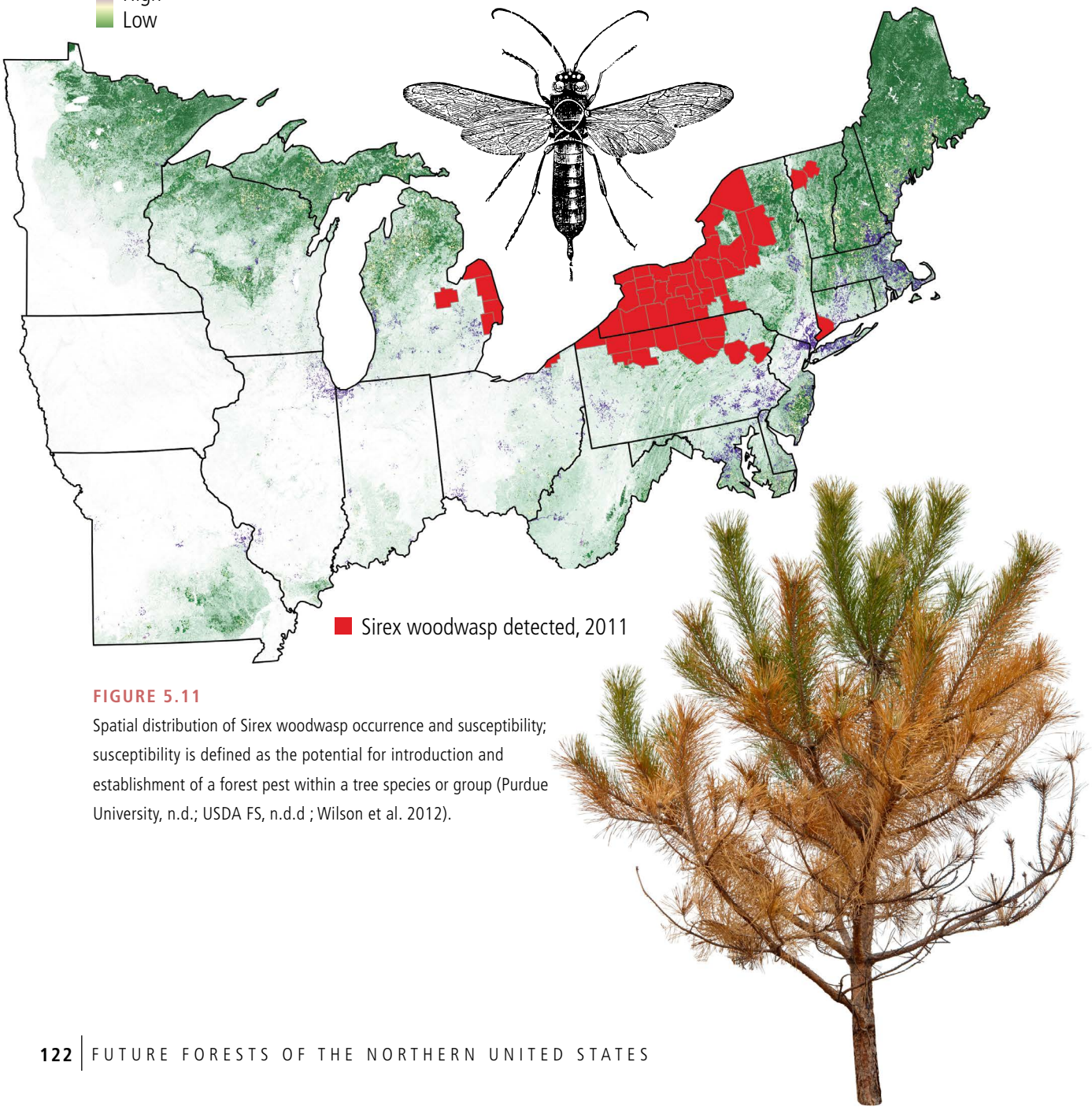


FIGURE 5.11

Spatial distribution of Sirex woodwasp occurrence and susceptibility; susceptibility is defined as the potential for introduction and establishment of a forest pest within a tree species or group (Purdue University, n.d.; USDA FS, n.d.d ; Wilson et al. 2012).

FIGURE 5.12
Counties with spruce budworm and range of four host tree species—spruce, fir, pine, and larch—in the North (USDA FS, n.d.a; Wilson et al. 2012).

Spruce Budworm

Eastern spruce budworm is one of the most destructive defoliators in North America and is the major defoliator of spruce and fir (*Abies* spp.) throughout eastern Canada and the eastern United States (Kucera and Orr, n.d.; PSU CAS 1987; Williams and Liebhold 2000). Over-mature, fire-suppressed stands of balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*) are particularly susceptible to spruce budworm outbreaks, but other softwoods are also vulnerable (Fig. 5.12).

Spruce budworm feeds on foliage and new shoots, causing extensive root mortality (Burns and Honkala 1990a). Although periodic budworm outbreaks are part of a natural cycle in spruce-fir forests, fire suppression and other human disturbances leading to unhealthy stand conditions can predispose forests to spruce budworm outbreaks (Boulanger and Arsenault 2004).

Winter Moth

Winter moth was first introduced in eastern Canada in the 1930s and is now established throughout coastal New England and New York (Childs et al. 2011). Native to Europe, this insect became a serious pest in eastern Canada, western Canada, and the U.S. Pacific Northwest; it now threatens to infest northern forests. Winter moth larvae defoliate a variety of woody species, including oaks, maples, cherries (*Prunus* spp.), basswood (*Tilia americana*), ash, elms, apples (*Malus* spp.), and spruces (Childs et al. 2011).

Other Invasive Insects

Other major pests of North American conifers include the nonnative balsam woolly adelgid (*Adelges piceae*) and the native jack pine budworm (*Choristoneura pinus*), which could cause considerable ecological and economic damage (McCullough et al. 1994).

Southern pine beetle (*Dendroctonus frontalis*) and pine engraver beetle (*Ips* spp.) cause extensive damage to yellow pines throughout the southeastern and western United States. Although damage is not as widespread in the U.S. North, both beetles are established and remain a threat. Other biotic agents that could pose serious problems to forests in the region include European spruce bark beetle (*Ips typographus*) and Mediterranean pine engraver beetle (*Orthotomicus erosus*).

NONNATIVE INVASIVE PLANTS

Invasive plants can cause considerable damage to ecosystem function, productivity, and species diversity (Lavoie 2010, McCullough et al. 2006). Other than habitat loss, invasive plants could pose the greatest threat to already imperiled North American plants and wildlife, with research showing that invasive plants contributed to the endangerment of 49 percent of all imperiled wildlife species and 57 percent of the imperiled plant species in the United States (Wilcove et al. 1998). In northern forests, invasive plants of major concern include tree, shrub, vine, herbaceous, and grass species (Olson and Cholewa 2009). Among the most widespread are garlic mustard (*Alliaria petiolata*), common buckthorn (*Rhamnus cathartica*), Morrow's honeysuckle (*Lonicera morrowii*), Japanese honeysuckle (*Lonicera japonica*), reed canarygrass (*Phalaris arundinacea*), Canada thistle (*Cirsium arvense*), Amur honeysuckle (*Lonicera maackii*), and autumn olive (*Elaeagnus umbellata*). Multiflora rose (*Rosa multiflora*), the most common invasive plant (Table 5.3) throughout northern forests (Kurtz 2013, Moser et al. 2009, Webster et al. 2006), is described here.

Table 5.3—Known occurrence of the major invasive plant threats in Northern States, 2005-2010 (Kurtz 2013)

State	Threat (marked by an X)								
	Multiflora rose	Garlic mustard	Common buckthorn	Morrow's honeysuckle	Japanese honeysuckle	Reed canarygrass	Canada thistle	Amur honeysuckle	Autumn olive
Connecticut	X	X	X	X	X	X	X		X
Delaware	X	X	X		X			X	X
Illinois	X	X	X	X	X	X	X	X	X
Indiana	X	X	X		X	X	X	X	X
Iowa	X	X	X	X		X	X	X	X
Maine	X		X	X		X	X	X	
Maryland	X	X	X	X	X		X	X	X
Massachusetts	X	X	X	X		X			X
Michigan	X	X	X	X	X	X	X	X	X
Minnesota	X	X	X	X	X	X	X	X	X
Missouri	X	X	X	X	X	X	X	X	X
New Hampshire	X		X			X			X
New Jersey	X	X	X	X	X	X		X	X
New York	X	X	X	X		X	X	X	X
Ohio	X	X	X	X	X	X	X	X	X
Pennsylvania	X	X	X	X	X	X	X	X	X
Rhode Island	X			X					X
Vermont	X		X	X					
West Virginia	X	X	X	X	X	X	X	X	X
Wisconsin	X	X	X	X	X	X	X	X	X
Percent[a]	17	5	4	4	4	3	3	3	3

[a]*The percentage of FIA plots where the monitored species was recorded.*

A native of Japan, Korea, and eastern China, multiflora rose was introduced to the eastern United States as rootstock for ornamental roses in 1866 (Plant Conservation Alliance 2005). This nonnative plant is extremely invasive in human-disturbed prairies, old fields, savannas, forest edges, and woodlands, forming dense thickets that can exclude native plant species, thereby decreasing species diversity. Multiflora rose has a broad ecological niche, tolerating various light, moisture, and soil conditions ranging from open fields to stream banks and roadsides to dense woods. It also produces abundant fruits that are widely consumed by birds, enhancing seed distribution.

COMPOUNDING EFFECTS OF ABIOTIC AGENTS

Forest Fragmentation

Forest land constitutes nearly 172 million acres, or 42 percent of the total land area in the U.S. North (Smith et al. 2009). In recent decades, U.S. forests have experienced a net increase in area. However, this increase includes conversions of land from agriculture to forest land, and from forest land that is contiguous to forest land that is fragmented by urbanization. As forest land becomes increasingly fragmented, the plants and wildlife that depend on forest ecosystems are subjected to increased competitive interactions among populations (O'Neill et al. 1988, 1992; Riitters et al. 2002). Fragmentation not only decreases the amount of habitat suitable for species adapted to the forest interior but also increases forest edge, thereby raising the chances of invasion from other land cover types (for example, agricultural, urban, barren, grassland, and shrub land) or water (Gardner et al. 1993, Tkacz et al. 2008).

In this manner, fragmentation can alter forest composition and structure and reduce forest health by predisposing the spread of nonnative and invasive species, reducing biodiversity, and dramatically changing ecological processes (Boulinier et al. 2001, Smith et al. 2009).

Multiflora rose in May. Photos by James H. Miller, U.S. Forest Service, Bugwood.org.

Human-caused fragmentation involves more frequent disturbances that lack the randomness of natural fragmentation, and often is more permanent than natural fragmentation because it is frequently the result of conversion to urban uses (Best 2002). Northern forest area is projected to decrease 5 percent by 2060 (Miles and Wear 2015). However, this includes both losses and gains, with much of the new acreage resulting from conversion of agricultural land to fragmented forest. Forest fragmentation is discussed in more detail in Chapter 3; conversion of urban and rural forest land is discussed in Chapter 10.

Climate Change

Climate is a major force that influences the composition of plant communities. Disturbances such as drought or fire often influence forests by promoting early successional, light-demanding vegetation (Abrams 1996). By changing successional pathways, severe or prolonged droughts can increase tree mortality and contribute to shifts in species composition (Allen et al. 2010). Although decreased available precipitation, increased temperature, and increased extent and severity of drought can have substantial impacts on forest ecosystems, the importance of these factors drastically increases when coupled with other forest threats, such as invasive species.

The Intergovernmental Panel on Climate Change generally suggests future global mean temperature will increase (Solomon et al. 2007). As with other invasive insect ranges, climate change may create warmer conditions favorable to nonnative invasive plant and insect habitat in areas that are currently unsuitable. For example, while the northward spread of insects has historically been limited by winter conditions, insects such as the emerald ash borer have rapidly spread to the north recently thanks to increasing winter temperatures (Chown and Terblanche 2006). However, the northern spread of emerald ash borer can be affected by complex weather relationships (DeSantis et al. 2013a).

Biotic and abiotic forces have altered forest ecosystems for millennia. Research suggests that climate has always played an important role in determining forest composition and structure (Allen 2009, Swetnam and Betancourt 1998, van Mantgem et al. 2009). One example is the decline of eastern hemlock in North America during the period that started 4700 years ago (and ended 3800 years ago), which one study (Filion and Quinty 1993) attributes to increasingly wet conditions and another (Allison et al. 1986) attributes to a pathogen. Both studies reported an eventual increase in eastern hemlock following the decline, and taken together they suggest that the interaction of biotic and abiotic forces is important to long-term changes in forest composition and structure. Along with evidence that climate is changing at an increasingly rapid pace (Solomon et al. 2007), there is the growing concern that background rates of forest change could increase and substantially alter the composition and structure of forests globally.

Fire

Wildfires pose several concerns, including risks to human life and property, species loss, adverse effects on forest productivity and health, carbon-cycle alteration, and air pollution. With a few exceptions, the annual amount of acreage burned in the North from 2004 to 2013 did not substantially change (Table 5.4). Although prescribed fire was used, most of the acreage that burned in northern forests was caused by wildfire.

Both the presence and absence of fire can have serious negative implications for forest ecosystems. The long-term effects of fire can be especially important for wildlife because of the potential for substantial changes to habitat and food sources (Bendell 1974). The long-term effects of fire suppression have indirectly altered forest health by influencing stand structure and composition (Lorimer 1985). For example, in northern forests that were once dominated by fire-adapted and fire-tolerant woody species or herbaceous vegetation, the suppression or decreased use of fire has enabled encroachment by other woody plants (Mutch 1970). When human population pressures and forest fragmentation decreased opportunities for safe burning, ecosystems historically maintained by human-caused fire often experienced shifts in species composition (Guyette et al. 2002, Nowacki and Abrams 2008).

The result was a decrease in fire-tolerant and fire-adapted vegetation such as oaks, which have substantially decreased in abundance in northern forests (Abrams 1992). Similar trends have occurred with yellow pine species in southern forests (Aldrich et al. 2010, Lafon et al. 2007, South and Buckner 2003). Given the amount of oak and pine in the region (30 percent of volume according to 2010 FIA data), such changes in species composition have broad-scale economic and ecological implications (Beisner et al. 2003, Scheffer et al. 2001). In addition, a decrease in fire is thought to have played an important role in oak decline throughout the range of northern oaks (Brose et al. 2001, Lorimer et al. 1994, Van Lear 2001).

Forests play an essential role in the global carbon cycle by acting as carbon sinks or sources. To address concerns about the effects of increasing atmospheric carbon dioxide on global climate, policy makers need accurate quantification of forest ecosystem carbon stocks, carbon fluxes between forests and the atmosphere, and effects of disturbances on forest carbon stocks and fluxes (Schulze et al. 2000). Depending on the forest type and stage of stand development, forests can act as carbon sinks or sources, but human-caused and natural disturbances can quickly change forest carbon sinks into sources. For example, stand-replacing wildfires that consumed jack pine (*Pinus banksiana*) forests in northern Michigan caused the rapid conversion of a carbon sink to a carbon source due to the consumption of respirable substrate (Rothstein et al. 2004).

Table 5.4—Acres burned by wildfire in North (NIFC, n.d.)

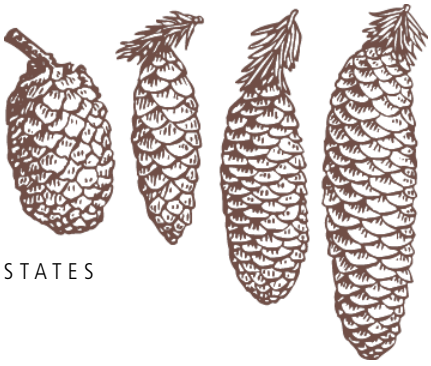
State	Area burned (acres)										
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average
Connecticut	94	263	419	288	893	246	262	244	417	238	336
Delaware	0	231	126	153	36	44	32	0	0	17	64
Illinois	476	733	1,040	611	16	1,155	630	2,019	1,848	55	858
Indiana	3,351	2,568	3,468	5,730	1,064	4,706	132	530	1,846	806	2,420
Iowa	585	10,566	827	684	2,217	8,565	2,722	2,145	349	14,704	4,336
Maine	960	822	1,794	423	535	481	318	116	489	743	668
Maryland	3,147	4,350	6,396	5,790	2,421	4,956	1,577	8,310	838	182	3,797
Massachusetts	1,534	2,530	2,821	2,687	2,918	1,144	2,117	545	1,027	879	1,820
Michigan	2,754	4,684	8,128	23,344	2,675	3,899	11,441	1,865	28,377	940	8,811
Minnesota	42,881	24,944	66,540	163,111	19,712	13,858	33,969	135,650	64,682	22,107	58,745
Missouri	32,542	19,621	24,308	10,537	9,765	42,241	17,620	55,395	26,456	1,660	24,015
New Hampshire	289	172	472	212	195	159	145	48	221	137	205
New Jersey	549	1,532	2,514	20,849	3,322	1,131	10,630	794	3,095	1,430	4,585
New York	390	656	2,508	855	3,629	1,404	2,066	232	2,127	1,073	1,494
Ohio	3,126	2,920	3,866	1,578	1,078	10,962	3,995	1,203	1,250	152	3,013
Pennsylvania	3	1,100	6,822	1,047	7,694	6,132	3,203	636	3,157	1,788	3,158
Rhode Island	81	84	120	61	132	45	23	27	41	27	64
Vermont	244	574	232	230	168	192	86	14	405	281	243
West Virginia	6,007	2,762	13,663	7,149	10,296	13,591	14,319	2,680	6,703	8,577	8,575
Wisconsin	2,385	6,311	2,287	4,713	1,050	3,746	2,185	719	2,880	9,196	3,547
Total	101,398	87,423	148,351	250,052	69,816	118,657	107,472	213,172	146,208	64,992	130,754

FIGURE 5.13
Serotiny of jack pine cones. Photo by Paul Wray, Iowa State University, Bugwood.org.

However, the extraordinary regeneration abilities of jack pine—producing seed from serotinous cones (Fig. 5.13)—enabled rapid establishment and conversion of a carbon source to a carbon sink. In other cases, the depletion of carbon sinks can sometimes be long term or even permanent (Balshi et al. 2009, Metsaranta et al. 2010).

FUTURE THREATS

In 1900, American chestnut (*Castanea dentata*) could be found throughout northern forests. Little did people know that one of the most dominant hardwood species would be devastated within 50 years. Since that time, Dutch elm disease (*Ophiostoma nova-ulmi*) has decimated American elm (*U. americana*), hemlock woolly adelgid has begun to decimate hemlock, and more recently, emerald ash borer has begun to decimate ash in northern forests. In addition, plants such as multiflora rose, intentionally introduced, have rapidly spread, competitively excluding native plant species. Asian longhorned beetle, Sirex woodwasp, and other recently introduced forest pests threaten to devastate maples and pines. Over the coming decades, new threats, including those from climate change and extreme storms, will inevitably materialize and negatively impact northern forests. Unfortunately, as has previously occurred, some destructive threats will emerge for which we lack the capacity to predict. Keeping forests intact and managing for forest health are the best defenses for resilience to these forest threats.



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Conservation and Maintenance of Soil and Water Resources

6

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Introduction

FOREST ECOSYSTEM PRODUCTIVITY and functioning depend on soil and water resources. But the reverse is also true—forest and land-use management activities can significantly alter forest soils, water quality, and associated aquatic habitats (Ice and Stednick 2004, Reid 1993, Wigmosta and Burges 2001). Soil and water resources are protected through the allocation of land for that purpose or through appropriate management regimes and best management practices (Blinn and Kilgore 2001, Young 2000). Because the biophysical linkage between soils and hydrological functions is strong, conservation land-use designations and best practices for forest management usually combine soil and water conservation objectives (California Department of Forestry and Fire Protection 2014, Minnesota Forest Resources Council 2013). In the absence of widespread, long-term direct measures of water and soil condition, information on land use, management activity, and application of best practices can serve as useful indicators of efforts to conserve soil and water resources.

Soil

Human society depends on soils for many essential services, which Blum (2005) categorized into six environmental, social, and economic functions: (1) biomass production, (2) protection of humans and the environment, (3) gene reservoir, (4) physical basis for human activities, (5) source of raw materials, and (6) soil and cultural heritage. Of these, the first three are most important from an environmental perspective:

- Biomass production is the aspect of soils that addresses the production of food, fiber, and fodder (Foley et al. 2005, Matson et al. 1997).
- The protection of humans and the environment includes those functions where soils filter, buffer, and transform water and gases among the terrestrial, hydrologic, and atmospheric systems—described narrowly by Gilliam (1994) and more broadly by Lowrance et al. (1984). Not all transformations are positive; for example, soil microbes convert elemental mercury to methyl mercury which bioaccumulates in the food chain (Jeremiason et al. 2006, Mitchell et al. 2008).
- As a gene reservoir, soil biota are critical to nutrient mineralization, which supports plant productivity (Van Der Heijden et al. 2008).

Key Findings

- Forest ecosystem productivity and function depend on soil and water resources. Forest and land-use management activities can significantly alter forest soils, water quality, and associated aquatic habitats.
- Across the Northern States, 76 million people depend on public and private forests for high quality water supplies.
- Thirty-six million acres (21 percent) of northern forest land is under Federal and State management.
- For private forest lands, which account for most of the forest land area in the North, Forest Stewardship Management Plans are of particular value in helping forest owners manage their resources sustainably; excluding land held by the forest products industry, 10 percent of private acreage is managed under such plans, but the covered area for individual States ranges from <5 percent to >30 percent.
- All Northern States except Minnesota have suboptimal conditions for one or more soil attributes on ≥50 percent of their survey plots; Delaware and Maryland have the largest number of plots with soil conditions that limit potential tree growth.
- The 10 States with the highest levels of suboptimal soil conditions are all located in the East.
- Only 2 of 551 northern watersheds have water supplies that currently are inadequate to meet societal demands, a number that is projected to increase substantially by 2060.
- Watersheds with the potential to produce high quality water tend to be found in forested regions of the upper Midwest, New England, and along the Appalachian Mountains; watersheds with relatively low potential to produce high quality water are located in the Midwest.
- State and Federal forest land area is expected to remain relatively constant for the next 50 years; however, expanding human populations are expected to place more pressure on public lands for freshwater supplies and other benefits.
- Under a future of moderately growing population and rapidly growing income, urban areas are projected to increase by 78 percent and forest areas are projected to shrink by 6 percent.
- Although total area of Federal and State forest land in the North is projected to remain stable through 2060, the relative area of 0.29 acres per person is projected to decrease to 0.23 acres per person due to increasing human population.
- On average for all northern watersheds, the amount of water used to meet societal demands is projected to increase under most future scenarios; for most watersheds, supplies would remain adequate, but the number of watersheds with the potential for shortfalls likely would increase.
- By 2060, the potential to supply high quality water is projected to decline for most watersheds in the North.
- At a regional scale, climate projections had more impact on future water supply and stress than did land-use or population projections, but there were some exceptions for individual watersheds.

Because soil is a limited resource, its six functions need to occur in appropriate spatial and temporal combinations to ensure its sustainability (Blum 2005).

Soils are dynamic and are commonly described as the result of five factors: climate, organisms, topographic relief, geologic parent material, and the passage of time (Jenny 1941). Understanding which of these factors are likely to remain stable and which are subject to change is critical to projecting future forest soil resources. Of the five soil-forming factors, global climate change and land-use change—two factors that are highly variable even in the current environment—will most strongly influence climate and organisms. Topographic relief and parent material can both change over geologic time, but they are relatively stable over human time scales, except when altered by direct human activities (such as surface mining or construction). One notable exception is the formation of soil along riparian corridors, where changes in river flow and sediment delivery resulting from land-use or climate change would influence the formation and character of future soils.

Climate influences soil formation and properties in two primary ways: temperature and precipitation. Temperature influences the physical, chemical, and biological processes that first transform raw parent material (such as sand, clay, and rock) into soil and then guide the development of the soil profile. Precipitation, both the total amount and the intensity of individual events, influences the transport of minerals through the soil profile to deeper horizons and eventually to local streams and other surface waters. Also, excessive water can lead to anaerobic conditions that again influence the physical, chemical, and biological processes in soil. Some soil properties change along a continuous temperature and precipitation gradient, but others strongly respond to thresholds, as reported by Dahlgren et al. (1997) in a study that placed the threshold along the effective winter snow line for soils in the California Sierra Nevada, thus reinforcing Jenny's (1941) conclusion that changes in climate can produce changes in soil properties. Such changes in soil properties could result in trees becoming nutrient stressed as changes also occur in the underlying cycles and interactions of essential mineral cycles (St. Clair et al. 2008). Of particular concern is the availability of soil minerals to trees, particularly in landscapes that experience precipitation decreases along with temperature increases. Oren et al. (2001) reported that soil nutrient and water deficits could limit tree growth responses to carbon dioxide enrichment. In addition, Saxe et al. (1998) reported that nutrient uptake by roots occurs primarily in the soil solution, and uptake can be greatly reduced with increasing drought events.

Organisms are important to soils. Not only do animals and plants modify the landscape in which they live, but they are also subject to climate and land-use changes, further exacerbating direct influences of climate and land use on soils. Observing forests developing on similar parent material, Finzi et al. (1998) found that community dynamics significantly influence surface soil acidity and base cation availability, thus altering potential plant productivity.

Another important contributor to forest soils is the glaciation that covered most of the northern landscape; these events essentially restarted the process of soil formation and plant succession.

Many plants and animals can migrate across great distances, an ability that some important soil forming organisms lack. Earthworms, which are nonnative throughout much of the North, are very slow colonizers. But these species have a profound influence on forest soils. Holdsworth et al. (2007) found that one of the best predictors of nonnative earthworm invasion is the distance to nearest road (Wisconsin) or cabin (Minnesota). Humans clearly play a role in the introduction of these nonnative "ecosystem engineers." Hale et al. (2005) found that the introduction of European worms to northern forests greatly reduces forest floor thickness, even to the point of complete removal. The invasion of nonnative earthworms could increase the pressure placed on forests already stressed by changing climates (Bohlen et al. 2004).

One of the concerns about land-use and climate change impacts on soils is the potential for feedback loops. According to Eswaran et al. (1993), the amount of organic carbon stored in soil is three times larger than what is stored in aboveground biomass, and double what is stored in the atmosphere. Although little is known about the potential complex feedbacks between a changing climate and soil carbon stocks, Davidson and Janssens (2006) reported that wetland, peatland, and permafrost soils are the most vulnerable to changing land-use and climate patterns.

Water

Adequate and reliable water supplies are critical to the proper functioning of social, economic, and ecological systems, all of which depend on forested watersheds for a broad range of aquatic benefits (or ecosystem services): freshwater supplies, stream-flow regulation, water-quality maintenance, and habitat for fish and other organisms. To varying degrees across the North, 76 million people rely on public and private forests for high quality water supplies (USDA FS 2005). Understanding the links among forests, water resources, and people is critical both for developing forest protection and management policies across the United States (Steen 2004). Many forest management policies and practices are designed to reduce negative impacts on water resources or improve conditions in places where disturbances have occurred (Aust and Blinn 2004).

As populations continue to grow in the region (Zarnoch et al. 2010), policy makers and managers need information about the potential effects of changing climate and land-use patterns on the ability of forested watersheds to supply sufficient water to this burgeoning population (Chapter 2).

Changing climate and land-use patterns have direct impacts on the quantity and quality of water resources at multiple scales. As temperatures increase, increasing rates of water loss through evapotranspiration can reduce the surface-water volume levels (Gleick 2000, Levin et al. 2002, National Assessment Synthesis Team 2000). However, volume will also be impacted by changes in the amount, timing, and variability of precipitation in addition to the frequency and intensity of storm events (Gleick 2000, Levin et al. 2002, National Assessment Synthesis Team 2000). Assessments of future water supplies also need to account for changes in land cover and land-use patterns, which have been shown to greatly affect the water balance in long-term watershed studies (Ford et al. 2011, Piao et al. 2007, Swank and Douglass 1974).

Changing land-use patterns can also affect water quality. Land-use conversions can change landscape-level forest composition and structure and can increase loading of sediments and other potential pollutants (Osborne and Kovacic 1993).

In particular, urbanization changes the quantity and character of trees and forests and increases the area of impervious surfaces (such as roads and parking lots). This reduces the ability of precipitation to infiltrate the soil (Sun and Lockaby 2012), resulting in an increase in the amount of surface runoff and, consequently, in the amount of sediment being delivered to streams (Booth and Jackson 1997). Other pollutants could also increase with an increase in urbanization. For example, wastewater and fertilizers increase phosphorous concentrations in urban streams (Paul and Meyer 2001), and in the western Great Lakes, turbidity is correlated with tree canopy disturbances and phosphorus is correlated with the amount of urban acreage in a watershed (Seilheimer et al. 2013).

Forest management practices can affect both the quantity and quality of water (National Research Council 2008), with impacts varying across areas, forest and treatment types, soils, climate, and harvesting intervals. As an example of effects on quantity, canopy removal during harvesting can reduce evapotranspiration levels, increasing water yield. This effect is usually transient, however, as the regrowth of young forest eventually results in a decrease of water yield. With respect to water quality, disturbances to soil during forest management activities could result in greater sediment delivery to surface waters. Recognition of the links between forest management practices and water resources has led to the development of best management practices (page 152) that focus on minimizing or eliminating deleterious effects (Aust and Blinn 2004).

Across the region, providing for future population and economic growth while meeting biodiversity conservation goals will require sufficient quantities of high quality water. Assessments of water quantity and quality under a range of plausible future climate and land-use scenarios answer a range of questions, including how levels of water quantity and quality might change in the future, where these changes might be the greatest, and whether water supplies will be sufficient to meet human demands. Answers to these questions will help inform policy and management decisions that could alter the trajectories of changing climate and land-use patterns.

INDICATORS OF SOIL AND WATER CONSERVATION AND MAINTENANCE

Some indicators of soil and water conservation and maintenance can be addressed using available data, for both current conditions and future projections, but others are much more difficult to project. For example, quantifying current acreage of lands enrolled in conservation easements and incentive programs is feasible, but predicting the future direction of legal, institutional, and policy conditions that affect these programs is much more difficult; so for these and other indicators, future conditions cannot be reliably predicted (Chapter 9).

Where Forest Management Focuses on Soil and Water Protection

The extent to which soil (land) and water resources in forested areas are protected by legislative or administrative designation or where their protection is the primary management focus is one indicator of forest sustainability. Such designations or management protections guard against degradation of soil resources, maintain soil quality, and prevent impairment of water supplies intended for public consumption (USDA FS 2011). A closely related indicator examines the proportion of forest management activities that meet best management practices or other relevant legislation to protect soil and water resources. Chapter 9 provides additional information about voluntary certification programs designed to protect soil and water resources, as well as the legal, institutional, and economic framework for forest conservation and sustainable management.

Because of the strong biophysical link between soils and hydrological functions, conservation land-use designations and best practices for forest management usually combine soil and water conservation objectives. Because data for these indicators was not available, information from State forestry reports of management activity and land-use designations was used.

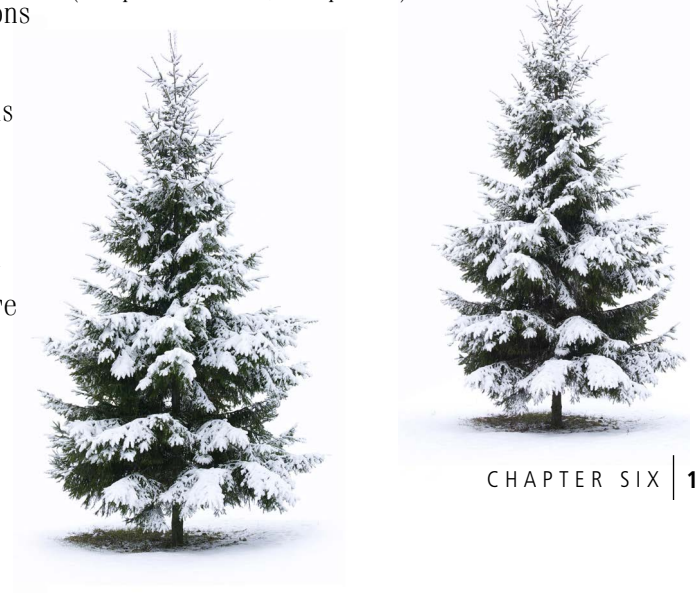
The lack of consistency among reporting protocols presented considerable challenges in addressing the indicators across an entire region (Carpenter 2007) and complicated efforts to predict public and private forest land-use patterns, practices, laws, and regulations and their associated impacts over the next 50 years. However, this is not to downplay the challenges of expanding human populations with resulting pressures on land and water resources. We simply describe best management practices and stewardship plans. Using a moderate population forecast, we show that increases in the forested land base over the last century are coming to an end, and per capita decreases are projected for the future. The public land ownership footprint is relatively small on the northern landscapes, and the private sector is where most land-use change and forest management will happen. The magnitude of forest area losses can have implications for the natural processes critical to ecosystem health as well as the environmental services that derive from clean air, water quality, and carbon storage (Carpenter 2007).

Stewardship Challenges for Private Forests

The northern forest landscape has been shaped by the stewardship ethic observed by generations of private landowners, local conservation and recreation groups, and public agencies. Lessons were learned from overzealous harvesting at the end of the 19th century. Now the lands and waters that will be needed to meet current and future conservation and recreation demands are under pressures unknown a generation ago.

Private lands that once supported high-quality family farmlands, working forests, and wetlands are now being converted to a variety of other uses (Chapter 10). The rural countryside is being divided into smaller parcels as an increasing number of people can afford a 10-, 20- or 40-acre private getaway. Often, this parcellation (Chapter 3) is self-fulfilling—the more that areas become fragmented, the more pressure there is to subdivide remaining parcels (Wisconsin DNR 2010).

Because most northern forest land is in private ownership (74 percent), private forest lands may well provide the bulk of wood products and other accessible natural resource raw materials like sands, gravels, oil, and gas minerals. Thus, they deserve careful consideration and thoughtful conservation measures to preserve soil and water benefits into the future. Partnerships involving government and nongovernment organizations, companies, and individuals are not only desirable but also necessary for the conservation and maintenance of forest ecosystems and the economic and social benefits that derive from them. Laws, regulations, and voluntary approaches all have a place in efforts to achieve sustainability (Carpenter 2007, Chapter 9).



Unlike governments that manage their forests with specialized staffs and resources, private citizens with small parcels often lack resources for developing their own plans for resource management. State and Federal agencies make an effort to provide technical assistance, help landowners recognize special areas, and support them in managing these areas for special values. In today's environment, progress toward sustainability requires continuous public awareness and discourse.

Based on a review of public programs and options for private forestry, Sampson and DeCoster (1997) concluded that Federal support is not keeping pace with changing demographics. In effect, the mosaic of U.S. forests, including those in the North, is managed by owners who have diverse cultural backgrounds and objectives and who operate within a complex framework of Federal, State, and local laws and regulations, private-property rights, and public land-management policies. Understanding the linkages among these factors and their aggregate impact is critical to understanding future forest sustainability.

Sampson and DeCoster (1997) recommend expanding service to rapidly developing communities and suggest more sophisticated marketing by policy leaders to target the needs of specific audiences. Implementing such a strategy would require more detailed information on forest landowners and the relationship between communities and the forest resource; however, inadequate funding for investments in marketing is cited as the major impediment to adopting these changes (Carpenter 2007).

More detailed information about forest ownership, management, and stewardship can be found in Chapter 9.

Best Management Practices

Best management practices are recommendations for working on the land. Forestry best management practices include a set of preventative measures designed to control or reduce the movement of sediment, nutrients, pesticides, or other pollutants from soils to surface waters (Aust and Blinn 2004). They capture and maintain a collective wisdom about how to protect the environment during operations such as harvesting and road building. They are meant to guide and regulate daily routine activities undertaken in the course of the (often) small projects that, taken together, alter stands, landscapes, and regions. They are designed to avoid excessive loss of productive soils from the landscape and to protect receiving surface waters from the excess sediment loads that result from accelerated erosion.

Best management practice categories include preharvest, stream management, logging roads, stream crossings, site preparation, chemical use, roads-to-bed, and wetlands (USDA FS 2011). All Northern States have some form of best management standards and guidelines across three general areas of management: silviculture, water (wetlands) and soils, and wildlife or biodiversity (Table 6.1). They can be voluntary or mandatory and can take the form of recommendations, guidelines, or standards. Once established, their effectiveness depends on whether they are maintained and whether their use is promoted (USDA FS 2011).

Table 6.1—Forest management standards and guidelines and their monitoring across ownership types for the North (Shifley et al. 2012); whether standards and guides are mandatory or voluntary; and whether the purpose of monitoring is for compliance with the standard or guideline or for effectiveness of the standard or guideline. (Note that information for Connecticut was missing from Shifley et al. [2012], but is included here.)

State	Standard or guideline					
	Silviculture		Water, soils		Wildlife, biodiversity	
	State forests	Private forests	State forests	Private forests	State forests	Private forests
Connecticut	Voluntary; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	Voluntary; no monitoring	Voluntary; no monitoring
Delaware	Mandatory; monitor for compliance	None	Mandatory; monitor for compliance	Mandatory; monitor for compliance	None	None
Iowa	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring
Illinois	Monitor for effectiveness	Voluntary; no monitoring	Monitor for effectiveness	Voluntary; no monitoring	None	None
Indiana	Mandatory; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; no monitoring	Voluntary; no monitoring
Massachusetts	Mandatory; monitor for compliance, effectiveness	None	Mandatory; monitor for compliance, effectiveness	None	Mandatory; monitor for compliance, effectiveness	None
Maryland	Voluntary; monitor for compliance, effectiveness	None	Mandatory; monitor for compliance, effectiveness	Mandatory; no monitoring	None	None
Maine	Voluntary; monitor for compliance, effectiveness	None	Voluntary; monitor for compliance, effectiveness	Voluntary; monitor for compliance, effectiveness	Voluntary; monitor for compliance, effectiveness	None
Michigan	Monitor for compliance	None	Mandatory; monitor for compliance	Voluntary; no monitoring	Mandatory; monitor for compliance	None
Minnesota	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance

Table 6.1 continued

State	Standard or guideline					
	Silviculture		Water, soils		Wildlife, biodiversity	
	State forests	Private forests	State forests	Private forests	State forests	Private forests
Missouri	Monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring
New Hampshire	Voluntary; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	None	None
New Jersey	Monitor for compliance, effectiveness	Voluntary; monitor for compliance	Mandatory; monitor for compliance	Mandatory; monitor for compliance	Monitor for compliance	Voluntary; monitor for compliance
New York	Monitor for compliance	Voluntary; no monitoring	Monitor for compliance	Voluntary; no monitoring	Monitor for compliance	Voluntary; no monitoring
Ohio	Mandatory; monitor for compliance	Mandatory; no monitoring	Mandatory; monitor for compliance	Mandatory; no monitoring	Mandatory; monitor for compliance	Mandatory; no monitoring
Pennsylvania	Mandatory; monitor for compliance	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring
Rhode Island	Mandatory; monitor for compliance, effectiveness	Voluntary; monitor for compliance	Mandatory; monitor for compliance, effectiveness	Voluntary; monitor for compliance	Mandatory; monitor for compliance	Voluntary; no monitoring
Vermont	Voluntary; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Voluntary; no monitoring
Wisconsin	Voluntary; monitor for compliance	Voluntary and mandatory; monitor for compliance	Voluntary and mandatory; monitor for compliance, effectiveness	Voluntary and mandatory; monitor for compliance, effectiveness	Voluntary and mandatory; monitor for compliance	Voluntary and mandatory; monitor for compliance
West Virginia	None	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	None	Voluntary; no monitoring

Forest Stewardship Management Plans

Forest stewardship management plans are particularly valuable in helping private forest owners manage their resources sustainably. Consulting foresters or State forestry staffs work with landowners to assess resources, determine management goals that include best management practices, and develop plans for operations and activities (including harvesting, timber stand improvement work, and wildlife habitat protection and maintenance). Ideally, the consulting forester is both a sounding board to help owners clarify their goals and intentions, and a source of expert and practical information about the potential for ensuring sustainability while pursuing other desired outcomes (Shifley et al. 2012). To meet the Federal standards, forest stewardship management plans must include consideration of soil stability and water quality.

As a case in point, many different methods are available for harvesting and removing trees from forest areas, and the way they are applied affects the kinds and degrees of impacts on ecosystems. For example, timber harvesting is known to remove soil nutrients—especially the base cations calcium, magnesium, and potassium—as part of the fiber removed from the site, and to increase the exposure of soil and residues to light, heat, and moisture. This results in accelerated decomposition of organic matter and some small acceleration of chemical weathering of inorganic minerals in soils and rocks, increasing the availability of nutrients for transport. Nitrogen, which normally would be taken up by living trees in the form of ammonium, is converted by soil microbes to nitrate, a form of nitrogen easily transported in water. This conversion results in a temporary flush of hydrogen atoms that replace base cations on soil particles and cause nutrients to move into the soil solution where they become susceptible to leaching. Stewardship plans that target soil organic matter content and nutrient stores would address issues related to timber harvesting (timing and intensity), land-use history, and the effects of potential nutrient losses resulting from soil erosion (Carpenter 2007).

Variations in the number of forest stewardship plans among States largely reflect differences in the amount of forest acreage and the number of owners, but States also differ in the degree of emphasis they place on stewardship planning in relation to other priorities. Because technical assistance from professional foresters is central to plan development, the number of plans and the number of acres covered are both sensitive to changes in the Federal and State funding that determines their availability (Shifley et al. 2012). An increasing number of landowners (with increasingly smaller landholdings) is also a critical challenge for those providing the needed technical assistance. About 10 percent of all northern nonindustrial private forest acreage (acreage not owned by forest products companies) is managed under stewardship plans, but the covered area for individual States ranges from <5 percent to >30 percent (Table 6.2).

Table 6.2—Cumulative area of private forest land in the North that is covered by active forest stewardship plans, 2010 (Shifley et al. 2012).

State	Area		
	Total forest area[ab]	Cumulative area under forest stewardship plans[c]	
	(thousand acres)		(percent)
Wisconsin	9,674	2,985	31
New Hampshire	2,844	634	22
Maryland	1,462	324	22
Illinois	3,509	628	18
Delaware	244	39	16
Minnesota	5,921	860	15
New Jersey	805	115	14
Massachusetts	1,998	276	14
Indiana	3,588	463	13
Iowa	2,511	295	12
Ohio	6,064	520	9
New York	12,190	975	8
Pennsylvania	9,603	531	6
West Virginia	7,174	270	4
Vermont	3,109	110	4
Connecticut	1,148	39	3
Maine	6,261	210	3
Missouri	11,755	343	3
Rhode Island	251	7	3
Michigan	9,458	203	2
Northern U.S. total	99,569	9,828	10

[a]*Includes family farms, real estate investment trusts, and timber investment management organizations but does not include land owned by the forest products industry.*

[b]*From Smith et al. (2009).*

[c]*From State data in the Performance Measurement Accountability System, provided by Michael Huneke, U.S. Forest Service.*

Other Conservation Efforts

Many Federal, State, and local laws are in place to conserve and protect special environmental, cultural, social, or scientific values. Agencies regulate against harm to special resources like soil, fisheries, water quality, watershed protection, air quality, and species at risk. They acquire or administer lands for special purposes, or provide technical assistance on how to mitigate the adverse impacts of forest management on special resources. For example, maintenance of soil and site quality is written into the management plan of every national forest, with monitoring protocols designed to detect forest-productivity losses that are ≥15 percent (Powers et al. 1990).

FOREST LAND WITH SIGNIFICANT SOIL DEGRADATION

Trees grow in response to available light, water, and nutrients. Tree stress increases when nutrient levels are suboptimal. Cronan and Grigal (1995) demonstrated that calcium/aluminum ratios measured in soil solution are useful indicators of tree stress, and Page-Dumroese et al. (2010) summarized the science of soil monitoring for managers of national forests and rangelands. In this analysis of suboptimal soil conditions, indicators of soil quality developed by Amacher et al. (2007) were applied to survey plots maintained by Forest Inventory and Analysis (Table 6.3).

Table 6.3—Percentage of forest inventory plots, 2000-2005, in the North that were reported to have suboptimal soil conditions (FIA data).

Soil Quality Indicator	Connecticut	Delaware	Illinois	Indiana	Iowa	Maine	Maryland	Massachusetts	Michigan
	At 0- to 10-cm depth (percent)								
Phosphorus[a] < 15 mg/kg	62	84	70	91	64	78	100	73	73
Phosphorus[b] < 10 mg/kg	NA[c]	NA	60	75	25	NA	NA	NA	33
Exchange aluminum > 100 mg/kg	92	83	14	35	0	81	88	81	27
Exchange calcium < 100 mg/kg	46	66	7	4	0	37	75	50	17
Exchange potassium < 100 mg/kg	69	76	41	65	19	79	88	69	81
Exchange magnesium < 50 mg/kg	54	62	10	17	0	60	75	69	45
Organic carbon < 1 percent	0	0	0	6	0	1	0	0	6
Total nitrogen < 0.1 percent	8	14	7	11	5	4	25	13	23
Water pH less than 4.0	0	59	0	0	0	25	25	31	8
	At 10- to 20-cm depth (percent)								
Phosphorus[a] < 15 mg/kg	69	90	75	91	53	84	83	82	70
Phosphorus[c] < 10 mg/kg	NA	NA	60	75	40	100	NA	NA	77
Exchange aluminum > 100 mg/kg	85	83	37	54	5	74	88	81	22
Exchange calcium < 100 mg/kg	77	90	11	24	0	61	75	81	40
Exchange potassium < 100 mg/kg	100	97	63	85	32	95	100	94	95
Exchange magnesium < 50 mg/kg	85	90	11	39	3	81	100	88	65
Organic carbon < 1 percent	23	10	26	20	11	5	0	0	34
Total nitrogen < 0.1 percent	46	55	49	44	22	14	88	19	57
Water pH < 4.0	0	28	0	0	0	7	0	6	2

[a]*Test performed according to Bray and Kurtz (1945).*

[b]*Test performed according to Olsen et al. (1954).*

[c]*NA = no data available.*

Table 6.3 continued

Soil Quality Indicator	Minnesota	Missouri	New Hampshire	New Jersey	New York	Ohio	Pennsylvania	Rhode Island	Vermont	West Virginia	Wisconsin
At 0- to 10-cm depth (percent)											
Phosphorus[a] < 15 mg/kg	44	88	77	100	76	88	80	50	89	96	49
Phosphorus[b] < 10 mg/kg	13	88	NA[c]	NA	50	100	NA	NA	NA	NA	22
Exchange aluminum > 100 mg/kg	24	20	85	50	67	35	85	100	63	58	32
Exchange calcium < 100 mg/kg	1	9	35	63	20	5	43	0	40	14	8
Exchange potassium < 100 mg/kg	48	49	74	88	64	49	72	0	90	54	74
Exchange magnesium < 50 mg/kg	11	14	65	88	42	19	70	0	63	31	26
Organic carbon < 1 percent	3	4	0	0	1	0	5	0	3	0	4
Total nitrogen < 0.1 percent	13	11	3	50	4	2	4	0	10	17	21
Water pH less than 4.0	2	0	18	50	33	2	30	0	23	10	5
At 10- to 20-cm depth (percent)											
Phosphorus[a] < 15 mg/kg	52	90	86	80	83	90	81	100	86	90	56
Phosphorus[c] < 10 mg/kg	64	80	NA	NA	0	100	100	NA	NA	NA	71
Exchange aluminum > 100 mg/kg	28	28	67	38	64	49	89	100	67	65	36
Exchange calcium < 100 mg/kg	3	24	70	88	42	28	61	50	50	29	17
Exchange potassium < 100 mg/kg	77	74	100	88	86	78	93	100	100	67	90
Exchange magnesium < 50 mg/kg	31	22	94	88	59	39	84	50	83	47	48
Organic carbon < 1 percent	31	40	3	13	4	38	22	0	0	10	27
Total nitrogen < 0.1 percent	54	55	21	88	13	47	35	0	17	53	55
Water pH < 4.0	2	0	6	25	13	0	8	0	10	2	1

Federal and State Land

A number of programs and legal instruments focus on preserving specific forest-soil-water interactions and conditions at State and Federal levels. An example is the 1891 Forest Reserve Act, which established the first forest reserves (designated as national forests in 1907). Its original purpose was to preserve water resources—that is, to protect watersheds from erosion and flooding—and to protect timber supplies from overexploitation; but it later became the basis for a growing conservation movement to preserve natural resources for future generations by applying multiple-use and sustained-yield principles to forest management. These principles stress the need to balance the uses of the major resources and benefits of forests—timber and soil productivity, water supplies, recreation, livestock forage, wildlife and fish, and minerals—in the best public interest.

To forecast changes in amount of Federal and State land area per person, it is assumed that State and Federal land area will remain relatively constant for the next 50 years, but projected increases in human populations will likely place more pressure on public land and water resources.

An examination of Federal and State forest land area illustrates differences in rankings among U.S. regions (Table 6.4). Thirty-six million acres (or 21 percent) of northern forest land is managed by Federal and State agencies. Federal and State forest land was 0.29 acres per person in 2007 and is expected to decrease to 0.23 acres per person by 2060 under an assumption of increasing urbanization (moderate population and high economic growth) and relatively stable to slightly decreasing forest area.

Table 6.4—Combined area of all Federal and State forest land in the United States, 2007, and projected change in acres per capita, 2007 to 2060, assuming constant forest area in these ownerships, with increasing population (Cordell et al. 2012, Smith et al. 2009).

Region	Federal and State forested area			
	2007			2060
	(thousands of acres)	(percent of total)	(acres per capita)	(acres per capita)
North	36,345	21	0.29	0.23
South	26,541	12	0.25	0.16
Rocky Mountains	112,597	75	3.99	2.27
Pacific Coast	141,762	66	2.87	1.86
U.S. total	317,244	42	1.03	0.71

Private Forest Land

Private forests are expected to continue being converted to developed uses. Smith et al. (2009) reported that the bulk of northern forest land (58 percent) is in private ownership (defined here as all private owners, excluding forest products companies); the remainder is held by the Federal government (8 percent), State and local governments (17 percent), and corporate forest ownership (17 percent).

Although lands in public ownership are expected to form the base for most "legislatively" protected or reserved forest, management and land-use change will have the biggest impacts on private lands. The increase in number of humans in the next 50 years could bring different demands on forest resources and other natural resources, particularly on private lands near the urban fringe. A variety of programs and legal instruments are in place to preserve specific forest-soil-water interactions and conditions regardless of ownership. These include establishing conservation easements, placing lands in private and public land trusts, and marketing rights that are traditionally associated with property.

PROJECTIONS OF WATER SUPPLY AND QUALITY

Water Quantity

Baseline conditions from 2010 and projected climate, land-use, and human population change were used to assess the ability of water supplies to meet societal demands from 2010 to 2060. Projections were based on unique combinations of IPCC (2007) storylines and general circulation models (Table 6.5). The projections used greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007, Chapter 2): A1B assumes moderate greenhouse gas emissions associated with moderate gains in population growth and large gains in income and energy consumption—but with a balanced renewable/fossil fuel portfolio, A2 assumes relatively high greenhouse gas emissions associated with large gains in population growth and energy consumption with moderate gains in income, and B2 assumes relatively low greenhouse gas emissions associated with moderate gains in population growth, income, and energy consumption. Storylines A1B and A2 storylines were used for our water resource assessments; storyline B2 was omitted because projected emissions under the B2 storyline may underestimate actual greenhouse gas emissions (Raupach et al. 2007). See Tavernia et al. (2013) for detailed description and assumptions.

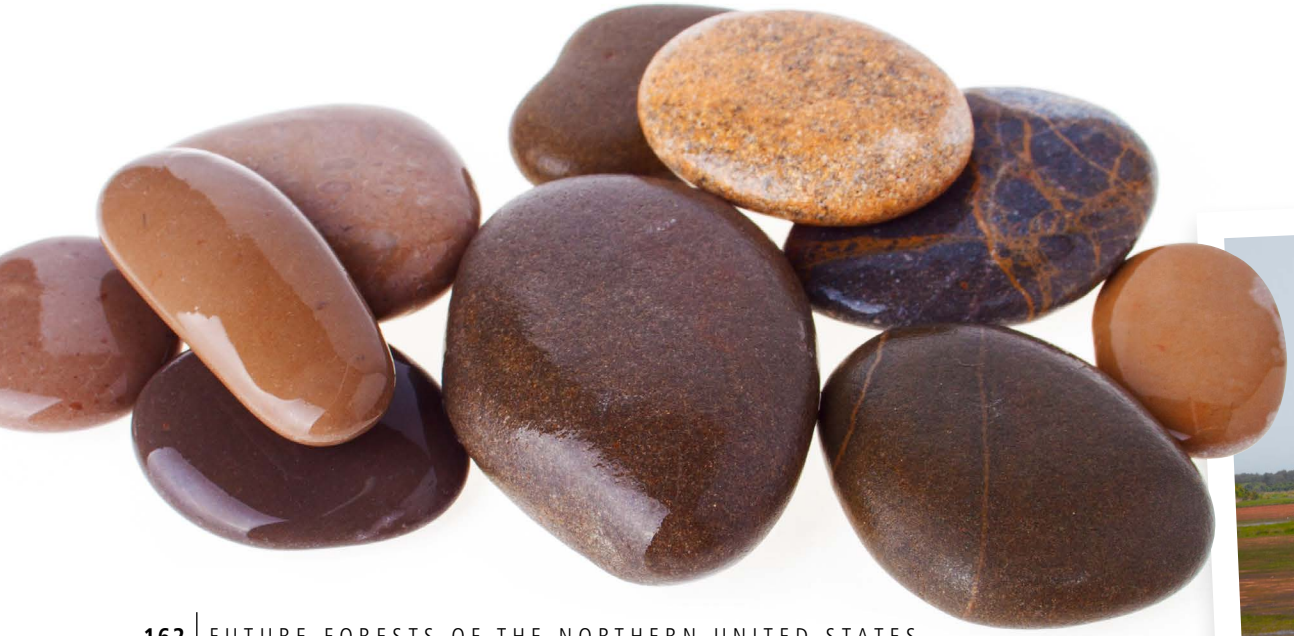
Table 6.5—Water supply and stress index (WaSSI) in the 551 watersheds of the North, estimated for 2010 and projected for 2060, under two IPCC (2007) greenhouse gas emissions storylines—A1B assumes moderate greenhouse gas emissions associated with large urbanization gains and moderate population growth and rapid income growth, and A2 assumes moderate greenhouse gas emissions associated with moderate urbanization gains, rapid population growth, and moderate income growth—combined with three general circulation models, CGCM-3.1MR, CSIRO-Mk 3.5, and MIROC3.2MR.

Estimate/scenario	Overall WaSSI[a]	Watersheds and populations in each category of water stress[b]					
		Low WaSSI		Moderate WaSSI		High WaSSI	
	Stress index	Number of watersheds (percent)	Million persons (percent)	Number of watersheds (percent)	Million persons (percent)	Number of watersheds (percent)	Million persons (percent)
Estimate, 2010	0.07	538 (98)	121.3 (98)	11 (2)	2.1 (2)	2 (0)	0.2 (0)
A1B+CGCM3.1[c]	0.08	536 (97)	150.6 (96)	13 (2)	6.0 (4)	2 (0)	0.2 (0)
A1B+CSIROMk3.5[c]	0.13	521 (95)	142.9 (91)	21 (4)	12.5 (8)	9 (2)	1.4 (1)
A1B+MIROC3.2[c]	0.19	504 (92)	135.5 (86)	29 (5)	18.1 (12)	18 (3)	3.2 (2)
A2+CGCM3.1	0.18	505 (92)	151.5 (86)	31 (6)	20.6 (12)	15 (3)	5.1 (3)
A2+CSIROMk3.5	0.09	532 (97)	155.5 (88)	15 (3)	19.5 (11)	4 (1)	2.2 (1)
A2+MIROC3.2	0.14	516 (94)	156.5 (88)	24 (4)	18.3 (10)	11 (2)	2.4 (1)

[a]*The proportion of the water supply that is used to meet societal demands; values represent an average of annual values for watersheds across the region.*

[b]*Watersheds are classified into three categories based on their WaSSI values: low (<0.50), moderate (0.50 to 1), and high (>1).*

[c]*Sources of models: CGCM3.1 = Canadian Centre for Climate Modeling and Analysis Third Generation Coupled Global Climate Model (T47 medium resolution version) (http://www.ec.gc.ca/ccmac-cccma); MIROC3.2 = University of Tokyo Center for Climate System Research, National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan, Model for Interdisciplinary Research on Climate version 3.2 (medium resolution) (http://www-pcmdi.llnl.gov/ipcc/model_documentation/MIROC3.2_hires.htm); CSIRO-Mk3.5 = Commonwealth Scientific and Industrial Research Organization, Australia, Mark 3.5 Global Climate Model (http://www.cawcr.gov.au/publications/technicalreports/CTR_021.pdf).*

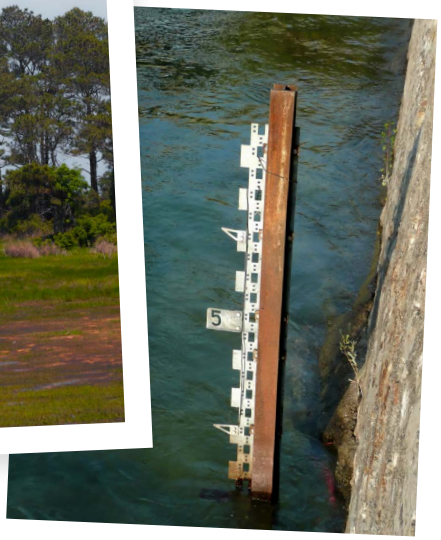


For these assessments, we used a water supply and stress index (WaSSI), defined by Sun et al. (2008) as the proportion of a watershed's water supply that is used to meet societal demands. When WaSSI values are >1, water supplies are insufficient and external sources could be needed to meet the deficit. Watersheds were classified into three categories based on their WaSSI values:

- <0.50—low stress
- 0.50 to 1—moderate stress
- >1—high stress

The working scale for WaSSI is the U.S. Geologic Survey 8-digit Hydrologic Unit Code, which describes approximately 2100 watersheds in the lower 48 States (USDA NRCS 2009). See Tavernia et al. (2013) for a detailed description of methods.

The 551 watersheds in the North currently experience little water stress (Fig. 6.1, Table 6.5). Across watersheds, the average annual WaSSI value was 0.07, and only two watersheds had high WaSSI values, indicating high stress. About 121 million people reside in watersheds with low stress values, 2 million in watersheds with moderate stress, and 200,000 people in two watersheds with high stress, one located in western Iowa, the other in central Illinois.



By 2060, changes in climate, land-use patterns, and human populations could individually and collectively alter water stress levels. Temperature levels across the region are expected to increase under all scenarios considered, although the magnitude of projected increase varies (Chapter 2). An increase in temperature could lead to increased evaporative loss and decreased water availability, thus increasing water stress. However, water abundance is primarily driven by precipitation (McCabe and Wolock 2011). Scenarios differ with respect to precipitation, with some suggesting that regional precipitation will increase and others suggesting that it will decrease (Chapter 2). For a specific location, projected changes in precipitation also vary in magnitude and direction. Urban land use is projected to increase across the region with variations in magnitude across scenarios and locations (Chapter 10). Because urban areas are less vegetated, are less permeable, and have lower evapotranspiration rates than other land-use types, water surface abundance would increase in some areas, but at a cost to water quality (Lull and Sopper 1966, 1969; Sun and Lockaby 2012). Although projections indicate that the overall human population in the region would increase under all scenarios considered, the rate of growth would vary among scenarios (see Chapter 2) and across the region, with some locations expected to have smaller populations by 2060. Increases in human populations can be expected to increase water demand and place an additional burden on water supplies.

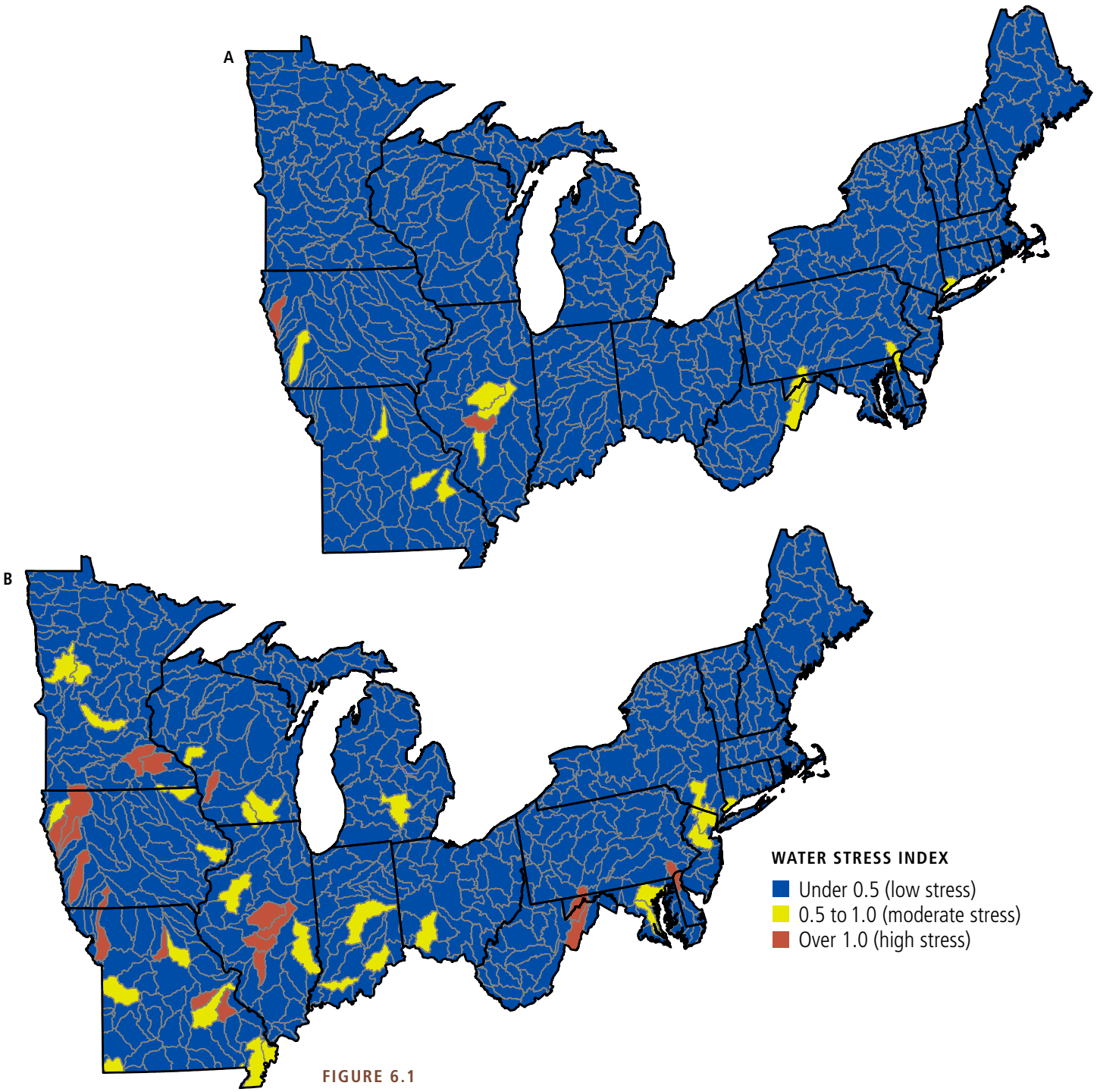


FIGURE 6.1

Average annual water supply and stress index values—the proportion of the water supply being used to meet societal demands—for watersheds in the North (A) in 2010 and (B) projected for 2060 under the MIROC3.2MR general circulation model from the Japanese National Institute for Environmental Studies combined with a greenhouse gas emissions storyline A1B (IPCC 2007) that predicts moderate greenhouse gas emissions, large urbanization gains, moderate population growth and rapid income growth. Maps for five additional projections (storyline-GCM combinations) can be viewed in Tavernia et al. (2013).

Regionally, assessments using the WaSSI model (Caldwell et al. 2012) suggest that WaSSI values would increase under most future scenarios (Fig. 6.1, Table 6.5). Although average annual WaSSI values would remain low under all scenarios, the number of watersheds classified as having moderate or high WaSSI values would increase. Increases in the average annual WaSSI value and the number of watersheds with moderate or high WaSSI values would be highest for storyline A1B with climate projected by the MIROC 3.2MR general circulation model (Table 6.5, Chapter 2). Under this scenario by 2060, approximately 136 million people are expected to live in watersheds with low water stress, 18 million in watersheds with moderate stress, and 3 million in watersheds with high stress. At a regional scale, climate projections had more impact than land-use or population projections, but there were some exceptions for individual watersheds. The results of WaSSI assessments could differ if conducted for localized areas within a watershed or at finer temporal scales, such as monthly (Tavernia et al. 2013).

Other researchers have used lower WaSSI thresholds for labelling watersheds as stressed. Ultimately, local water management strategies affect the level at which a watershed becomes stressed. See Tavernia et al. (2013) for additional discussion.

Water Quality

The suitability of water for a given use (such as drinking, industrial processes, or recreation) depends on its quality; for this reason, assessments of future water supplies need to account for the effect of changing land use on water quality. Projections for 2060 suggest that urban areas will increase at the expense of forest and agricultural land (Chapters 2, 10). Projected increases are expected to be highest under storyline A1B (resulting from moderate population growth and high economic growth). Under A1B, urban areas are projected to grow from 37 to 66 million acres (78-percent increase) whereas forest areas are projected to shrink from 174 to 163 million acres (6-percent decrease).

Conversion of forests to urban areas would negatively impact water quality in a variety of ways, including changing stream temperatures and increasing the load and concentration of sediments, nutrients, pesticides, and other pollutants (Paul and Meyer 2001, Sun and Lockaby 2012).

The potential for the biophysical and land-use characteristics of a watershed to support production of high quality water resources under the 2010 baseline and the land-use conditions projected for 2060, was assessed using a Clean Water Potential Index (CWPI), based on an index developed by Barnes et al. (2009) but modified to substitute some attributes for which future projections are unavailable. Watersheds were assigned individual values based on soil erodibility and the percentage cover of forest, riparian-forest, agricultural, and urban areas. We computed CWPI by combining these values into a composite value that ranged from 5 (low potential for clean water) to 20 (high potential for clean water), assuming constant percentage cover of riparian forest and constant soil erodibility over time. CWPI values are useful for ranking the ability of watersheds to support the production of high quality water resources based on landscape conditions, but realized water quality also depends on additional factors, such as water treatment capacity, that are beyond the scope of this assessment.

Currently, watersheds with relatively high CWPI values tend to be found in forested areas of the upper Midwest, New England, and along the Appalachian Mountains. Relatively low CWPI is found in midwestern watersheds that have low forest use, high agricultural use, and sometimes high urban use (Fig. 6.2). By 2060, land-use changes, predominantly by increases in urban land use, are projected to decrease CWPI values for the majority of watersheds in the region. Under storyline A1B, 362 of 551 (66 percent) watersheds would have lower CWPI values compared to 293 (53 percent) under A2 (Fig. 6.2). Agreement between storylines A1B and A2 was high (Fig. 6.3) with both storylines predicting losses for 288 watersheds and only a few watersheds predicted to experience losses under one or the other alone—74 watersheds under A1B and 5 watersheds under A2. Declines in CWPI values are expected to occur for watersheds scattered throughout the region, suggesting that landscapes within these watersheds will be less able to produce high quality water.

For the vast majority of watersheds, projections indicate that the amount of high-quality water available for human use will be adequate, but some could face shortages, leading to water stress or increasing water treatment costs. Policies including zoning regulations and financial incentives such as conservation easements could help safeguard the role of forests in providing high quality water to human populations.

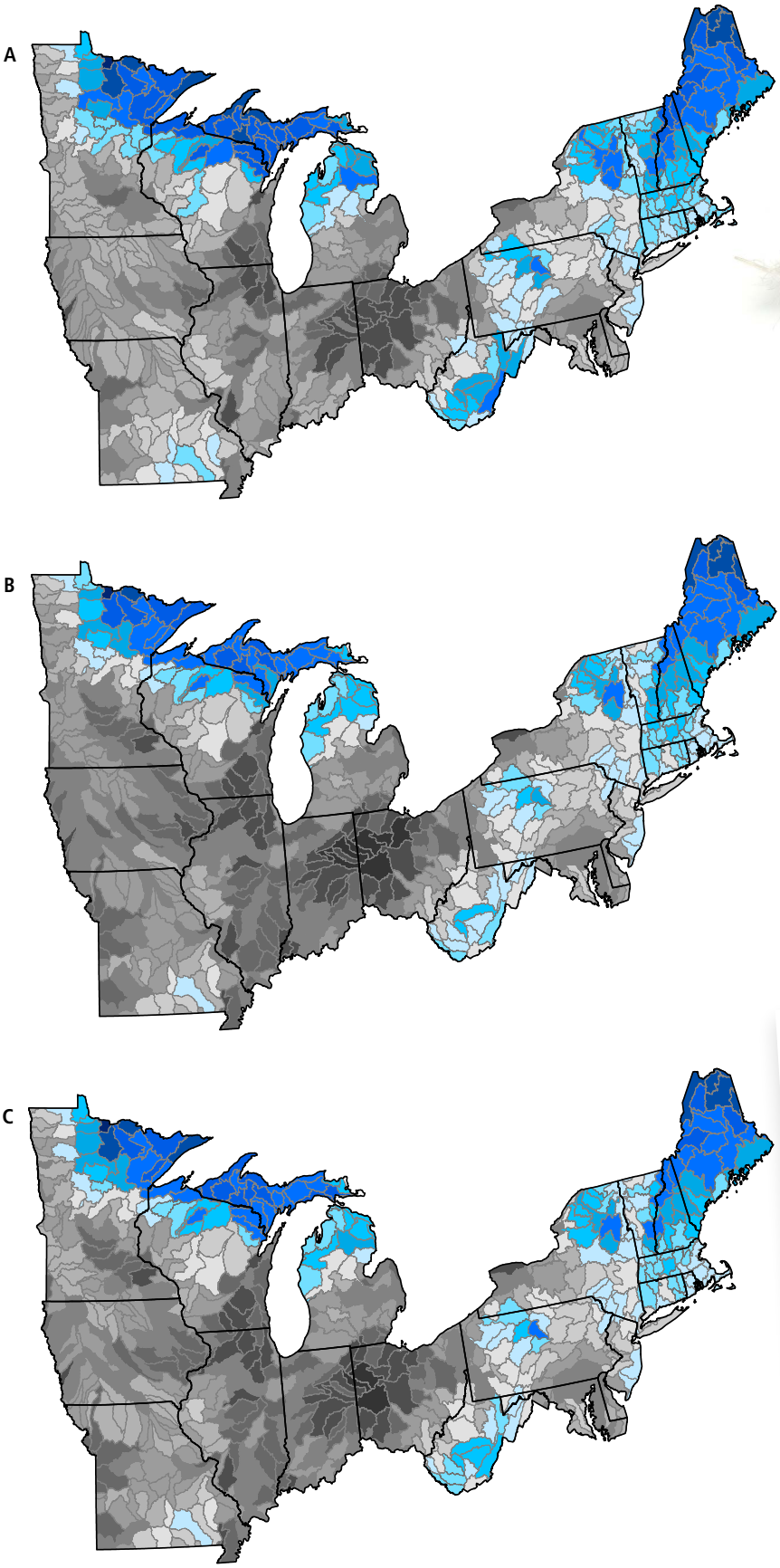


FIGURE 6.2

Clean water potential index values for watersheds in the North (A) in 2010; (B) projected for 2060 under storyline A1B that predicts moderate greenhouse gas emissions, large urbanization gains, moderate population growth and rapid income growth; and (C) projected for 2060 under storyline A2 that predicts high greenhouse gas emissions, moderate urbanization gains, rapid population growth, and moderate income growth. Index values are a composite of soil erodibility and percentage cover of forest, riparian-forest, agricultural, and urban areas.

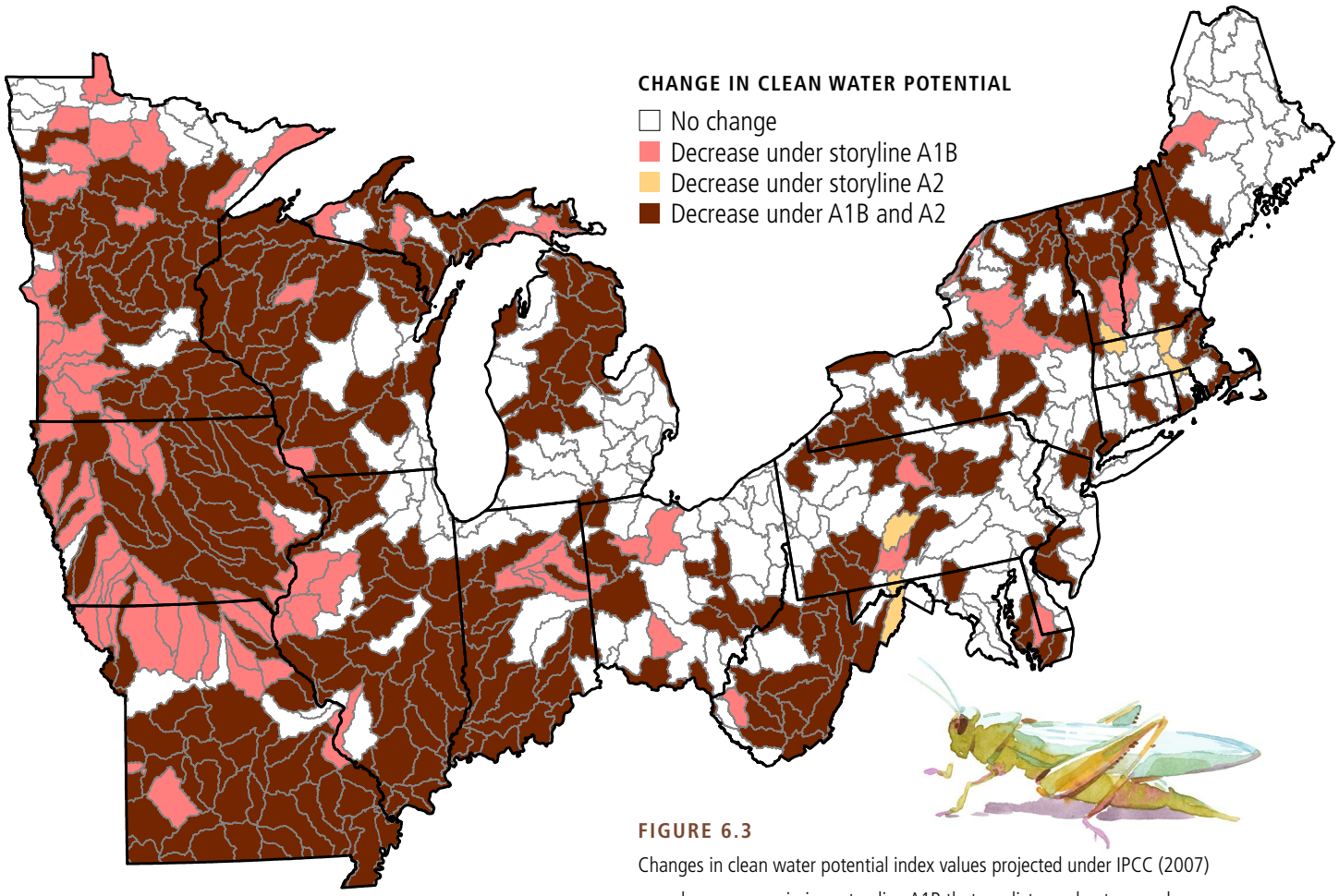


FIGURE 6.3

Changes in clean water potential index values projected under IPCC (2007) greenhouse gas emissions storyline A1B that predicts moderate greenhouse gas emissions, large urbanization gains, moderate population growth, and rapid income growth; and under storyline A2 that predicts high greenhouse gas emissions, moderate urbanization gains, rapid population growth, and moderate income growth. Index values are a composite of soil erodibility and percentage cover of forest, riparian-forest, agricultural, and urban areas.

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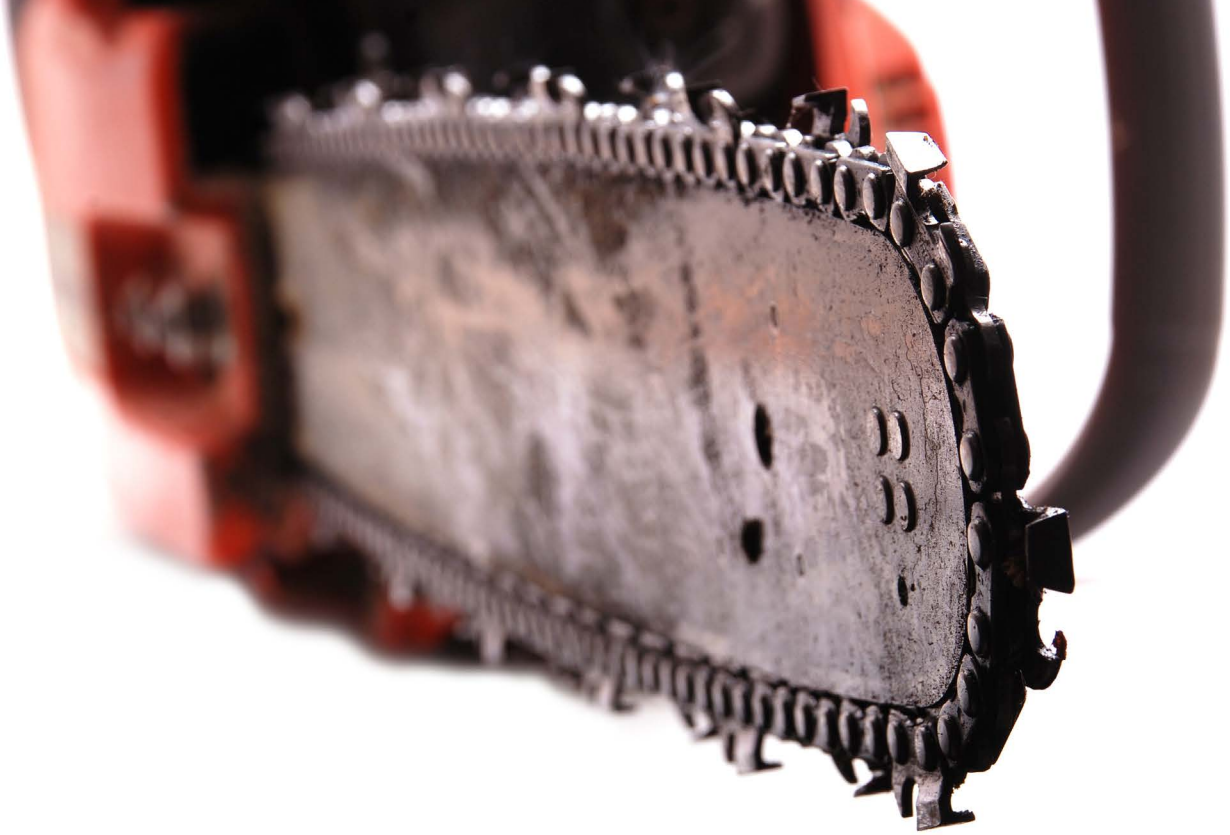


Projections of Forest Contributions to Global Carbon Cycles

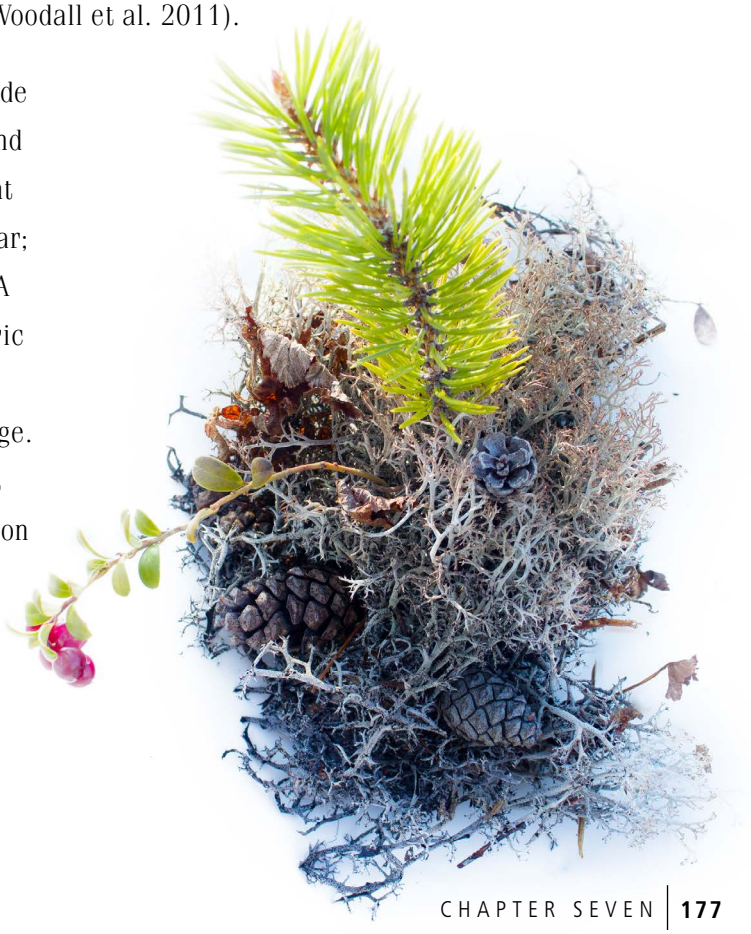
7

Michael E. Goerndt, Stephen R. Shifley, Patrick D. Miles, David N. Wear, and Francisco X. Aguilar

Introduction

FORESTS COVER 42 PERCENT of the Northern United States, and collectively they store 13 billion tons of carbon in live trees (29 percent), roots (6 percent), forest floor (9 percent), dead trees (6 percent), and soils (50 percent). About half the biomass of a live tree (dry weight basis) is sequestered carbon (Woodall et al. 2011)—not the largest but the most dynamic source of sequestered forest carbon over time. Through photosynthesis, live trees emit oxygen in exchange for the carbon dioxide that they pull from the atmosphere, storing the carbon in wood above ground and roots below ground as they grow. Dead trees and down logs are also reservoirs of stored carbon, which is released back into the atmosphere slowly through decomposition or rapidly through combustion (McKinley 2011, Woodall et al. 2011).

Society emits enormous amounts of carbon dioxide during electricity production, transportation, and other activities. Emissions for each U.S. resident average about 18 tons of carbon dioxide per year; this corresponds to 5 tons of carbon (USDOE EIA 2010, US EPA 2011). Increases in atmospheric carbon dioxide and other greenhouse gasses have been implicated in global climate change. Forests, because of their geographical extent and their capacity to sequester additional carbon or to release stored carbon, serve as important sinks or sources of carbon, thereby playing an important role in regional and global carbon cycles (McKinley et al. 2011, Pan et al. 2011).



Key Findings

PRESENT DAY

- In the United States, the total amount of sequestered carbon in forests is equal to about 27 years of carbon dioxide emissions.
- The yearly accumulation of carbon in U.S. forests is estimated to offset 13 percent of total annual carbon emissions.
- In 2007, 2 percent of the energy consumed in the United States came from wood firing by industry (1.3 percent), residential units (0.4 percent), utilities (0.2 percent), and other (0.1 percent) users.
- Less than 1 percent of the U.S. electric power is generated from wood.

PROJECTED

- Total carbon sequestered by northern forests is expected to decrease by about 2 percent from 2010 to 2060, primarily the result of reduced forested acreage combined with the slower growth that is typical for mature trees.
- Aboveground forest biomass is expected to increase by 3.9 percent from 2010 to 2060.
- Both sequestered forest carbon and aboveground woody biomass are expected to increase in the Midwest and decrease in many eastern States.
- By 2030, U.S. electrical power generated from all biomass is expected to increase 350 percent over 2010 levels; in the North, biomass will still be used in <6 percent of total electric production.
- The potential for increased woody biomass use in co-firing (with coal) is highest in States that border the Great Lakes and in the Northeast; the potential increase for co-firing across the region would improve if power plants were upgraded to higher efficiency co-generation status.

Global climate change associated with changes in atmospheric carbon dioxide can have significant impacts on the condition of future forests, and consequently on the plant and animal (and human) communities that depend on forest habitats and services (Kurz et al. 2008). Some forest management activities can increase carbon sequestration to partially offset the human activities that emit carbon dioxide and associated greenhouse gases. For example, afforestation and certain thinning protocols can increase the quantity of carbon sequestered in trees (Hoover and Stout 2007). Energy production from woody biomass can offset carbon that otherwise would be released by burning fossil fuels, provided that a comparable amount of the carbon is reincorporated into the new trees that regenerate to replace those harvested (Malmsheimer et al. 2008). In contrast, the energy production from fossil fuels, such as coal and oil, emits carbon that has been sequestered underground for millennia.

The projections of forest biomass and carbon presented in this chapter are juxtaposed with projections of energy consumption at State, regional, and national scales (USDOE EIA 2010). This facilitates the comparison of three important carbon-cycle considerations for the North: (1) projected carbon sequestration in forests, (2) projected woody biomass growth and utilization, and (3) projected total and renewable energy consumption and likely consequences for carbon emissions. Together these provide insight into the dynamics and interactions among forest biomass, forest carbon, and energy utilization.

The following sections present:

- Total quantity of carbon stored in forests
- How forest carbon is expected to change over time
- The role of woody biomass for energy production
- Current and projected energy profiles for the Northern States
- Current and projected capacity to curb carbon emissions by substituting woody biomass for fossil fuels in electricity production
- Current status and future potential of co-firing biomass with coal for energy production

CARBON SEQUESTRATION

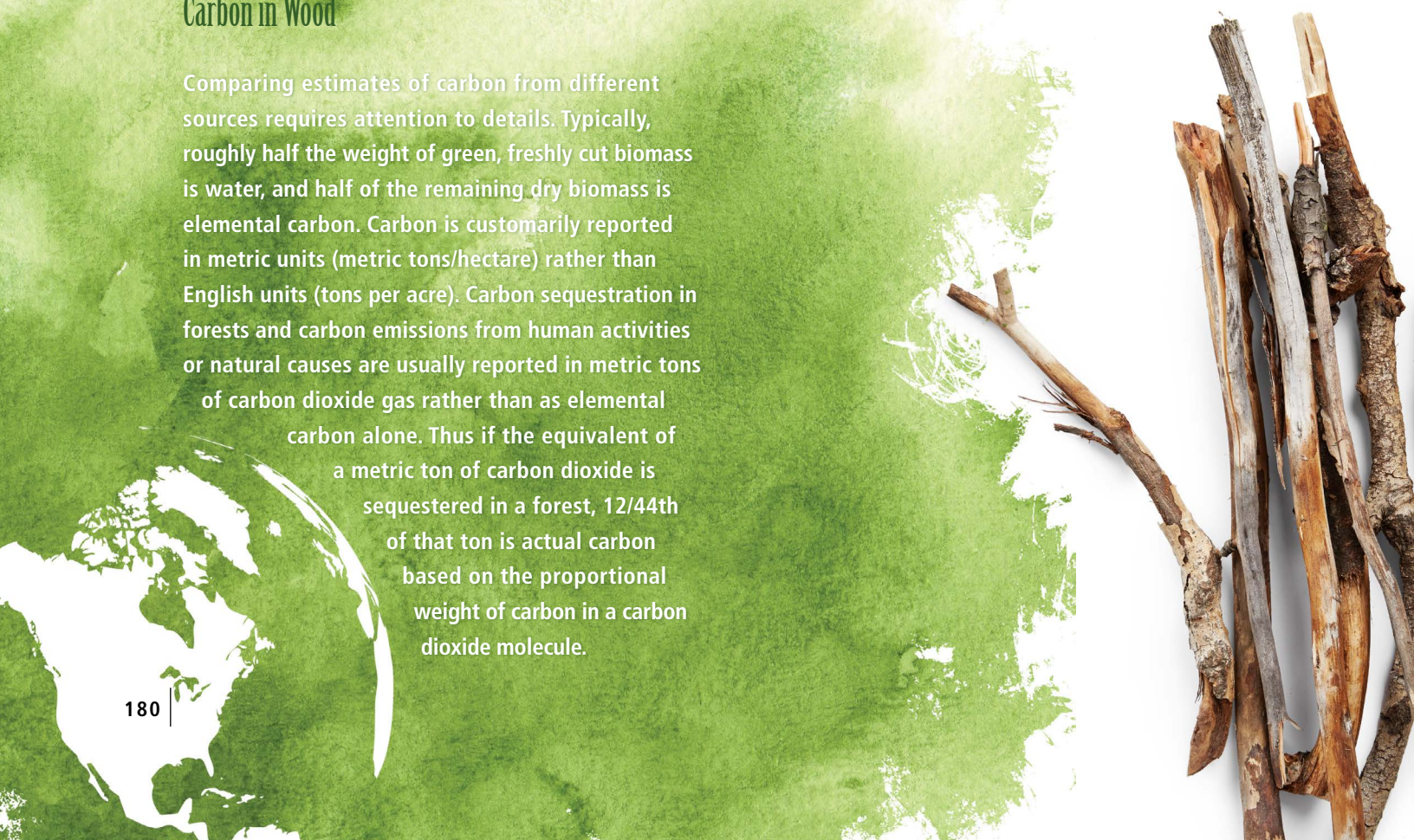
Through photosynthesis, trees sequester (absorb and store) carbon in wood, bark, leaves, flowers, roots, and seeds. Carbon is found in cellulose, hemicellulose, lignin, and other compounds that form the wood and other parts of the tree, all of which are defined as woody biomass. When a tree or some part of a tree dies, the carbon it contains is released during decomposition. Carbon in decomposing roots can remain in the soil and gradually add to the large store of sequestered carbon in forest soils. Leaves are short-lived and release carbon back to the atmosphere quickly as they decompose, but carbon can be sequestered for centuries in the wood of long-lived trees. Large dead and down trees can sequester carbon for decades as they decompose slowly and gradually release carbon dioxide back to the atmosphere.

When trees are harvested, the carbon they contain is removed from the forest, but it can continue to be sequestered for decades as long-lived wood products or as wood and paper products in landfills. Harvested forests and those that suffer heavy mortality will typically regenerate to new forests and accumulate carbon over future decades as they grow, provided the land is not converted to agricultural, urban, suburban, developed, or other uses. When forests are converted to other land uses, the carbon sequestered in aboveground woody biomass is typically released. Soil carbon can be retained following the conversion, but that soil carbon is no longer classified as forest carbon and therefore is excluded in future estimates of forest carbon storage and sequestration.

The 2010 per capita carbon emissions in the United States, largely resulting from combustion of fossil fuels, amounted to 5 tons of carbon which equates to 18 tons of carbon dioxide gas (USDOE EIA 2010). This is roughly equivalent to the carbon in 20 tons of green wood (i.e., wood weight when harvested). Based on storyline A1B (Chapter 2; IPCC 2007) that assumes a moderate level of future greenhouse gas emissions, the per capita emissions in the United States would decrease by about 15 percent to 4.5 tons of carbon (16.5 tons of carbon dioxide) by 2030. However, the U.S. population is expected to increase by 55 million (18 percent), resulting in a net increase of 0.2 percent in total carbon emissions.

Carbon in Wood

Comparing estimates of carbon from different sources requires attention to details. Typically, roughly half the weight of green, freshly cut biomass is water, and half of the remaining dry biomass is elemental carbon. Carbon is customarily reported in metric units (metric tons/hectare) rather than English units (tons per acre). Carbon sequestration in forests and carbon emissions from human activities or natural causes are usually reported in metric tons of carbon dioxide gas rather than as elemental carbon alone. Thus if the equivalent of a metric ton of carbon dioxide is sequestered in a forest, 12/44th of that ton is actual carbon based on the proportional weight of carbon in a carbon dioxide molecule.



For the same time period the population in the North is expected to increase by only 10 percent (12 million people), potentially leading to a small net decrease in carbon emissions in the North relative to the 2010 level (U.S. Census Bureau 2009, USDOE EIA 2012).

The total amount of sequestered forest carbon in the region (including carbon in forest soils) is expected to decrease slightly in the next five decades, falling to about 97 percent of the 2010 total by 2060 (Fig. 7.1). This overall decrease in carbon occurs even though the total dry weight of live aboveground forest biomass (which is 50 percent carbon) increases slightly under all storylines (Table 7.1). The decrease in total forest carbon occurs primarily because of a decrease in forest area and a resulting decrease in carbon levels associated with forest soils.

Thus, the predicted gradual decrease in sequestered carbon in northern forests from 2010 to 2060 (Fig. 7.1) is primarily attributable to conversion of forest area to other land uses. Forest conversion results in a corresponding decrease in forest area and the "loss" of aboveground and soil carbon that was previously considered part of the forest carbon pool. This does not imply that the carbon stored in forest soils is eliminated through conversion of forest land to other uses, but rather that it ceases to be part of the forest carbon pool.

In addition to forest carbon losses resulting from land-use changes, sequestered carbon in aboveground woody biomass is affected by changes associated with forest age, species composition, and location (Nowak and Crane 2002).

FIGURE 7.1

Sources of forest carbon sequestration in the North, 2010 to 2060, under a greenhouse gas emissions storyline A2 that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) combined with high energy consumption (Miles et al. 2015, USDA FS 2012b).

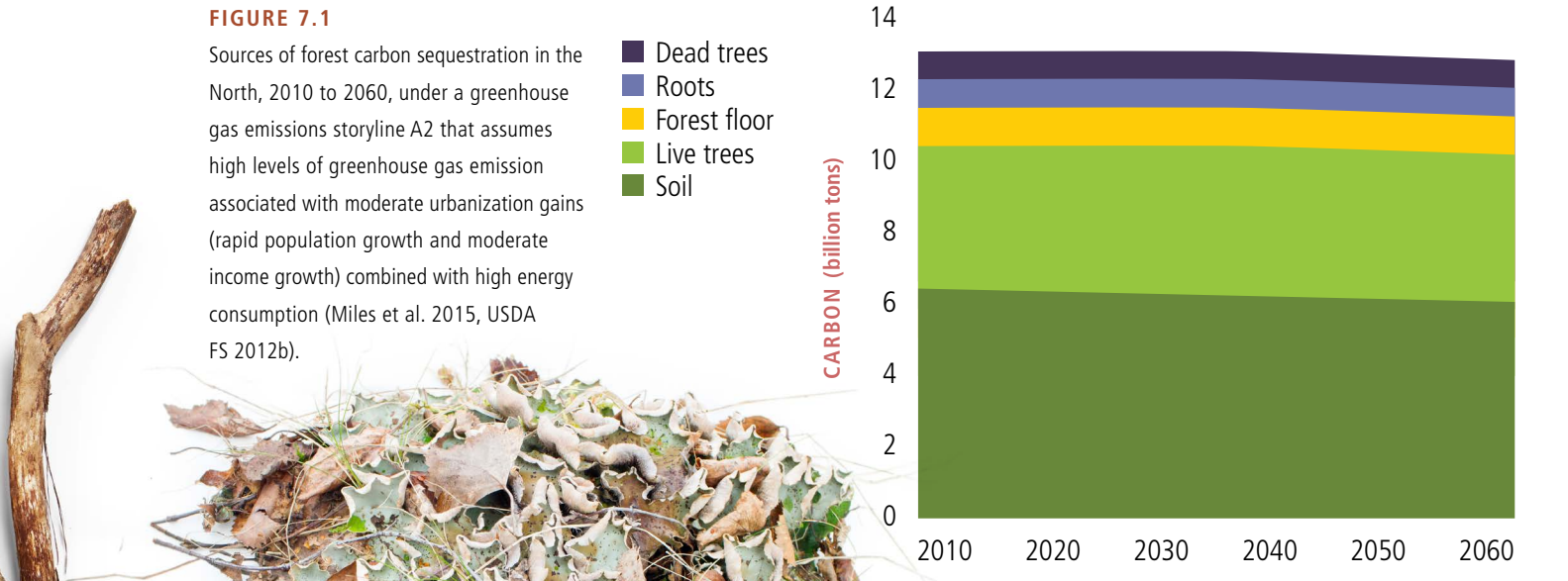


Table 7.1—Aboveground biomass on timberland in the North, 2010 to 2060, under three scenarios—A1B-C assumes moderate levels of greenhouse gas emissions associated with moderate gains in population growth and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio), A2-C assumes high levels of greenhouse gas emissions associated with large gains in population growth and energy consumption with moderate gains in income, and B2-C assumes low levels of greenhouse gas emissions associated with moderate gains in population growth, income, and energy consumption—combined with the assumption that harvesting will continue at rates observed from 1995 to 2005 and not increase substantially to meet future demand for bioenergy.

State	Initial for all scenarios	Projected for 2020 to 2050 (A2-C only)				Projected for 2060 (all storylines)					
		2020	2030	2040	2050	A2-C	A1B-C	B2-C	A2-C	A1B-C	B2-C
	(million dry tons)					(million dry tons)			Change from 2010 (percent)		
Connecticut	119	123	123	120	117	107	113	113	-9.8	-4.7	-5.3
Delaware	23	23	22	21	20	20	20	22	-12.4	-14.9	-6.1
Illinois	229	236	234	232	230	231	223	241	1.1	-2.5	5.4
Indiana	250	261	261	257	253	271	259	268	8.4	3.7	7.2
Iowa	111	126	129	128	127	134	125	134	20.3	12.4	20.9
Maine	647	670	679	676	674	666	651	672	2.9	0.5	3.8
Maryland	168	160	147	136	126	117	120	126	-30.0	-28.4	-24.7
Massachusetts	198	194	195	190	184	178	172	184	-10.0	-12.9	-7.1
Michigan	774	794	796	789	780	812	805	840	4.9	4.1	8.5
Minnesota	428	443	472	468	464	487	481	471	13.7	12.2	10.0
Missouri	606	640	648	643	638	675	668	689	11.3	10.2	13.7
New Hampshire	270	281	282	277	272	265	264	273	-1.6	-2.0	1.3
New Jersey	101	89	89	82	75	70	70	82	-31.3	-30.8	-19.1
New York	880	936	955	949	941	962	962	985	9.3	9.4	12.0
Ohio	452	493	497	492	487	505	525	521	11.8	16.2	15.2
Pennsylvania	980	962	972	957	939	951	932	983	-3.0	-4.9	0.3
Rhode Island	22	22	19	18	17	16	17	19	-27.1	-22.0	-12.8
Vermont	270	272	284	282	280	284	271	277	5.3	0.4	2.5
West Virginia	766	756	748	742	734	744	714	750	-2.9	-6.9	-2.1
Wisconsin	595	640	664	659	654	690	676	691	15.9	13.6	16.0
Total for North	7,890	8,121	8,215	8,119	8,011	8,184	8,069	8,342	3.7	2.3	5.7

National assessments based on greenhouse gas emissions storylines predict that sequestered carbon in forests will decrease by 2.3 to 2.8 billion tons—half of which is expected to occur in the North—from 2040 to 2060 (USDA FS 2012a). The expected decrease for the North as a whole would be unevenly distributed among the States (Fig. 7.2).

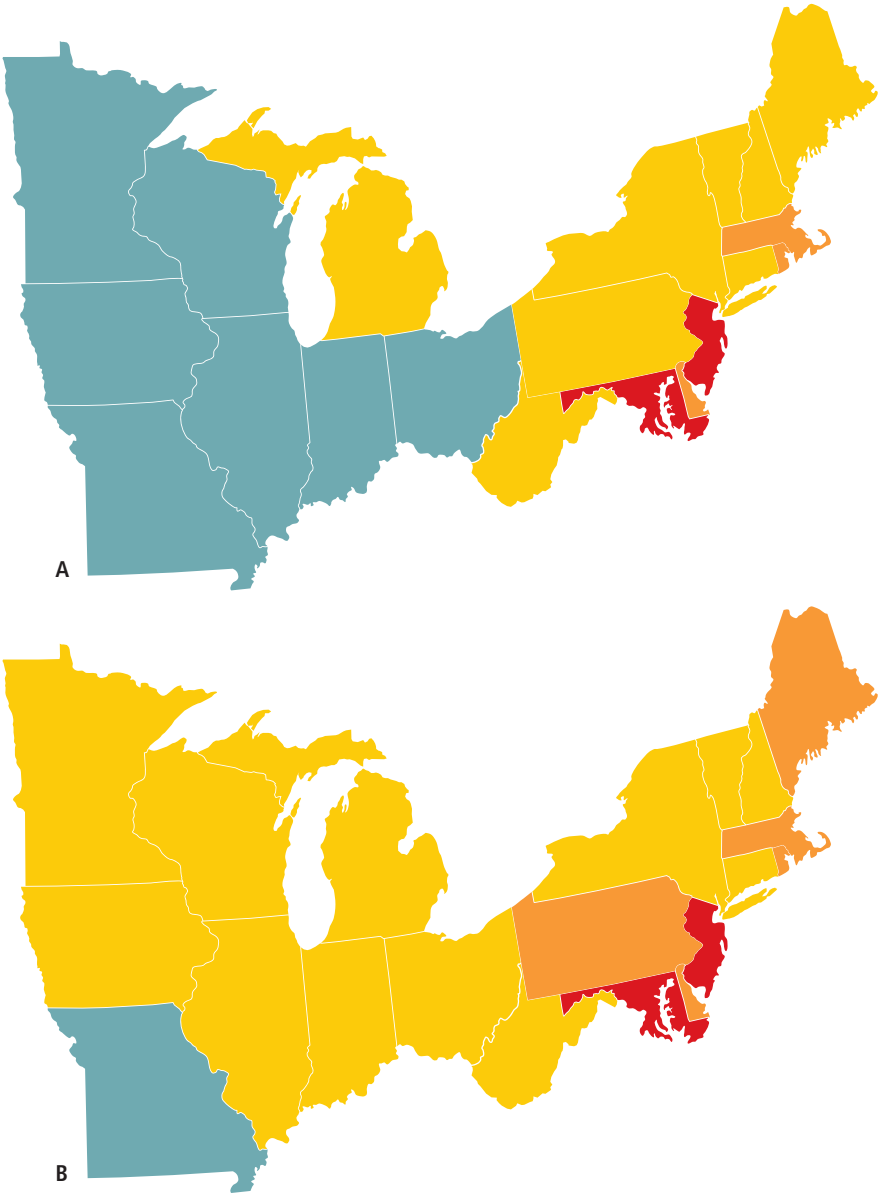


FIGURE 7.2

Projected change in sequestered carbon on forest land including soil, 2010 to 2060, in the North under greenhouse gas emissions storyline A2 that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) with (A) harvest rates continuing to follow historical trends (scenario A2-C), and (B) increased harvesting to satisfy greater demands for bioenergy (scenario A2-BIO).

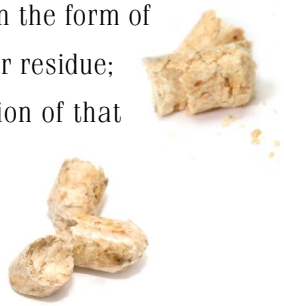
Three scenarios examined for the North resulted from adding accelerated woody biomass utilization to the assumptions for storylines A1B, A2, and B2 (Chapter 2). These scenarios (A1B-BIO, A2-BIO, and B2-BIO) were based on the implications of increasing oil prices (peak oil) and corresponding increases in demand for energy from woody biomass (Chapter 2). The assumed increased biomass utilization for energy would have a noticeable effect on sequestered carbon, as demonstrated by the substantial decreases in sequestered carbon for scenario A2-BIO compared to A2-C (Fig. 7.2). This change would primarily result from increased removals of aboveground biomass, which would decrease the total carbon sequestration capacity of the live trees (Figs. 7.1, 7.2; Appendix 2).

Most sequestered carbon in northern forests (Fig. 7.1) is primarily stored in soil organic matter and aboveground biomass (Shifley et al. 2012). Second only to soil organic matter, aboveground biomass is a highly dynamic component of the carbon sequestration profile and is constantly changing as trees grow, die, or are removed. As a forest ages in the absence of major disturbances, the quantity of aboveground biomass and carbon typically increases. Cut, dead, dying, and down trees serve as reservoirs of sequestered carbon that will be emitted to the atmosphere gradually as the trees decompose. When cut trees are converted to forest products, the carbon in those products will continue to be sequestered until the products decompose or are burned.

For perspective, a cubic foot of wood in a living or freshly harvested oak tree (*Quercus* spp.) weighs about 60 pounds (green weight), with roughly half that weight in water. This means that the dry weight of a cubic foot of oak is about 30 pounds, about half of which is carbon (i.e., 15 pounds or roughly a quarter of the green weight). Fifteen pounds of carbon is equivalent to the amount of carbon in 55 pounds of carbon dioxide gas.

PROJECTED WOODY BIOMASS IN NORTHERN FORESTS

Projected changes in forest area, tree size distribution, and tree species composition that are expected to result from the climate change and disturbance scenarios described in Chapters 2 and 4 were further analyzed to predict changes in forest biomass. As with the forest changes analyzed in other chapters, the primary focus here is on storylines A1B, A2, and B2 as well as variants of those storylines assuming increased biomass utilization. For consistency with other chapters of this document, biomass is reported in United States short tons (2,000 pounds) and acres rather than in metric tons and hectares, as is typical for international reporting. Because carbon constitutes about half the dry weight of biomass, or roughly a quarter the green weight of biomass, readers may prefer to visualize tons of woody biomass in the form of boles, limbs, branches, bark, roots, or residue; and to think of carbon as a proportion of that biomass (Fig. 7.3).



Although woody biomass is a collective term for the mass (weight) of all the material in trees, it is often used to summarize the components that are relevant to wood harvesting and merchandising: boles above stump height, tops and limbs, cull trees versus those that can be utilized for wood products, and composition by species or diameter class. Biomass can be reported in green tons or in equivalent dry weight, which is used to compute the energy value in wood and to compare biomass yields among different harvesting treatments or different geographic locations. Total biomass per tree is often computed using an equation that is based on tree diameter, with the biomass of various tree components estimated as a proportion of total biomass. Aboveground woody biomass per acre is usually proportional to the cubic volume of wood or the basal area per acre.

FIGURE 7.3
Schematic of the combined forest tree components that constitute woody biomass and the elemental carbon that is contained therein (stump, bole, branches).

Coinciding with the slight increase (4 percent) projected for aboveground sequestered carbon (Fig. 7.1) is a projected 4-percent increase in aboveground northern forest biomass from 2010 to 2060 for scenario A2-C (Fig. 7.4, Table 7.1). The variations among predictions of aboveground biomass are small; the largest difference of 277 million dry tons in 2060 is only 3.3 percent of the 2010 estimate (Fig. 7.4, Table 7.1). But the contrast between the expected increase in aboveground biomass and the expected decrease in the total amount of carbon sequestration merits further discussion. Total timberland[1] in the North is expected to decrease by nearly 6 percent by 2060 (Chapter 4). Because aboveground biomass and soil (with its considerable quantity of sequestered carbon) are considered "removed" from the forest when forest land is converted to other uses, gradual losses of forest land can result in a net decrease in total sequestered carbon—due primarily to removal of the carbon in the associated forest soils—even though aboveground biomass and aboveground carbon sequestered increases.

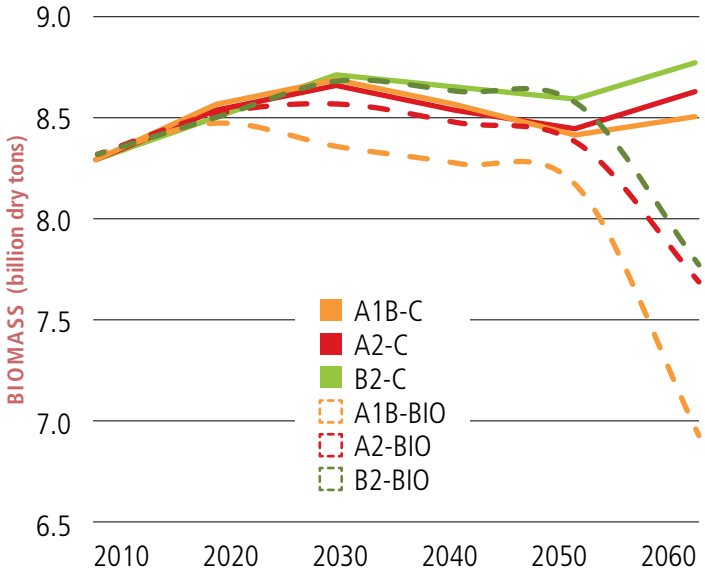


FIGURE 7.4

Projected total aboveground biomass on forest land in the North, 2010 to 2060, under six scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO).

[1] *Timberland is defined as forest land that maintains a minimum potential for growth of 20 cubic feet per acre per year and is not restricted from active forest management by statute or regulation.*

Lichen on stump

A closer examination of aboveground woody biomass estimated for 2010 (Fig. 7.5) and projected for 2060 (Fig. 7.6) reveals substantial variation among the Northern States. Under scenario A2-C, aboveground woody biomass is expected to decrease in several of the States along the Atlantic seaboard (Table 7.1). New Jersey, Maryland, Delaware, and Rhode Island are all projected to experience decreases of >15 percent. Additionally, the increase of aboveground forest biomass for the region does not completely reflect some of the interim trends that occur within the 50-year time period. Under all three scenarios (A2-C, A1B-C, B2-C), total aboveground forest biomass would actually decrease from 2030 to 2050, and then increase again in the last decade of the projection period (Fig. 7.4). This is a sharp contrast to the enhanced biomass-utilization scenarios (A1B-BIO, A2-BIO, and B2-BIO), which all show an overall decrease in aboveground forest biomass from 2030 to 2060 (Figs. 7.4, 7.6). The large decreases in aboveground forest biomass for the enhanced biomass utilization scenarios are projected to take place primarily from 2020 to 2030 and from 2050 to 2060. This trend reflects both the current rise in woody biomass utilization for energy and the assumption that limited supplies and higher costs of fossil fuels (peak oil) will result in increased biomass utilization in about 40 years. From 2010 to 2060, aboveground forest biomass is expected to increase in 11 Northern States under scenario A2-C compared to only two States (Missouri and New York) under A2-BIO (Appendix 7).

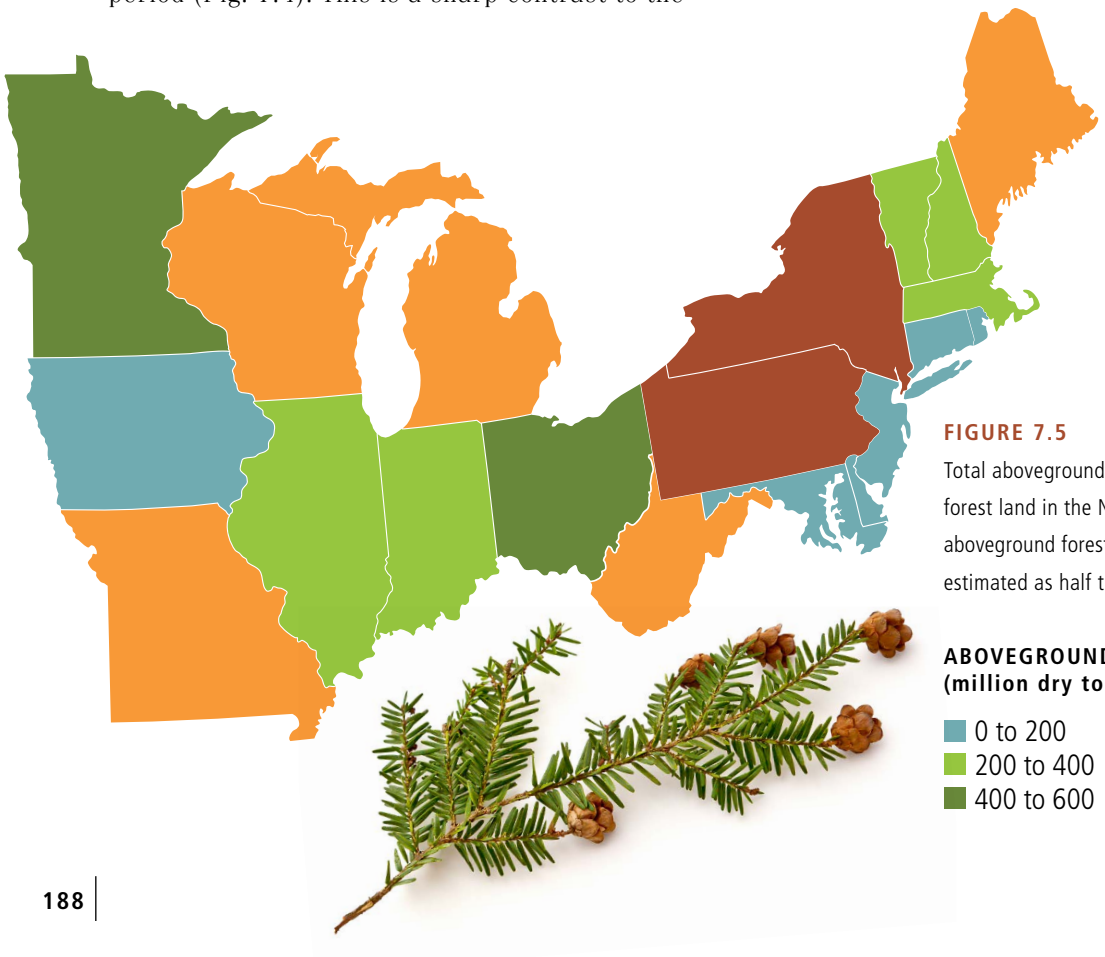
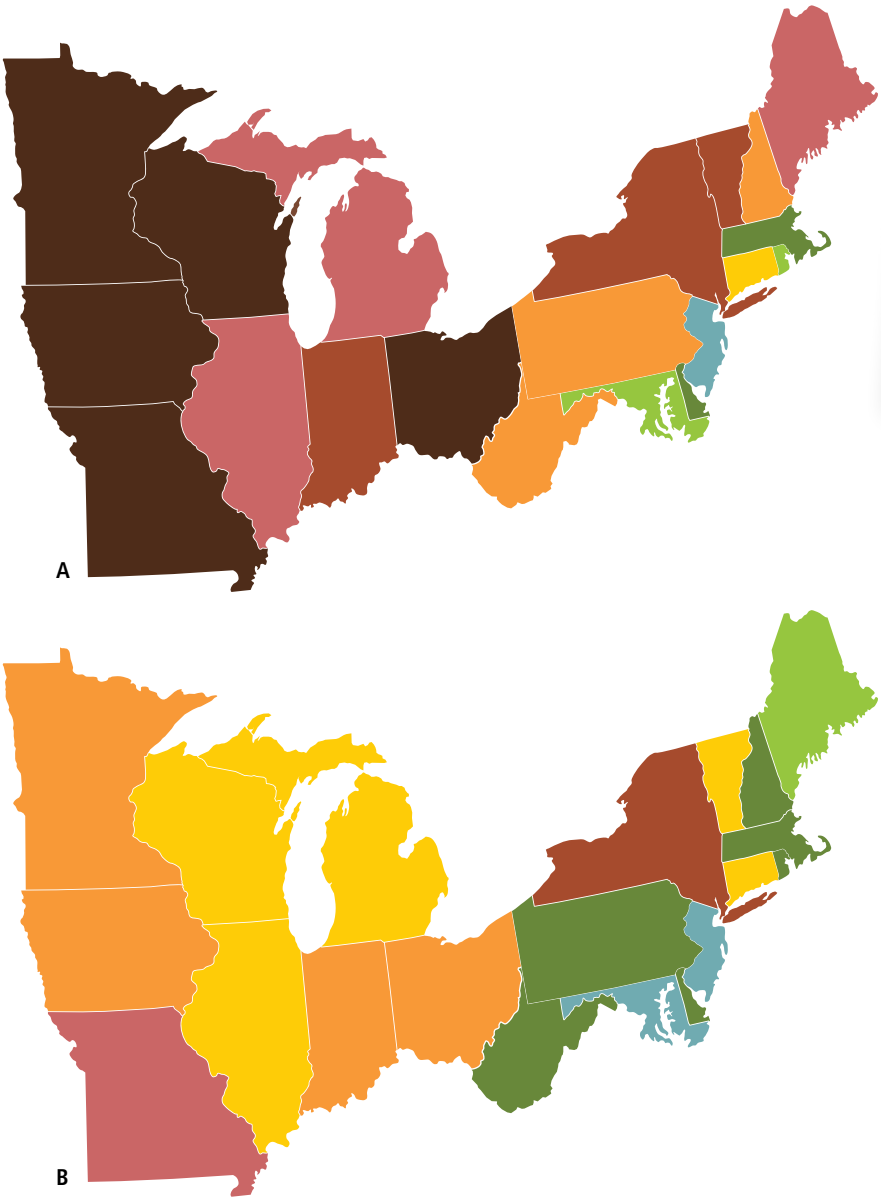


FIGURE 7.5

Total aboveground live-tree biomass on forest land in the North, 2010; note that aboveground forest carbon in million tons is estimated as half the biomass dry weight.



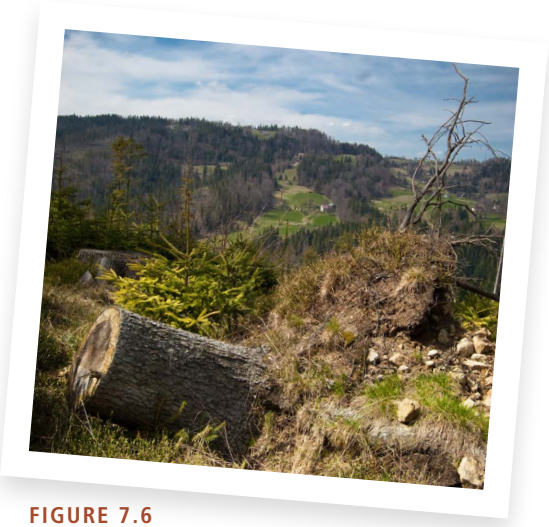


FIGURE 7.6
Change in total aboveground live tree biomass on timberland for the North, 2010 to 2060, under greenhouse gas emissions storyline A2 that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) combined with high energy consumption under the assumption of (A) harvest rates continuing to follow historical trends (scenario A2-C), or (B) increasing harvest rates to satisfy demands for bioenergy (scenario A2-BIO).

In a few Northern States, the conversion of forest land to other uses would decrease both total aboveground woody biomass and timberland area from 2010 to 2060; however, for most States, average aboveground biomass per acre is expected to increase on the forested acres that remain after conversion. Aboveground woody biomass per acre of retained forest would increase for almost every State in the region, even though total aboveground woody biomass would decrease in nine States (Fig. 7.7) primarily due to a decline in total forest area. This is an indication of the large influence that projected land-use change has in projections of woody biomass. The increase in woody biomass for acres that remain forested is also an important factor for the future of energy from woody biomass in the region, as discussed below.

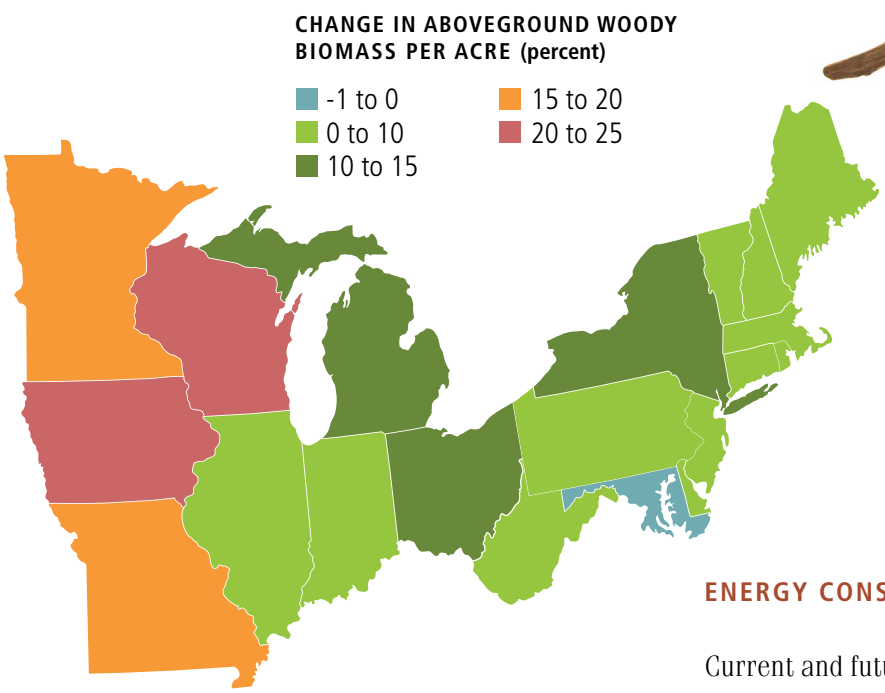


FIGURE 7.7

Change in aboveground woody biomass per acre of timberland, 2010 to 2060, in the North under scenario A2-C, which assumes high greenhouse gas emissions, large gains in population and energy consumption, moderate gains in income, and harvest rates that continue at recently observed levels.

Projections of biomass increases for northern forests under scenario A2-C are expected to differ from national-level projections (USDA FS 2012a, USDA FS 2012c), with aboveground volume of growing stock (a surrogate for aboveground biomass or carbon) increasing more slowly than the national rate from 2020 to 2030 and then continuing to increase from 2050 to 2060 in contrast to a national trend of growing-stock volume decreases. Over the 50-year period, the result would be a small decrease in growing-stock volume at the national scale but a modest increase for the Northern States.

ENERGY CONSUMPTION

Current and future patterns of energy consumption affect the quantity of carbon emissions and the quantity of biomass utilized for energy. Patterns of biomass utilization affect rates of forest harvesting, forest age structure, and the associated capacity of forests to sequester carbon.

Annual energy consumption per capita in the United States is expected to decrease by 9 percent, from 318 million Btu in 2010 to 290 million Btu in 2030 (USDOE EIA 2012). However, population in the North (based on storyline A2) is expected to increase by 16 million from 2010 to 2030 and by 36 million by 2050 (Appendix Table A2.1). Thus, even with declining per capita energy consumption, total energy consumption in the region is likely to increase from 41 quadrillion Btu in 2010 to 42 quadrillion Btu in 2030 and would continue to increase because the projected rate of population increase exceeds the rate of decrease in per capita energy consumption (USDOE EIA 2012, USDA FS 2012a).

In 2010, about 4 percent of all U.S. energy consumption came from wood combustion. Less than 1 percent of electrical power consumed in the United States comes from wood or wood byproducts (USDOE EIA 2010). In the North, this percentage is slightly higher (Fig. 7.8), with electric utilities throughout the region using wood for part of their energy (USDA FS 2011).

Electricity consumption alone makes up approximately 41 percent of the annual national energy consumption, with the Northern States accounting for 40 percent of the national electricity consumption total. About 55 percent of northern electricity consumption is fueled by coal, followed by 27 percent fueled by nuclear energy (Fig. 7.8, Table 7.2). Individual States vary greatly in the source of the electricity consumed, with coal-generated electricity ranging from 0 to 97 percent and nuclear energy ranging from 0 to 66 percent (Table 7.2).

Two percent of total annual electricity consumption in the region is derived from a combination of woody and herbaceous biomass (Fig. 7.8); this is about 25 percent of total annual electricity consumption from all renewables including hydroelectric and wind sources (Table 7.2). Among the different biomass feedstocks for electricity, woody biomass accounts for the largest share (53 percent), meaning that about 1 percent of all electric production is from woody biomass.

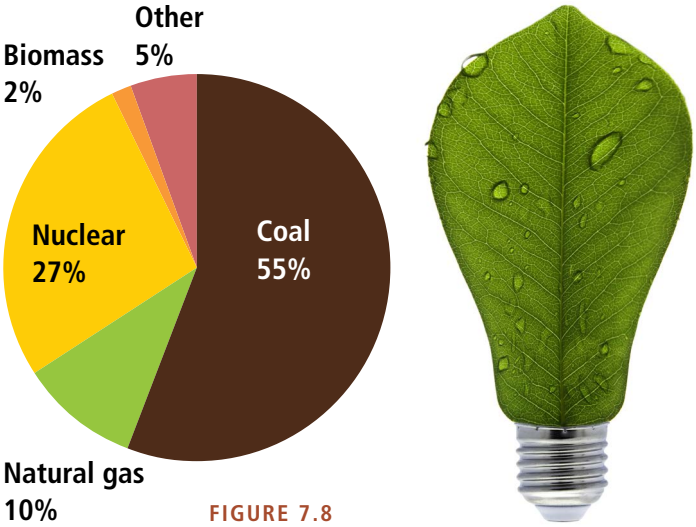


FIGURE 7.8

Electricity consumption in 2010 by source in the North; note that wood and wood residue constitute about half of all biomass, or about 1 percent of all electricity consumption.

USING WOODY BIOMASS FOR ENERGY

Burning fossil fuels to produce energy releases carbon dioxide that was previously sequestered for millennia as carbon in coal, oil, or natural gas. By converting to woody biomass, society may be able to reduce the amount of carbon emissions from fossil fuels. Burning woody biomass also releases carbon into the atmosphere, but when forests harvested for biomass regenerate and regrow, carbon is again sequestered in the trees growing in the regenerated forest. Thus, some carbon would be cycled from the forest to the atmosphere and eventually sequestered back into forest regrowth. Methods to account for carbon emissions and sequestration when using woody biomass for energy are still evolving.

Table 7.2—Electricity consumption by source in the North, 2010 (USDOE EIA 2010).

State	Energy source							
	Coal	Natural gas	Petroleum	Nuclear	Hydroelectric	Biomass[a]	Wind	Total consumption
	(percent)							(trillion Btu)
Pennsylvania	49.3	10.0	0.4	37.2	1.2	1.3	0.5	2,172
Illinois	46.6	1.7	0.1	49.7	0.1	0.5	1.4	2,009
Ohio	84.2	2.8	1.0	11.4	0.4	0.2	0.0	1,390
New York	9.8	27.9	2.0	33.8	20.0	2.3	1.6	1,344
Indiana	95.0	3.1	0.1	0.0	0.4	0.3	1.1	1,193
Michigan	64.6	8.0	0.3	21.6	1.2	2.1	0.3	1,057
Missouri	81.9	3.3	0.1	11.8	1.9	0.1	0.5	909
West Virginia	97.2	0.2	0.3	0.0	1.4	0.0	1.0	716
Wisconsin	64.6	6.9	1.1	22.0	2.1	1.6	1.7	602
New Jersey	9.9	28.2	0.1	59.9	0.1	1.8	0.0	600
Minnesota	54.2	4.2	0.1	23.0	1.2	3.7	8.8	563
Iowa	73.1	1.9	0.2	9.3	1.8	0.3	13.7	528
Maryland	54.9	4.3	0.9	34.2	4.1	1.7	0.0	445
Massachusetts	25.2	43.2	2.5	15.7	3.2	5.8	0.0	360
Connecticut	8.7	23.7	1.1	57.6	1.7	4.5	0.0	302
New Hampshire	16.1	19.3	0.9	45.2	8.0	8.5	0.3	204
Maine	0.8	33.1	2.8	0.0	29.0	26.0	2.5	116
Vermont	0.0	0.1	0.0	66.1	16.8	6.7	0.1	85
Rhode Island	0.0	92.6	0.2	0.0	0.0	2.9	0.0	61
Delaware	70.5	23.8	2.3	0.0	0.0	3.4	0.0	47
Total for North	55.3	9.9	0.6	26.9	3.2	1.6	1.5	14,702
U.S. total	47.8	18.5	1.0	21.9	7.0	1.2	1.9	38,094

[a]*All biomass*

The carbon and energy balance associated with broader use of woody biomass and other plant-derived biomass for energy production depends on numerous assumptions used in the computations (Malmsheimer et al. 2008).

Because feedstocks are relatively abundant and infrastructure for utilization is already in place, woody biomass represents an opportunity for replacing some portion of fossil fuels used for energy production in the Northern States.

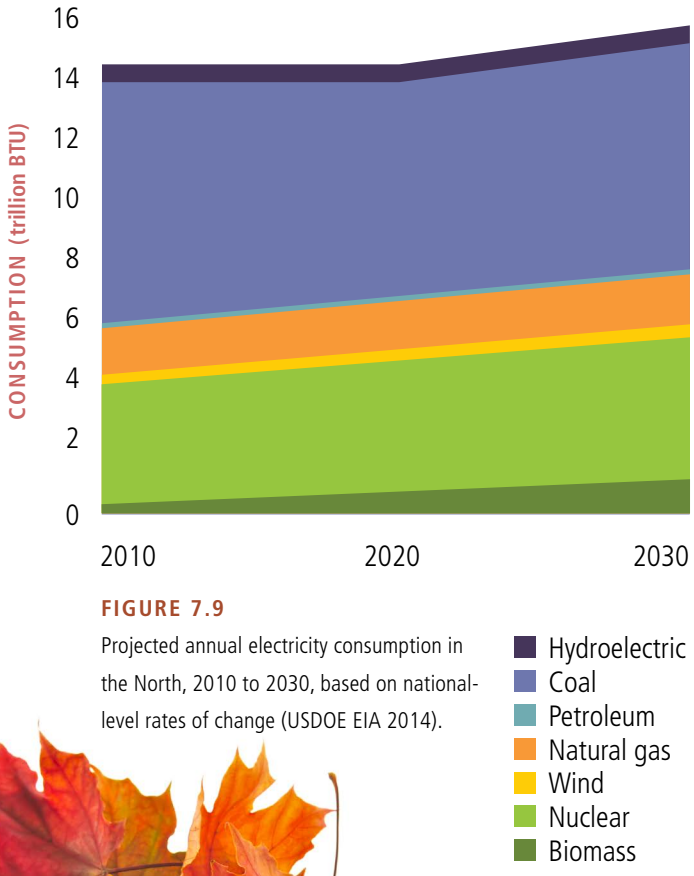


FIGURE 7.9

Projected annual electricity consumption in the North, 2010 to 2030, based on national-level rates of change (USDOE EIA 2014).

Nevertheless, long-term projections by the U.S. Department of Energy's Energy Information Administration (EIA) indicate the vast majority of electricity generation will continue to come from coal, natural gas, and nuclear fuels. These projections indicate that biomass from all sources will continue to be only a small part of the total energy profile (USDOE EIA 2010), but also that total electricity derived from biomass will increase from 2010 to 2030 (Fig. 7.9). Although small in absolute terms compared to other feedstocks, this would represent a 350-percent increase in biomass utilization from 2010 to 2020, the greatest percentage increase of any electricity source (Fig. 7.10).

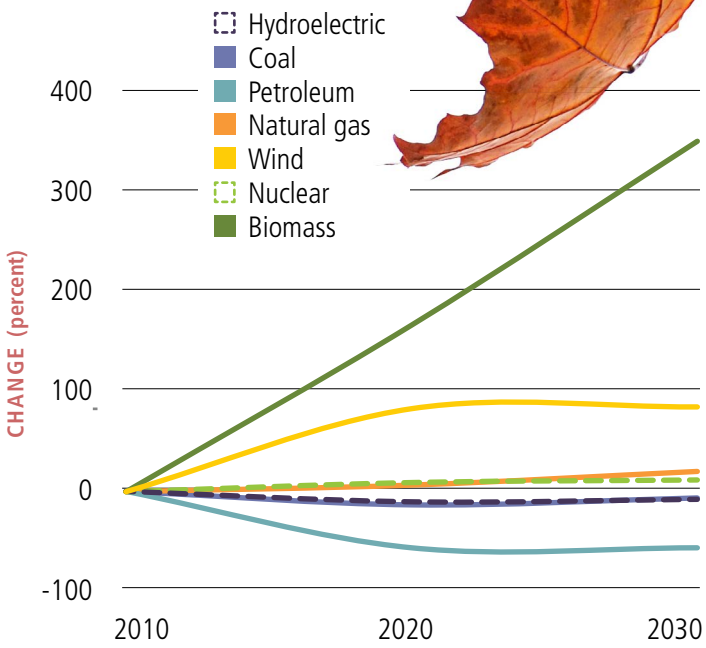


FIGURE 7.10

Projected change in annual electricity consumption by electricity source, 2010 to 2030, in the United States; note that the projections were derived using national-level projections and adjustment factors that were based on 2010 proportions of electricity consumption (USDOE EIA 2014).

The increase in biomass utilization for electricity production is part of a more gradual overall increase in bioenergy consumption that started at the turn of this century in response to a developing market for corn-based ethanol (USDOE 2011). However, unlike ethanol producers, which primarily serve the transportation sector, the forest products industry has traditionally been both the primary supplier and the primary consumer of woody biomass for energy production (USDOE 2011). In 2010, annual consumption of harvested roundwood fuelwood was 1.6 million cubic feet, and consumption is expected to increase by 230 percent in 2060 (Ince et al. 2011, USDA FS 2012a). Fuelwood utilization extends beyond electricity production to include industrial production of steam and heat in paper and wood-processing mills and residential heating.

CO-FIRING OF BIOMASS FOR ELECTRICITY

Because wood biomass is likely to remain a relatively small component of total energy production through 2030, future increases in its use for electrical energy could be clustered around locations that have a comparative advantage in the quantity of raw materials, the transportation network, or existing energy infrastructures. Spatial analyses were used to identify places where an increase in the use of biomass may be practical in co-firing boilers that combine wood with coal.

The use of biomass with coal during electric generation could be a low-risk, short-term option for rapidly increasing renewable energy production because adding wood as a feedstock to existing coal-fired electric plants would be relatively inexpensive. Furthermore, unlike wind and solar energy, woody biomass can be readily stored as chips or on the stump until needed. With an abundant, widely dispersed biomass resource base, a large number of coal-fired power plants (360), and a long history of woody biomass use, the North has a relatively high potential for future utilization of biomass for electricity production (USDOE 2011).

One way to assess the feasibility of replacing fossil fuels with biomass is to examine the regional electric energy footprint with respect to biomass resources. Clearly, total replacement of fossil fuels with biomass would not be feasible. Doing so would consume 11 percent of all standing woody biomass in the North to generate the electricity consumed in a single year (Table 7.3); after 9 years, virtually all the wood in the region would have been used to generate electricity. However, increasing woody biomass used for electricity production above the 0.2 percent level would not have dire ecological consequences (Table 7.3).

Table 7.3—Proportion of electricity produced from coal and biomass by State with the proportion of the State's total aboveground woody biomass that would be required annually to instead generate electricity from woody biomass.

State	Electricity produced from coal	Electricity produced from biomass	Proportion of State's total aboveground woody biomass needed annually to replace:	
			All coal-generated electricity	Electricity from all sources
	(percent)			
Rhode Island	0.0	0.5	0	16
Vermont	0.0	0.1	0	2
Maine	0.8	0.3	< 1	1
Connecticut	8.7	0.7	2	15
New Jersey	9.9	0.8	6	36
New York	9.8	0.2	1	10
New Hampshire	16.1	0.4	1	5
Massachusetts	25.2	0.6	3	12
Illinois	46.6	0.2	25	153
Pennsylvania	49.3	0.2	7	13
Minnesota	54.2	0.2	5	8
Maryland	54.9	0.3	10	17
Wisconsin	64.6	0.1	4	6
Michigan	64.6	0.2	5	9
Delaware	70.5	0.5	15	19
Iowa	73.1	<0.1	22	28
Missouri	81.9	<0.1	7	9
Ohio	84.2	<0.1	17	20
Indiana	95.0	<0.1	30	31
West Virginia	97.2	0.0	7	7
All States	55.0	0.2	6	11

Although energy footprints are a good way to calculate the limitations of woody biomass as an energy source based on energy consumption, they are relatively uninformative as indicators of the actual resource potential for woody biomass as an energy feedstock in the Northern States. Annual net forest inventory change is more informative because it accounts for annual growth minus annual removals from harvesting, mortality, and land-use change, thus showing which States have (or will have) annual woody-biomass increases (after accounting for removals) that could satisfy energy demands without perpetually depleting existing forests. The projected mean annual net inventory change over the preceding decade was calculated for 2020, 2030, 2040, and 2050 for multiple scenarios (Table 7.4). At 2060, mean annual net inventory change was calculated for the 2050 to 2060 interval, and over the entire 50-year interval (2010 to 2060) for comparison.

Lake and midwestern States would generally have the highest positive net inventory change from 2010 to 2060 under all scenarios (Table 7.4). In one 20-year period (2030 to 2050) all States in the North are expected to have a net annual decrease in aboveground biomass. States along the Atlantic seaboard (such as Maryland, New Jersey, and Massachusetts) would have negative values throughout most of the projection period, reflecting an expected decrease in total aboveground biomass over the next 50 years. However, this does not imply that these States have no potential for biomass energy. Most of the projected 6-percent loss of timberland in the region (Chapter 4) is expected to take place in the States farthest east, which are projected to experience net annual decreases in woody biomass due to loss of forest through urbanization. However, most of these States would also experience increases in average aboveground woody biomass per acre of forest land retained as forest (Figure 7.7). Therefore, negative values for annual inventory change do not necessarily mean that woody biomass will not be available from existing timberland in the future.

Nevertheless, increases in demand for woody biomass for energy could potentially lead to decreases in available woody biomass on timberland. The enhanced woody biomass utilization scenarios offer a hypothetical assessment of this contingency based on two primary assumptions: (1) the adjustment for harvesting probability was applied using the same predetermined proportions across the entire region, and (2) conversions from forest/timberland into other land uses were not reflected, but rather higher utilization on timberland currently existing and expected to exist in the future was simulated.

Overall, the enhanced biomass utilization scenarios (A1B-BIO, A2-BIO, B2-BIO) predict decreases in woody biomass from 2010 to 2060 when compared to the non-enhanced counterparts (Fig. 7.4). With northern timberland projected to decrease by about 6 percent from 2010 to 2060, levels assumed by the enhanced biomass utilization scenarios in eastern States could perpetually reduce the amount of available woody biomass from timberland (Appendix 7).

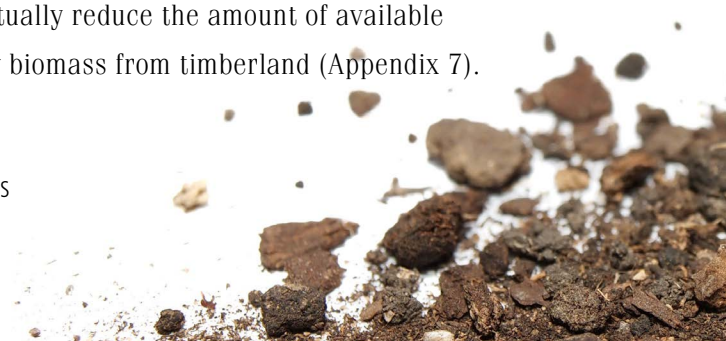


Table 7.4—Annual net forest biomass change for the North under three scenarios— A1B-C assumes moderate levels of greenhouse gas emissions associated with moderate gains in population growth and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio), A2-C assumes high levels of greenhouse gas emissions associated with large gains in population growth and energy consumption with moderate gains in income, and B2-C assumes low levels of greenhouse gas emissions associated with moderate gains in population growth, income, and energy consumption—combined with the assumption that harvesting will continue at rates observed from 1995 to 2005 and not increase substantially to meet future demand for bioenergy.

State	Estimated for 2010[a]	Projected mean annual changes (A2-C only)				Projected mean annual changes (all scenarios)					
		2010 to 2020	2020 to 2030	2030 to 2040	2040 to 2050	2050 to 2060			2010 to 2060		
						A1B-C	A2-C	B2-C	A1B-C	A2-C	B2-C
	(thousand dry tons)										
Maryland	3,406	-772	-1,333	-1,076	-955	-630	-891	5	-953	-1,006	-826
New Jersey	2,155	-1,232	-27	-692	-683	-494	-547	698	-626	-636	-387
Pennsylvania	10,095	-1,795	1,018	-1,522	-1,816	-683	1,186	4,433	-960	-586	64
West Virginia	9,013	-1,047	-770	-653	-801	-1,994	999	1,661	-1,053	-454	-322
Massachusetts	3,465	-376	48	-508	-538	-1,172	-614	-34	-509	-398	-282
Connecticut	459	449	-34	-292	-346	-334	-941	-402	-112	-233	-125
Rhode Island	565	-6	-245	-105	-116	-4	-87	196	-95	-112	-55
New Hampshire	2,708	1,116	86	-450	-505	-796	-690	107	-110	-89	71
Delaware	772	-39	-61	-85	-95	-60	-4	141	-68	-57	-28
Illinois	5,612	751	-233	-164	-186	-743	95	1,071	-115	53	248
Vermont	1,184	179	1,231	-223	-256	-832	480	-263	20	282	134
Maine	-930	2,286	865	-242	-290	-2,285	-749	-179	67	374	488
Indiana	6,930	1,101	7	-357	-432	594	1,792	1,479	183	422	360
Iowa	2,274	1,479	268	-67	-80	-224	657	724	275	452	465
Michigan	9,713	1,970	291	-772	-919	2,566	3,248	6,037	627	764	1,322
Ohio	7,555	4,054	375	-448	-560	3,891	1,859	3,465	1,462	1,056	1,377
Minnesota	4,166	1,510	2,827	-359	-390	1,632	2,293	706	1,044	1,176	859
Missouri	11,209	3,394	765	-477	-576	3,086	3,743	5,191	1,238	1,370	1,660
New York	10,362	5,592	1,911	-616	-740	2,114	2,042	4,413	1,652	1,638	2,112
Wisconsin	6,784	4,441	2,407	-440	-528	2,211	3,553	3,661	1,618	1,887	1,908
Total for region	97,497	23,056	9,396	-9,549	-10,814	5,843	17,425	33,111	3,586	5,903	9,040

[a]*Calculated using volume growth and removals from the most current data from Forest Inventory and Analysis (FIA).*

Net annual change in forest inventory is only one of many factors to consider when assessing resource potential for woody biomass as a feedstock. Another way is net annual woody biomass increase, which simply assumes a value of zero for negative estimates of net annual inventory change (Goerndt et al. 2012) and focuses purely on the extra woody biomass that is available every year (if any) after accounting for growth and removals.

Other forest-derived sources of woody biomass for bioenergy include residues from wood processing mills and logging residues (tops and limbs) from roundwood, snags (standing dead trees), harvesting, and downed woody material from natural mortality or human activity. Volume of logging-residue availability was calculated as 30 percent of the harvesting removals reported by Forest Inventory and Analysis (USDOE 2011). Of the total logging residue, it is assumed 35 percent will be retained on site (USDOE 2011) as coarse woody material providing ecological values.

Figure 7.11 shows 2010 estimates for potential sources of woody biomass feedstocks including annual woody biomass increase, logging residues, standing dead trees, and mill byproducts that are currently unused (Miles 2010, USDA FS 2012d). Unused mill byproducts are the smallest component of available woody biomass for bioenergy (Figs 7.11, 7.12)—primarily because most are already being used, often as a feedstock to supplement power for wood-processing mills. Annual woody biomass increase is the largest (Fig. 7.12). Even assuming a 35 percent retention rate, the biomass of dead standing material is only slightly larger than logging residues, probably because salvaging standing dead trees is traditionally rare in northern forests. However, if an energy-driven market develops for such material and if procurement regimes such as integrated harvesting of roundwood and biomass are implemented, standing dead trees could become an available source of woody biomass.

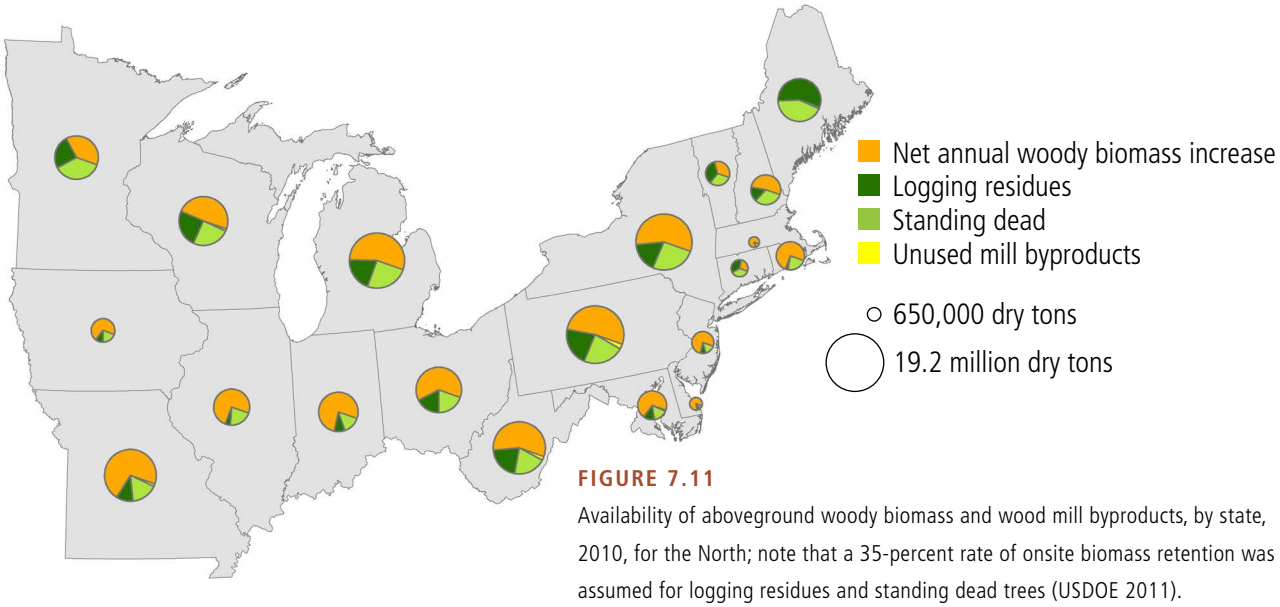


FIGURE 7.11

Availability of aboveground woody biomass and wood mill byproducts, by state, 2010, for the North; note that a 35-percent rate of onsite biomass retention was assumed for logging residues and standing dead trees (USDOE 2011).

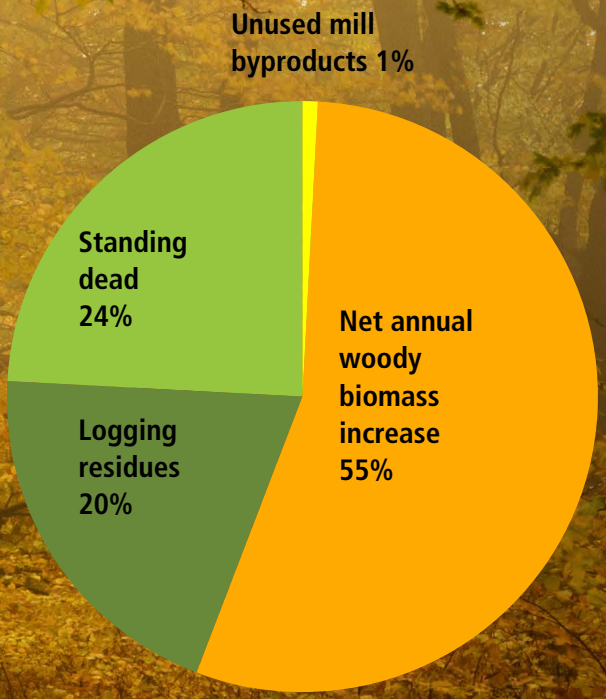


FIGURE 7.12

Availability of aboveground woody biomass and wood mill byproducts for the North in 2010; note that a 35-percent rate of onsite biomass retention was assumed for logging residues and standing dead trees (USDOE 2011).

States with the highest availability of logging residues also tend to have higher estimates for mill byproducts and lower estimates for annual woody biomass increase (Appendix Table A7.3). This illustrates the symbiotic relationship between wood processing and harvesting, as well as the reduction in extra available timberland biomass in States with intensive harvesting. Based on the 35 percent retention rate for both logging residues and dead standing material, the northern region would have a combined potential to generate approximately 303 million megawatt hours of electricity annually from all sources of woody biomass feedstock.

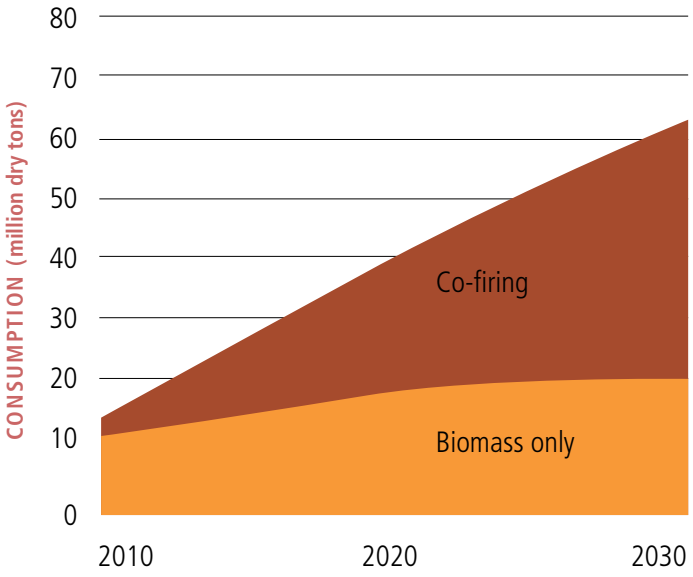


FIGURE 7.13

Electricity consumption by co-firing plants and plants that burn biomass only in the North, 2010 to 2030, based on national-level rates of change (USDOE EIA 2012); note that in 2010, biomass burned in co-firing plants accounted for 17 percent of the total.

Opportunities for co-firing of coal and woody biomass for electricity production appear to be abundant in the Northern States. Of the electricity currently produced from biomass (Fig. 7.13), approximately 83 percent comes from dedicated plants compared to only 17 percent from co-firing plants (USDOE EIA 2010). However, Figure 7.13 shows that biomass electricity production is expected to increase dramatically; moreover, co-firing is likely to be the primary means of biomass-fuel electricity production by 2020 (USDOE EIA 2014). A key consideration is the location of exising coal-fired plants that could incorporate woody biomass as a fuel. This is a first step in identifying northern locations that would have a relative advantage for co-firing.

We evaluated the effects of several physical, environmental, and socioeconomic factors that would influence adoption of co-firing of biomass and coal in the North. The analysis was performed using logistic regression models that accounted for location of existing coal-fired power plants, condition of infrastructure such as roads and railways, implementation of renewable energy portfolio standards, and available biomass feedstocks (such as wood processing residues). Data consisted of projected energy consumption values from the U.S. Energy Information Administration (USDOE EIA 2012) and projected biomass resources under scenario A2-C. Results from the analysis were summarized at the county level (Aguilar et al. 2012) for 2010 and 2030 (Fig. 7.14).

Many of the counties that appear to have high potential for biomass and coal co-firing are in the Lake States (Wisconsin, Minnesota, and Michigan) and in the mid-Atlantic States of West Virginia and Pennsylvania. This is not surprising, as these States tend to have either a large amount of available woody biomass, a large number of coal-fired power plants, or both. Total co-firing probability would not increase dramatically across the region from 2010 to 2030. The States that in the future are expected to have more counties with a high probability of co-firing are primarily in the Midwest (Aguilar et al. 2012), and that increase is attributable to projected increases in available woody mill residues. The overall number of counties with high probability of co-firing is not expected to increase significantly from 2010 to 2030.

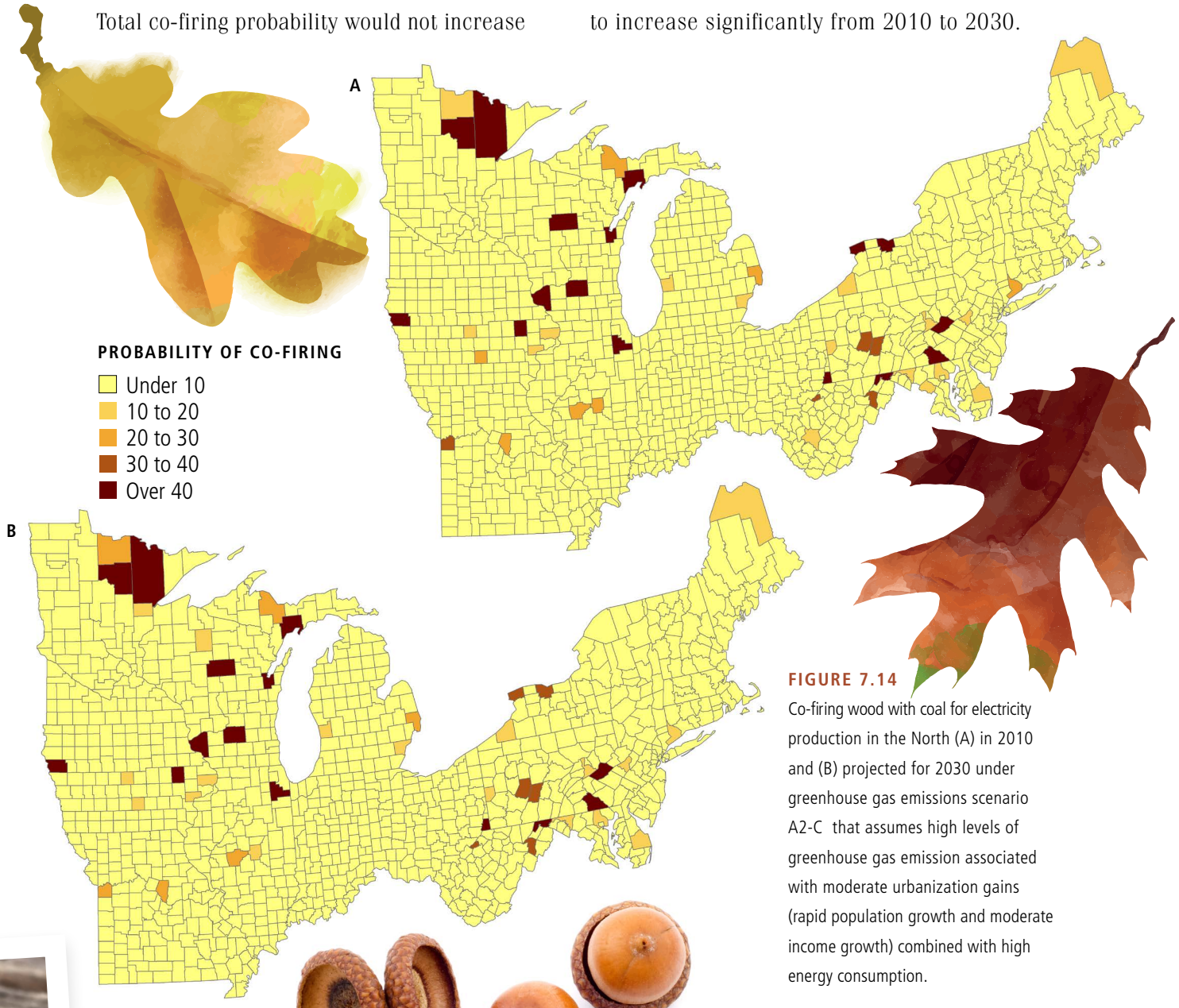


FIGURE 7.14
Co-firing wood with coal for electricity production in the North (A) in 2010 and (B) projected for 2030 under greenhouse gas emissions scenario A2-C that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) combined with high energy consumption.

Although increases in population and electricity demand in the States farther east would lead to increased probability of co-firing, projected decreases in timber harvesting, and therefore wood mill byproducts, would counteract this effect. Though projected increases in potential of co-firing in the North are relatively low, this could change with the conversion of some power plants to higher efficiency of woody biomass use through co-generation of both heat and electricity.

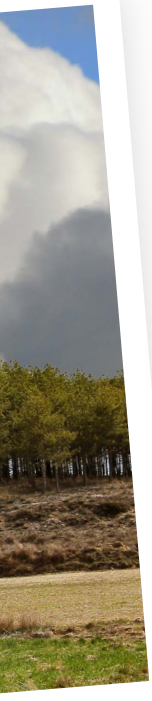
CONCLUSIONS

The total amount of carbon sequestered in forest biomass and forest soils in the United States is about 27 times the total annual carbon emissions from energy production. However, the carbon sequestered annually by tree growth is only about 13 percent of total annual U.S. carbon emissions (USDA FS 2011, Vose et al. 2012). Thus, the capacity of forests to offset greenhouse gas emission through carbon sequestration, though important, is relatively small compared to the total quantity of emissions. In the Northern States, this shortfall represents an ecological carbon footprint (biomass equivalent of atmospheric carbon) of approximately 24 million acres or 14 percent of existing forest land. For perspective, consider that to sequester enough carbon to offset northern carbon dioxide emissions from fossil fuels, northern forest land would have to increase by 14 percent every year (i.e., double every 7 years). Total fossil fuel emissions will continue to increase with increasing population even though per capita emissions will decrease, both for the United States as a whole and for the Northern States.

In the past, woody biomass has been a relatively small part of the total energy profile for the United States and likely will remain small, but increase proportionally. Nevertheless, as a percentage of current levels of utilization, woody biomass is expected to experience the largest relative increase in use of any power source (350 percent) by 2030 (USDOE EIA 2014). Assuming a future of moderate urbanization (high population growth and moderate income growth) combined with high energy consumption (storyline A2), use of forest-derived roundwood fuelwood as the sole energy source (for heat and power at pulp mills, residences, and other venues) is projected to increase by 230 percent from 2010 to 2060. One form of woody biomass energy that will likely see a dramatic increase is electricity produced in power plants that co-fire coal and wood. This is the result of advances in biomass energy technology as well as a shift from viewing biomass as a localized fuel source (primarily for energy at pulp and paper mills or primary wood processing plants) to a more universally accepted biofuel that can be combined with other feedstocks.

Making biomass utilization feasible for the North would require resolution of barriers associated with infrastructure, economics, and compatibility with other conservation goals. An example is efforts to find markets for small diameter trees that must be removed during savannah and woodland restoration. Residential fuel wood and other biomass energy used by individuals could also have a measurable impact on the future energy profile of the region. Residential heating with wood can be highly efficient, and the potential users (demand) are widely dispersed among the abundant woody biomass resource (Song et al. 2012). Additionally, increased use of urban wood waste can provide an additional source of fuel for bioenergy in the future.

Although the projections used to describe future trends in both carbon and woody biomass for the Northern States are based on intensive study of past trends, the projected energy future of the region is subject to alterations from unpredictable—and unknowable—factors. A recent example is the sharp increase in availability of natural gas that could lead to falling energy prices and thereby reduce economic incentives for biomass use. As assumed in all scenarios that are based on enhanced woody biomass utilization, demand for woody biomass energy feedstocks could increase dramatically if fossil fuels become scarce or cost prohibitive. Implementation of practical cellulosic ethanol technologies would be a game-changer, leading to increased consideration of woody biomass beyond the realm of fuelwood and co-firing and thereby increasing the market base, but perhaps also placing unsustainable demand on the northern woody biomass resource. Carbon emissions regulations will also be influential. Decisions about the carbon or bioenergy future of the North will need to address the woody biomass resource situation within the context of larger energy issues.



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Maintenance and Enhancement of Long-term Multiple Socioeconomic Benefits to Meet the Needs of Societies

8

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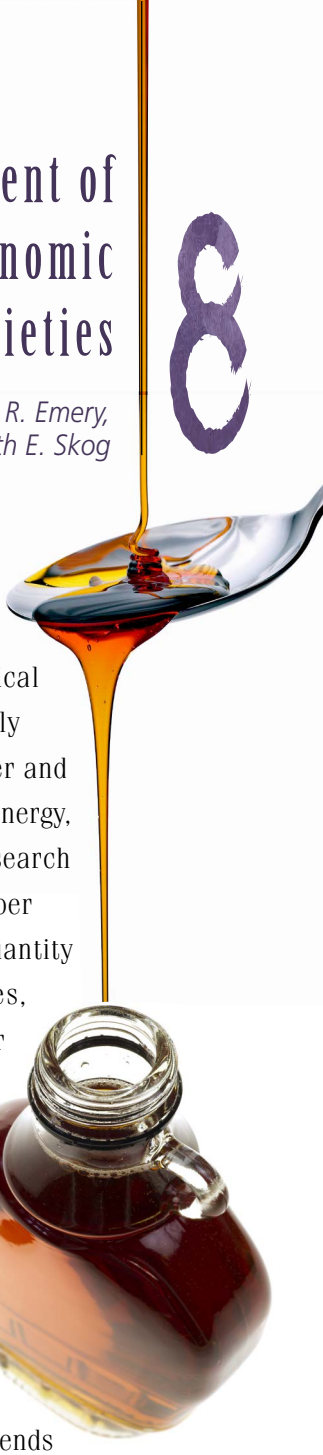
Introduction



FORESTS ARE AN important source of timber and nontimber products, recreation, ecological services, and employment in the Northern United States. Timber products are primarily used for building homes; manufacturing flooring, furniture, and cabinets; and making paper and paperboard. Residues from forest harvesting operations and wood processing are used for bioenergy, charcoal, and landscaping mulch. The employment opportunities in forestry range from research and development to logging and manufacturing. Maple syrup is the most prominent nontimber forest product in the North in terms of annual quantity produced and market value. The quantity and value of nontimber products are dwarfed by the wood products and paper industries, but gathering nontimber products has considerable cultural and economic importance for local communities. The dollar value of forest-based recreation is hard to quantify, but the vast majority of people who participate is a strong indicator of its importance to society. In addition, forest-based recreation generates demand for travel and equipment and creates employment for recreation managers and service providers.

In addition to provisioning and cultural ecosystem services provided by forest products and recreation, regulating ecosystem services from forests includes clean water, carbon sequestration, and diversity of plant and animal species (Chapters 3, 4, 6, and 7). As with recreation, the value of these services is difficult to quantify, but maintaining them is an essential part of sustainable forest management.

This chapter describes indicators of tangible socioeconomic benefits from northern forests. To the extent possible, the indicators are described quantitatively, but some are limited to qualitative descriptions because of large data gaps. For many indicators, descriptions are limited to trends rather than projections. The methods described in Chapter 2 were used to project growing-stock roundwood removals from 2010 to 2060 for the seven alternative scenarios. Forecasts of forest products were based on a forest products model described by Ince et al. (2011). Modeling of future recreation participation was based on assumptions about changes in population demographics, land use, and other factors.

Key Findings

- Overall employment in forestry is declining, but productivity (total value of shipments per employee) is increasing.
- Capital investments by government in both production and research are negatively affected by the recent economic recession that followed the 2007 U.S. financial crisis.
- Real-dollar wages in forestry have been relatively constant from 2001 to 2010.
- Under scenarios that assume a constant rate of harvesting without added demands for bioenergy feedstocks, the average annual projected removal of growing stock on timberland from 2010 to 2060 would be 1.3 percent, about half of the projected rate of forest growth.
- Under scenarios that assume greater biomass consumption for energy, the average annual projected removals of growing stock on timberland from 2010 to 2060 would range from 1.7 to 2.7 percent of growing stock.
- Production of lumber and wood panels is expected to increase under a scenario that assumes large gains in urbanization but would decrease under scenarios that assume smaller gains in urbanization.
- Paper and paperboard production is projected to be variable in the next decade and is expected to decrease before 2060 under scenarios that assume a constant rate of harvesting without added demand for bioenergy feedstocks.
- The low rates of wood recovered from construction and demolition waste can be attributed to high cost and low returns, but up to 70 percent of wood waste from construction and demolition could potentially be reused.
- The wholesale value of wild-harvested nontimber products is estimated at $682 million for the entire United States.
- Nearly all commercial U.S. maple syrup production is from the North; total annual production in 2013 was about 3.5 million gallons and was valued at $132 million.
- The total volume of wood and paper products from northern forests is about 40 percent of the quantity consumed by residents in this region; that percentage is expected to decrease under all scenarios by 2060.
- Projected population increases from 2008 to 2060 in the North are expected to cause per capita Federal and State park land to decrease by 19 percent and per capita non-Federal forest land to decrease by 26 percent.
- Under a scenario that assumes large gains in urbanization, increases in participation (compared to current participation) are projected for horseback riding on trails, downhill skiing, motor boating, and visiting interpretative sites; decreases are expected for hunting, back-country skiing, and snowmobiling.

WOOD AND WOOD PRODUCTS

Production Volumes

As described in Chapter 4, volume removals attributable to harvesting and land-use change are projected to increase moderately under scenarios that assume a constant rate of harvesting without added demands for bioenergy feedstocks, but could more than double under scenarios that assume enhanced biomass consumption for energy (Chapter 7).

Removals on timberland in the North were about 3.6 billion cubic feet in 2007, and the removal rate as a proportion of total growing-stock volume was 1.4 percent, or roughly half the 2.5-percent net annual growth rate (Shifley et al. 2012). The projected 1.3 percent mean annual removals rate from 2010 to 2060 under scenarios that assume a continuation of current harvest rates (i.e., scenarios A1B-C, A2-C, B2-C, A2-EAB) are close to the 2007 baseline or about half of estimated net annual growth, but removals rates under the scenarios with enhanced biomass consumption would range from 1.7 to 2.7 percent (Table 8.1). When coupled with projected growth and mortality, the projected removals for the three scenarios with accelerated biomass harvesting are large enough to result in a net decrease in total standing volume over the period. Chapter 4 describes the volume growth, mortality, and removals patterns in detail for all scenarios.

Table 8.1—Projected average annual growing-stock removal rates on timberland in the North, 2010 to 2060. States are ordered from greatest to least growing-stock volume in 2012.

States	Estimated, 2010		Projected[a] annual removal rate, 2010 to 2060						
	Total growing-stock volume	Removal rate	A1B-C	A2-C	B2-C	A2-EAB	A1B-BIO	A2-BIO	B2-BIO
	(billion ft^3)	(percent)	(percent)						
Pennsylvania	32.0	1.3	1.3	1.3	1.1	1.3	2.6	1.9	1.6
New York	29.3	1.0	0.7	0.7	0.7	0.7	1.4	1.0	0.9
Michigan	28.4	1.2	1.3	1.3	1.2	1.2	2.8	2.1	1.7
West Virginia	25.0	1.3	1.3	1.3	1.3	1.3	3.0	2.2	1.7
Maine	23.1	2.4	2.3	2.3	2.3	2.3	4.7	3.8	3.1
Wisconsin	20.9	1.6	1.7	1.7	1.8	1.7	3.8	2.9	2.4
Missouri	16.8	1.0	0.9	0.9	0.9	0.9	2.0	1.4	1.2
Minnesota	14.5	2.0	1.8	1.8	1.7	1.9	3.7	2.5	2.4
Ohio	14.1	1.3	1.4	1.5	1.4	1.4	3.3	2.4	1.9
New Hampshire	9.5	1.0	1.2	1.1	1.1	1.1	2.8	2.0	1.6
Vermont	9.0	1.3	1.2	1.0	1.1	1.1	2.5	1.8	1.4
Indiana	8.6	0.9	1.3	1.2	1.1	1.1	2.8	2.1	1.6
Illinois	7.2	0.8	0.7	0.6	0.7	0.7	1.3	1.1	0.9
Massachusetts	6.9	0.5	0.4	0.4	0.4	0.5	0.6	0.6	0.4
Maryland	5.9	1.1	1.5	1.5	1.4	1.5	2.6	2.1	1.7
Connecticut	3.8	1.4	0.6	0.7	0.5	0.7	0.8	0.7	0.6
New Jersey	3.5	0.8	1.5	1.5	1.1	1.6	2.3	2.1	1.4
Iowa	3.0	1.5	1.4	1.3	1.7	1.3	3.4	2.3	2.1
Delaware	0.8	0.9	1.0	1.1	1.0	1.1	1.8	1.4	1.2
Rhode Island	0.7	0.3	0.7	0.8	0.4	0.7	0.9	0.8	0.4
Total	263.4	1.3	1.3	1.3	1.3	1.3	2.7	2.1	1.7

[a]*Removal rates are projected under six scenarios, each representing a global greenhouse storyline (IPCC 2007)—A1B assumes moderate greenhouse gas emissions, moderate gains in population growth with large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio), A2 assumes high greenhouse gas emissions, large gains in population growth and energy consumption with moderate gains in income, or B2 assumes low greenhouse gas emissions, moderate gains in population growth, income, and energy consumption—combined with the assumption that bioenergy demands will stimulate an increase in roundwood harvesting (-BIO) or that roundwood harvesting will stay constant (-C); a seventh scenario—A2-EAB—assumes that roundwood harvesting will stay constant and that all ash species will succumb to an infestation by the nonnative emerald ash borer.*

The removals in Pennsylvania, Michigan, Maine, and Wisconsin are expected to account for about half of the total removals in the North. Predictions suggest that hardwoods will continue to dominate timber production and account for about three-fourths of total removals.

The future production of lumber, wood panels, and paper and paperboard in the North (Fig. 8.1) was estimated by Ince et al. (2011) using global demand and supply factors that affect wood product markets for all U.S. regions. Projected changes in production reflect anticipated market demand and therefore are greatly affected by the economic assumptions that underlay the greenhouse gas emissions storylines and additional assumptions utilized by Ince et al. (2011). Under assumptions for storyline A1B, the production of primary solid wood products—the total of lumber and wood panels production—in the North could increase 68 percent from 870 million cubic feet in 2006 to 1,461 million cubic feet in 2060. However, in the same period under the assumptions for storylines A2 and B2, the production of primary solid wood products could decline by 28 percent (Fig. 8.1). The 50-year predictions for paper and paperboard production eventually trend downward under all storylines.

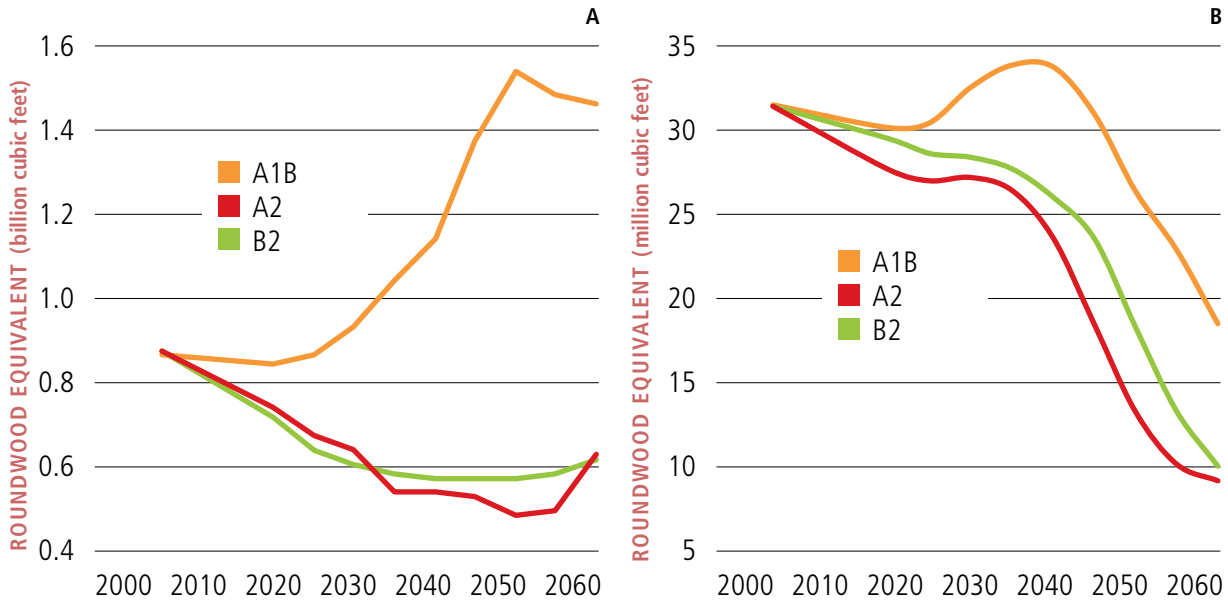


FIGURE 8.1

Projected (A) lumber and wood panels and (B) paper and paperboard production in the North, 2010 to 2060, based on the U.S. Forest Products Module (Ince et al. 2011) applied with three global greenhouse gas storylines (IPCC 2007). Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Additional assumptions of the Forest Products Module are described by Ince et al. (2011).

Timber removals in the North totaled 3,045 million cubic feet in 2007, and the population was 120 million people at that time (Shifley et al. 2012, Smith et al. 2009). Thus, the average annual timber removals per capita in the North (including removals associated with conversion of forest to other land use categories) were only 25 cubic feet. Total wood production in the region is expected to increase by 2060 under all scenarios, but due to increased population, the removals per capita between 2010 and 2060 are expected to decline slightly for all scenarios except those with large increases in biomass harvest for energy (i.e., scenarios A1B-BIO, A2-BIO, and B2-BIO) (Fig. 8.2).

Total and Per Capita Consumption

U.S. annual timber product consumption averaged 69 cubic feet per capita from 1965 to 2011. Due to weak market demand since 2007, per capita consumption hit a low of 41 cubic feet in 2009 and 2010 but rebounded modestly to 47 cubic feet by 2011(Howard and Westby 2013, Howard et al. 2010). With recovery of the U.S. economy, housing starts and per capita timber product consumption will likely increase.

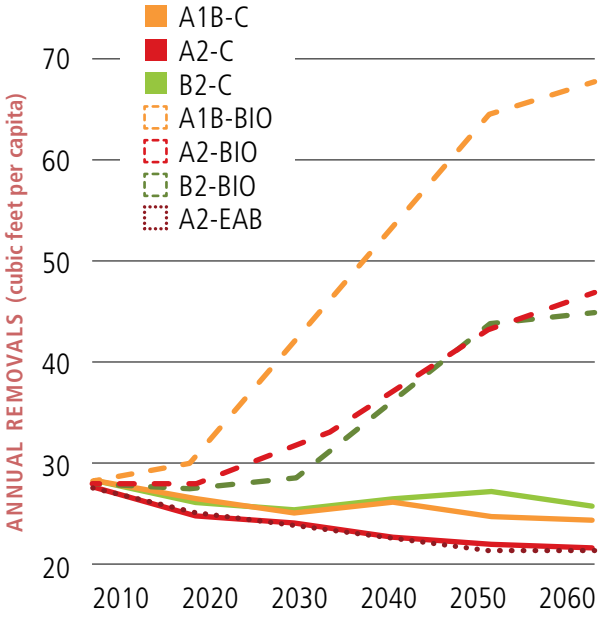
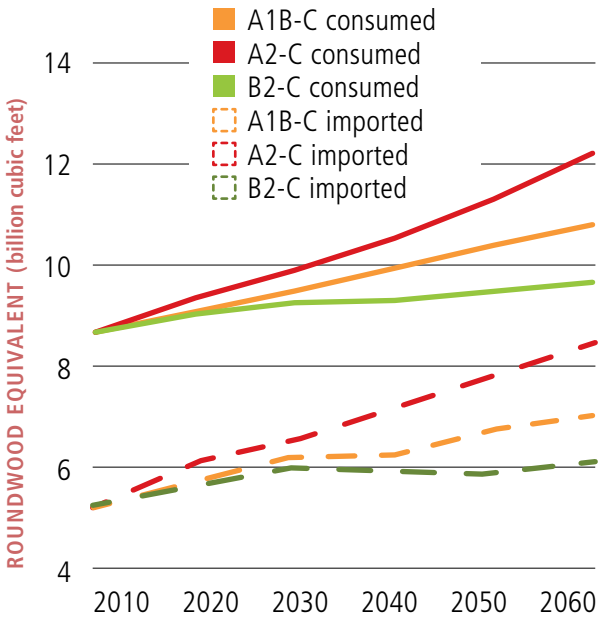


FIGURE 8.2

Projected per capita wood growing-stock removals on timberland in the North, 2010 to 2060 under seven scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.

Future total consumption of wood products in the North can be estimated from projections of population growth and per capita consumption. Based on the population projections for each of the 1,037 counties in the U.S. North and Washington, D.C., the predicted population in the region for 2060 would be 158 million people (+26 percent) under storyline A1B, 178 million people (+42 percent) under storyline A2, and 140 million people (+12 percent) under storyline B2 (Zarnoch et al. 2010). Assuming that future per capita wood consumption in the North would mirror the 46-year national average (69 cubic feet per year), the projected 2060 consumption reaches 10.9 billion cubic feet under storyline A1B, 12.3 billion cubic feet under storyline A2, or 9.7 billion cubic feet under storyline B2 (Fig. 8.3).



Exports and Imports of Wood Products

The net import of wood products into the U.S. North can be estimated by calculating the difference between future consumption (assumed 69 cubic feet per capita) and the predicted production for scenarios A1B-C, A2-C, or B2-C. Table 8.2 suggests that a net equivalent of >60 percent of the wood products consumed in the region will have to be imported from other regions or foreign countries. The net import of wood products is predicted to increase over time under scenarios A1B-C, A2-C, and B2-C (Fig. 8.3). The assumption of 69 cubic feet per capita consumption does not apply to A1B-BIO, A2-BIO, and B2-BIO, which assume greatly increased woody biomass demand.

FIGURE 8.3

Projected roundwood equivalent volumes of wood products consumed and imported in the North, 2010 to 2060, under three scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. These scenarios assume harvest will continue at recently observed levels, and when paired with a specific storyline these scenarios are labeled A1B-C, A2-C, and B2-C. Import values are estimated by subtracting the projected production from the assumed per capita consumption multiplied by projected population.

Table 8.2—Predicted proportion of total wood product consumption in the North, 2010 to 2060, that is expected to be met by net imports from other regions and countries.

Scenario[a]	2010	2020	2030	2040	2050	2060
	(percent)					
A1B-C	61	63	65	64	66	66
A2-C	62	66	66	68	70	70
B2-C	61	64	65	64	63	64
A2-EAB	62	65	67	69	70	71

[a]*Removal rates are projected under six scenarios, each representing a global greenhouse storyline (IPCC 2007)—A1B assumes moderate greenhouse gas emissions, moderate gains in population growth with large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio), A2 assumes high greenhouse gas emissions, large gains in population growth and energy consumption with moderate gains in income, or B2 assumes low greenhouse gas emissions, moderate gains in population growth, income, and energy consumption—combined with the assumption that bioenergy demands will stimulate an increase in roundwood harvesting (-BIO) or that roundwood harvesting will stay constant (-C); a seventh scenario—A2-EAB—assumes that roundwood harvesting will stay constant and that all ash species will succumb to an infestation by the nonnative emerald ash borer.*

Many of the timber and nontimber products from northern forests are exported to other regions or other countries. However, available trade statistics are insufficient to track trade into and out of the region for specific products.

NONTIMBER FOREST PRODUCTS

Nontimber forest products include hundreds of plant materials and fungi collected for food, medicine, and other purposes. While much of the nontimber forest products harvested are used for subsistence or personal consumption, or are traded in local markets, some are traded in national and global markets. The quantity and dollar value of northern nontimber forest products entering commercial markets is typically small compared to timber harvested for lumber, pulp, fuel, and similar commodities.

Nonetheless, nontimber products can be very important to local peoples and economies. Information about the type and quantity of nontimber forest products harvested and consumed is limited, but Alexander et al. (2011) estimated the 2007 wholesale value of U.S. wild-harvested nontimber forest products entering commercial markets at $682 million (Fig. 8.4) and the corresponding value to nontimber forest product gatherers at their first point of sale (cash value to gatherers if selling to a wholesaler) at $272 million or 40 percent of the wholesale value. The estimated total value of commercially traded nontimber forest products varies from year to year but has gradually decreased by 23 percent from 1998 to 2007. Product categories that increased in value were herbal and medicinal plants, craft and floral items, and grass and forage.

U.S. exports of major nontimber forest products tracked by the U.S. Department of Agriculture were >$400 million in 2007, compared to >$700 million in imports (Table 8.3). Although current data are not sufficient to justify comprehensive regional or State-level analyses, they suggest that imports substantially exceed exports for several important northern nontimber forest products including maple syrup, wild blueberries, mushrooms, and decorative foliage.

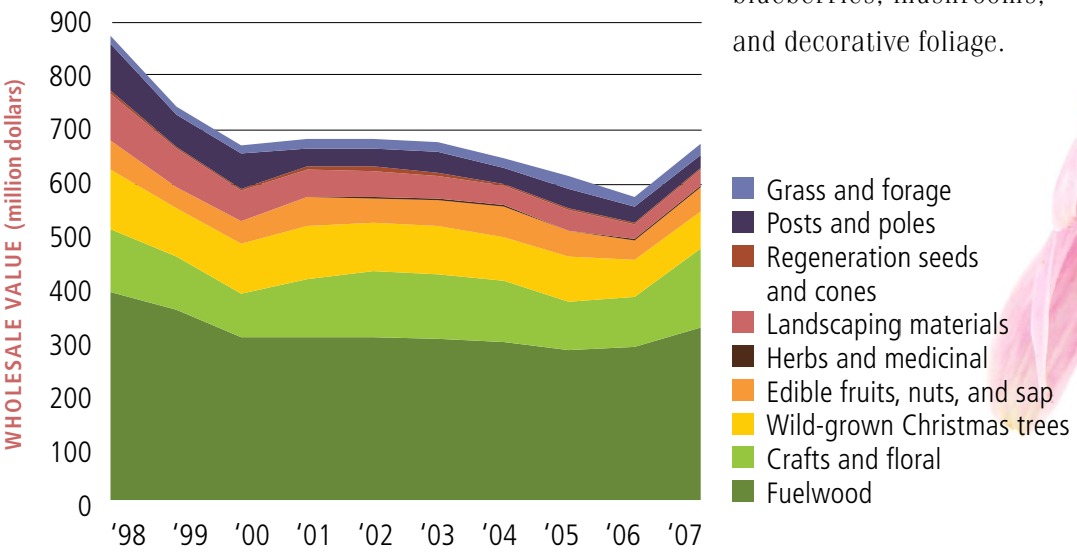


FIGURE 8.4
Estimated wholesale value (in nominal dollars) of commercially traded nontimber forest products in the United States, 1998 to 2007 (Alexander et al. 2011).

Table 8.3—Estimated annual value of U.S. imports and exports of selected nontimber forest products, 2007 (Alexander et al. 2011).

Exports		Imports	
Product	Value	Product	Value
	(million dollars)		(million dollars)
Pecans	187	Pecans	147
Ginseng, wild or cultivated	52	Maple syrup	142
Foliage, branches	48	Wild blueberries	109
Wild blueberries	48	Foliage, branches	96
Other fruits	32	Pine nuts	54
Mushrooms, truffles	14	Cranberries	49
Pine oil	12	Vanilla beans	43
Maple syrup, sugar	8	Mushrooms, truffles	34
Oil of cedarwood, clove or nutmeg	5	Ginseng, wild or cultivated	25
Gum, turpentine	5	Mosses and lichens	4
Total	411	Total	703

Common wild-harvested herbal and medicinal plants include 15 species found in northern forests (Table 8.4), but none are exclusive to the region. Harvesting estimates are not available separately for northern forests. However, large-scale field cultivation of ginseng occurs almost exclusively in Wisconsin, and 12 of the 19 States meeting Federal requirements for export of wild and wild-simulated ginseng are in the region: Illinois, Indiana, Iowa, Massachusetts, Minnesota, Missouri, New York, Ohio, Pennsylvania, Vermont, West Virginia, and Wisconsin (USDI FWS 2011).

The value of per capita consumption of commercially marketed nontimber forest products, adjusted for imports and exports, was estimated at $2.46 for 2007, down from $3.31 in 2003 (Alexander et al. 2011). These overall totals mask the economic importance of products such as ginseng, maple syrup, or balsam boughs to some individual households and communities.

Nearly all U.S. commercial maple syrup production occurs in the North. Ten Northern States (Fig. 8.5) produced an average of 2 million gallons of syrup per year from 2006 to 2012 (USDA NASS 2014). Although production has gradually increased over the last 20 years, there can be substantial year-to-year variation. In 2012, maple syrup production

Table 8.4—Wild-harvested plants found in northern U.S. forests that are used for herbal and medicinal purposes, 1997 to 2005 (Alexander et al. 2011); entries are sorted from greatest to least total harvest weight for the United States as a whole.

Plant	Part(s) used	Estimated average annual U.S. harvest (pounds)
Black cohosh	root, rhizome	259,617
Slippery elm	bark	189,208
Goldenseal	root, rhizome, leaf	106,728
Wild yam	tuber	42,400
Bloodroot	root	28,798
Eastern purple coneflower	root, herb	20,208
Pale purple coneflower	root, herb	9,759
Blue cohosh	root	6,460
Fairywand	root	4,529
Red trillium	whole plant	1,234
Beard lichen	whole plant	1,094
White colicroot	root	1,019
Virginia snakeroot	root	149
Lady's slipper	whole plant	58
Arnica	whole plant	21
Total		671,282

and value dropped sharply throughout the North, attributable to prevailing high temperatures that limited sap flow. Weather conditions were favorable in 2013; consequently annual production in the North increased by 85 percent relative to 2012. Output in 2013 totaled 3.5 million gallons, which is 0.7 million gallons more than the highest output reported for the previous 30 years. The average value of maple syrup produced from 2006 to 2012 was $75 million annually, up from $39 million during the prior 5-year period. The value of production reached $132 million in 2013. Vermont leads all States in maple syrup production (valued at $49 million in 2013) and accounts for about 40 percent of total U.S. output.

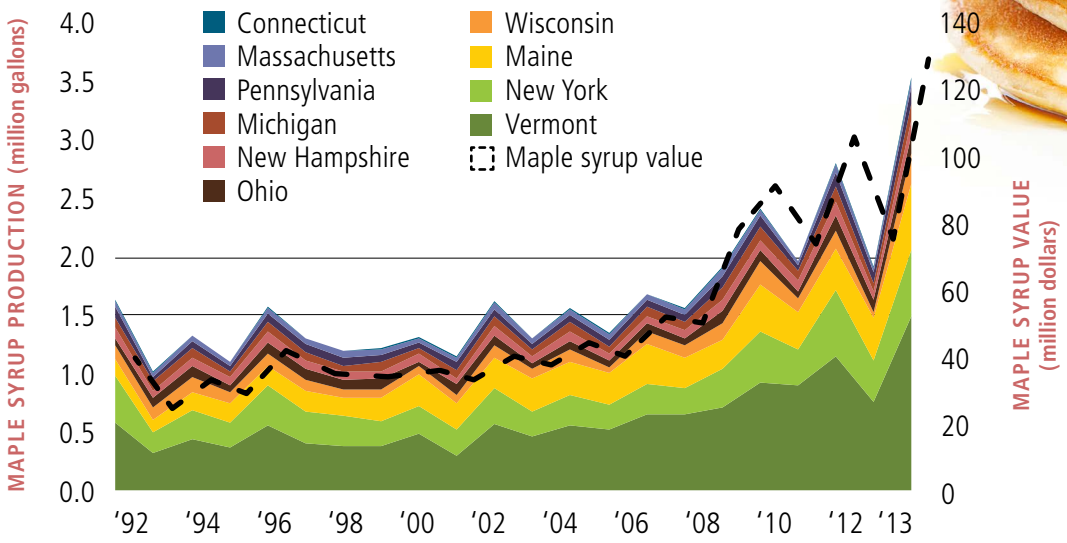


FIGURE 8.5
Volume and value (in nominal dollars) of maple syrup production in the North, 1992 to 2013 (USDA NASS 2014).

The annual variations in sap and syrup production attributed to weather conditions have heightened concerns about future impacts of climate change. In addition to concerns about unfavorable temperature for sap production, climate change is expected to reduce the extent of favorable habitat for sugar maple trees in the region (Iverson et al. 2008, USDA FS 2014) with the additional concern that maples are highly valued for autumn color and important to the recreation and tourism industries discussed in the Outdoor Recreation section of this chapter.

As is true for any commodity, markets and economic values for nontimber forest products can be expected to fluctuate in the future. Economic downturns will depress demand for discretionary items such as floral greens and decoratives, and research about adverse effects will continue to eliminate markets for individual medicinal species. However, growing interest in local foods and medicinal supplements can be expected to drive overall growth in demand for species that fill these niches. Economic downturns can also increase harvesting of desirable nontimber forest products for personal consumption and sale. As markets for herbal supplements and medicinal products develop, harvesting volumes can be expected to increase. For some species, markets will be short lived, but for those with enduring markets, cultivation efforts and offshore sourcing could fill a growing portion of demand, resulting in less harvesting from northern forests.

RECOVERY OR RECYCLING OF FOREST PRODUCTS

Recycling of forest products includes the reuse of any wood and paper product except wood waste used for energy. Many wood products such as furniture, pallets, boxes, and wood from demolition are reused. The recycling rate for some types of wood products is already high. For example, most pallets in the United States are reused or repaired for reuse (Bush et al. 2007). Manufacturing wood residues are used as fuel wood or recycled for making engineered wood products, landscaping products, and animal bedding.

Paper and wood account for about a third of total U.S. municipal solid waste by weight (Fig. 8.6). In the Northeastern States (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont), paper and paperboard make up about 29 percent of municipal solid waste, and wood makes up about 6 percent of municipal solid waste (Northeast Waste Management Officials' Association 2009). With the growth of opportunities and requirements for recycling, an increasing proportion of wood and paper products will be reused in increasingly efficient ways. The national rate of paper and paperboard recycling was 67 percent in 2010, about twice the 1999 rate of 34 percent (Paper

Industry Association Council 2012). The recovery rate of wood from the municipal waste stream has also increased but is low compared to other reusable wastes (Fig. 8.6). For example, the U.S. recovery rate of wood from municipal solid waste in 2006 was only 12 percent.

Wood was an estimated 10 percent of construction demolition waste, and its estimated recovery rate is about 15 percent, with large variation among Northeastern States (Northeast Waste Management Officials' Association 2009). Corresponding recovery rates in other Northern States have not been reported, but Falk and McKeever (2004) suggest that low rates of recovery of wood in construction demolition waste can be attributed to high costs and low returns, and also that up to 70 percent of such wood waste could be reused.

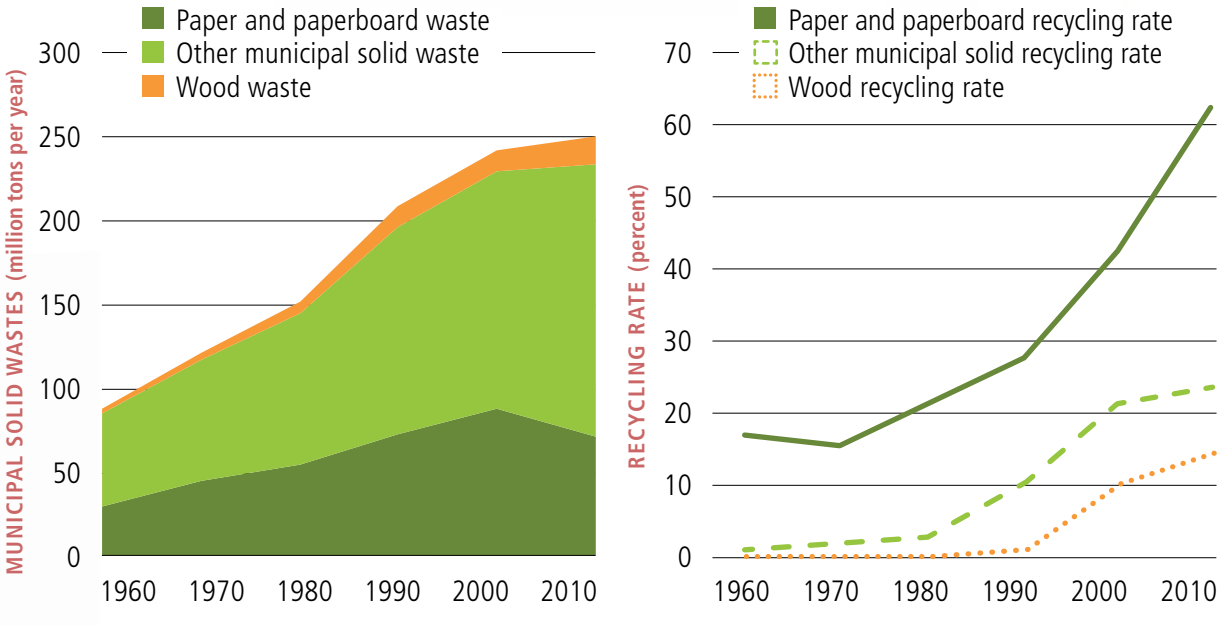


FIGURE 8.6

Comparison of wood-products and other materials in municipal wastes, 1960 to 2010, in the Northern United States by (A) volume generated and (B) percent recycled (US EPA 2011).

FORESTRY INVESTMENTS AND RETURNS

Private Landowner Investments

Historically, investments in tree planting in northern forests have been small compared to forests in other regions. This is partially because hardwoods, the dominant component, can regenerate naturally. The planted forest area in the North is <4 percent of total forest land compared to 8 percent for all U.S. forest land, and tree planting area has decreased to <0.2 million acres each year in recent decades (USDA FS 2009). The acreage planted is expected to remain at that level or slowly decrease unless there are large investments in wood bioenergy plantations.

The degree to which an assisted migration strategy for tree species could affect future rates of tree planting is unknown. Assisted migration uses planting to expand the occurrence of a species outside its natural range into locations that are presumed to be better suited to its growth and survival under a changing climate. Assisted migration is a widely discussed climate change adaptation strategy that remains controversial (McLachlan et al. 2007, Vose et al. 2012).

The increasing number of forest owners and the decreasing average size of private forest ownerships in the region contribute to low investments in forest management (Chapter 9). Nevertheless, participation of landowners in conservation programs in recent decades has increased as measured by tax deductions and increased enrollment in easements and other incentive programs (Land trust Alliance 2011, Song et al. 2014). Recreational investment is expected to increase in anticipation of an increasing number of people participating in outdoor activities (Bowker and Askew 2013, Bowker et al. 2012, Cordell 2012).

Wood Products Industry Investments

Capital investments in wood products—the North American Industry Classification System (NAICS) category 321—increased to $1.2 billion in 2006 in the U.S. North (Shifley et al. 2012). After the 2007 U.S. financial crisis, capital investment in wood products decreased to a low of $0.5 billion in 2011 (U.S. Census Bureau 2012), a rate that is expected to increase as the overall economy continues to recover.

In contrast, investment in pulp and paper production in the North has been declining since 1997 due to weak demand and intensive competition. Total investments in the pulp and paper industry in the North decreased from $2.9 billion in 2006 to $2.2 billion in 2010. It is unknown when the decline of investments in this industry will stop.

Federal Investments

Federal government investment in forest management in the North has remained relatively flat. A modest increase in combined funding for the National Forest System and the State and Private Forestry Program of the U.S. Forest Service has been more than offset by the effects of the Federal budget sequestration (Fig. 8.7).

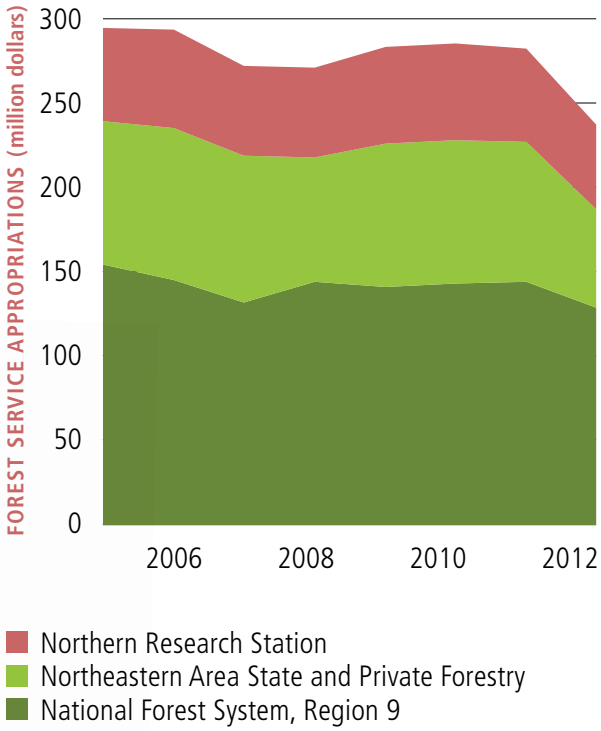


FIGURE 8.7

U.S. Forest Service discretionary appropriations in the North, 2006 to 2012, for the National Forest System (Region 9), Northeastern Area State and Private Forestry, and the Northern Research Station.

The total Federal government investment in forest research, landowner support, and national forest management decreased slightly in nominal dollars from 2005 to 2011 (Fig. 8.7). However, in 2012, the combined expenditure was $280 million, down 5 percent from 2005 and down 15 percent from the 2011 high.

EMPLOYMENT IN FOREST INDUSTRIES

Numbers of Employees

Employment in six major NAICS categories is forest-related (Table 8.5). In addition, forest-associated employment includes jobs in forest administration offices, forest research stations, universities, consulting firms, and conservation organizations, but statistics for these jobs are indirectly included in employment numbers of government, education, research, conservation, and other job categories and cannot be separated for forestry related employment.

Direct forest production and service sectors in the North provided a combined total 427,000 jobs in 2010, which was 36 percent of the U.S. total for these sectors (1.2 million jobs). Most jobs (94 percent) were in manufacturing: wood products manufacturing, paper and paperboard products manufacturing, and wood furniture manufacturing (Table 8.5).

Table 8.5—Comparison of forest production and service employment, 2001 to 2010, in the United States and in the North (U.S. Department of Labor, Bureau of Labor Statistics 2012).

	Employment North American Industry Classification System category (NAICS code)						
	Forestry and logging	Hunting and trapping	Wood products	Paper and paperboard	Wood furniture	Parks and recreation	Total
	(113)	(1142)	(321)	(322)	(337110, 337122, 337211, 337212)	(71219)	
Northern States							
2001 (employees)	12,243	809	205,516	300,389	125,389	11,993	656,339
2010 (employees)	9,495	407	125,390	197,905	78,626	15,121	426,944
Change (percent)	-22	-50	-39	-34	-37	26	-35
United States							
2001 (employees)	82,526	3,619	646,964	577,030	313,308	69,934	1,693,381
2010 (employees)	60,065	1,665	473,495	392,853	169,898	80,642	1,178,618
Change (percent)	-27	-54	-27	-32	-46	15	-30

Forest-related Job Categories in the North American Industry Classification System

The job data used in this report are from the Quarterly Census of Employment and Wages (U.S. Department of Labor, Bureau of Labor Statistics 2012) for private establishments and government installations with one or more paid employees. Survey units without paid employees are excluded, as are government agencies, education, research, and conservation employees.

Forestry and logging (NAICS 113)—Establishments and government installations growing and harvesting timber on a long production cycle (≥10 years). Consequently, Christmas tree production and other production involving production cycles <10 years are not in this subsector. Silvicultural activities, harvesting timber, and gathering forest products (such as gums, barks, balsam needles, rhizomes, fibers, Spanish moss, ginseng, and truffles) are included in this subsector.

Hunting and trapping (NAICS 1142)—Establishments that do commercial hunting and trapping or operate commercial hunting and game preserves.

Wood products (NAICS 321)—Establishments manufacturing wood products (from logs and bolts) that are sawed and shaped, and establishments purchasing sawed lumber and making wood products. Products of this subsector include lumber, plywood, veneers, wood containers, wood flooring, wood trusses, manufactured homes (mobile homes), and prefabricated wood buildings.

Paper and paperboard (NAICS 322)—Establishments making pulp, paper, or converted paper products. Converted paper products are made from paper and other materials by various cutting, shaping, coating, and laminating activities. Products of converted paper products include paperboard containers, paper bags, coated and treated paper, stationery, sanitary paper, tissue paper, and disposable diapers. Excluded from this subsector are photosensitive papers.

Wood furniture—Establishments manufacturing wood kitchen cabinet and countertop (NAICS 337110), non-upholstered wood household furniture (NAICS 337122), wood office furniture (NAICS 337211), and custom architectural woodwork and millwork (NAICS 337212).

Parks and recreation (NAICS 71219)—Establishments or government installations primarily engaged in the preservation and exhibition of natural areas or settings. National and State parks, reserves, conservation areas, wildlife sanctuary, and waterfalls are all included in this subsector.

Employment in the North from 2001 to 2010 declined in all the forest-associated categories except parks and recreation (NAICS 71219). During these years, total forest-associated employment in the region dropped by 35 percent; jobs in forestry and logging (NAICS 113) dropped by 22 percent, from about 12,000 to 9,000 jobs (Fig. 8.8); jobs in hunting and trapping dropped by 50 percent; jobs in wood products manufacturing dropped by 39 percent; jobs in paper and paperboard products manufacturing dropped by 34 percent; and jobs in wood furniture manufacturing dropped by 37 percent. Although they make up a small proportion of the total, jobs in parks and recreation increased by 26 percent.

More than half of the decreases in forest-associated employment occurred after the 2007 U.S. financial crisis (Fig. 8.8). A long-term trend of declining employment in the forest-associated industries appears to have been exacerbated by the economic downturn. Future changes in employment will likely be linked to economic conditions, and future rates of decline could be smaller as the economy recovers. Table 8.5 shows employment numbers by job category for 2001 and 2010, and Table 8.6 shows employment numbers, by State, from 2001 to 2010.

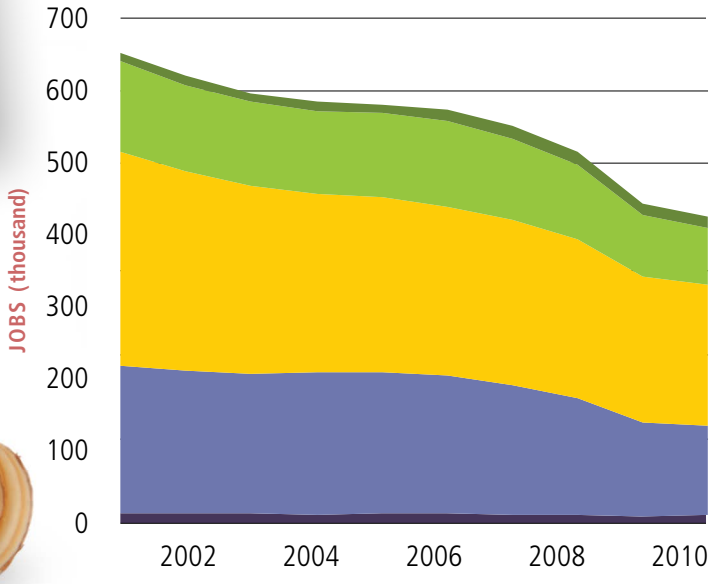


FIGURE 8.8
Forest production and service job categories that employed >1,000 workers in the North, 2001 to 2010.

The economic recession that followed the 2007 financial crisis helps explain the particularly large drop in forest-related employment in 2009, as does the weak demand for U.S. paper products since 1990. An additional factor was an overall increase in productivity per employee (average dollars of product shipment per employee), which was a major reason for employment declines in the forest products industry and one of several reasons for declines in the paper and paperboard industry. From 1997 to 2011, per employee shipments increased from $0.13 million to $0.20 million in the forest products industry and nearly doubled from 0.24 to 0.45 million dollars in the paper and paperboard industry (Fig. 8.9).

Average productivity values measured in million dollars per job per year for these two industries generally increased from 1997 to 2011 but showed considerable variation among States (Fig. 8.10). The increasing value of shipments per employee suggests a trend of higher productivity in these industries (Maine Forest Products Council 2013). Similar trends exist for the northern logging industry, where the number of workers has decreased although total timber production has increased over the last half century.

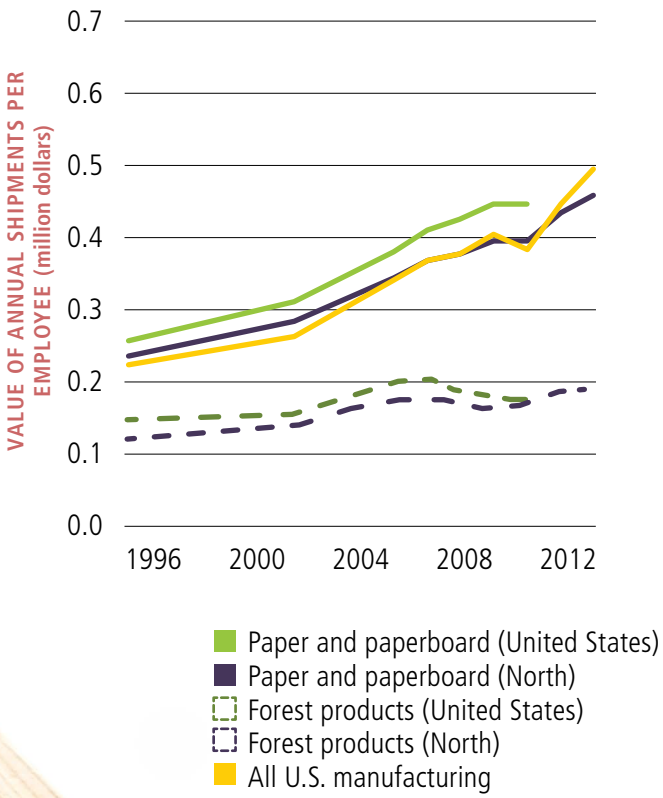


FIGURE 8.9

Comparison of forest-industry employee productivity (defined as shipment value per employee) in the United States and the North, 1997 to 2011 (U.S. Census Bureau 2012).

Table 8.6—Numbers of forest production and service jobs, reported for the U.S. North by State and year, 2001 to 2010, [NAICS categories 113, 321, 1142, 71219, 337110, 337122, 337211, and 337212] (U.S. Department of Labor, Bureau of Labor Statistics 2012).

State	2001	2002	2003	2004	2005
	(number of workers)				
Connecticut	11,211	10,666	10,432	10,017	9,369
Delaware	2,519	2,661	2,455	2,022	1,367
District of Columbia[a]	33	14	17	NA	NA
Illinois	49,626	47,589	46,325	44,248	44,786
Indiana	52,365	50,357	48,638	49,056	49,395
Iowa	21,720	20,887	20,979	20,684	22,061
Maine	23,478	22,332	19,849	19,835	20,011
Maryland	13,033	12,302	11,898	11,653	12,018
Massachusetts	24,463	22,878	21,488	21,169	20,251
Michigan	42,640	39,780	38,341	36,777	36,995
Minesotta	41,207	40,466	40,048	39,916	40,184
Missouri	29,397	27,962	26,778	26,720	26,012
New Hampshire	8,593	7,814	7,093	7,298	7,092
New Jersey	28,076	25,818	25,034	24,388	23,534
New York	50,826	47,126	45,082	44,626	43,990
Ohio	69,032	65,722	63,185	61,478	60,012
Pennsylvania	79,135	76,632	74,337	72,829	73,442
Rhode Island	3,685	1,011	3,337	2,488	2,234
Vermont	7,149	6,498	5,766	5,593	5,587
West Virginia	12,548	12,541	12,597	12,806	12,650
Wisconsin	85,603	83,141	76,576	74,452	73,691
North total	656,339	624,197	600,255	588,055	584,681
U.S. total	1,693,381	1,620,104	1,547,753	1,505,504	1,484,624
North/U.S. (percent)	39	39	39	39	39

[a]*Record keeping stopped in 2004, designated as NA.*

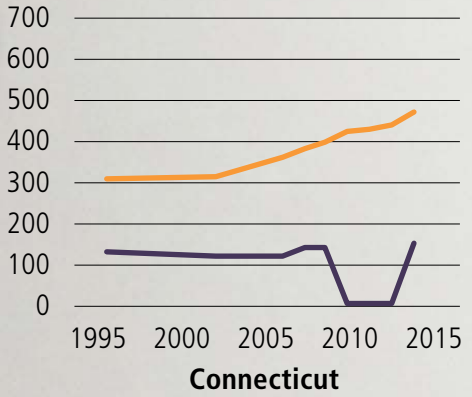
Table 8.6 continued

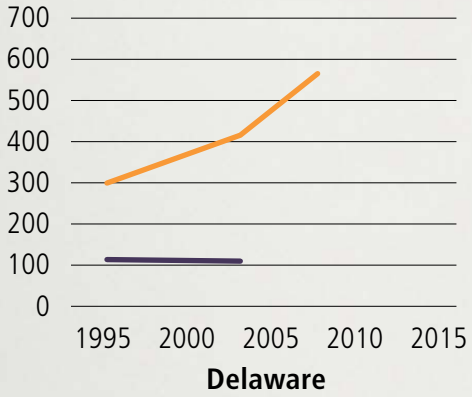
State	2006	2007	2008	2009	2010	Change 2001 to 2010
	(number of workers)					(percent)
Connecticut	9,366	9,537	9,163	7,725	7,148	-36
Delaware	1,622	1,574	1,472	1,337	1,329	-47
District of Columbia[a]	NA	NA	NA	NA	NA	NA
Illinois	44,488	43,290	41,474	36,320	34,022	-31
Indiana	48,814	46,410	42,548	34,630	33,551	-36
Iowa	22,043	21,203	19,095	15,932	15,175	-30
Maine	19,151	18,170	17,196	15,013	14,888	-37
Maryland	11,717	10,586	9,545	8,035	7,432	-43
Massachusetts	19,139	18,780	17,145	14,682	14,251	-42
Michigan	35,523	34,095	31,768	27,248	26,597	-38
Minesotta	39,202	36,987	34,253	29,629	28,797	-30
Missouri	26,043	24,849	22,917	19,786	18,974	-35
New Hampshire	6,447	5,869	5,233	4,434	4,124	-52
New Jersey	22,670	21,533	20,747	17,910	17,654	-37
New York	46,827	45,634	43,753	38,240	33,177	-35
Ohio	58,221	55,932	52,711	45,009	43,402	-37
Pennsylvania	73,656	70,499	65,716	56,469	55,013	-30
Rhode Island	2,137	2,880	2,428	2,779	2,867	-22
Vermont	5,308	5,227	5,147	4,310	3,976	-44
West Virginia	12,501	11,552	10,147	8,465	8,091	-36
Wisconsin	72,145	69,775	66,337	58,360	56,476	-34
North total	577,020	554,382	518,795	446,313	426,944	-35
U.S. total	1,453,356	1,408,614	1,351,194	1,224,524	1,178,618	-30
North/U.S. (percent)	40	39	38	36	36	NA

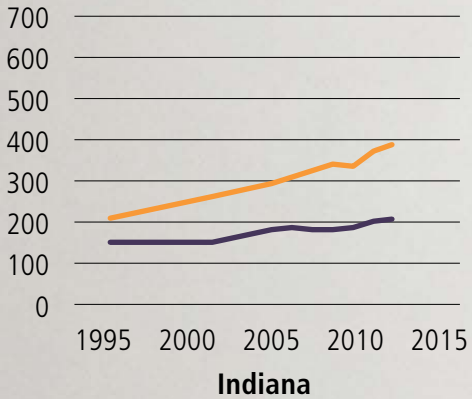
[a]*Record keeping stopped in 2004, designated as NA.*

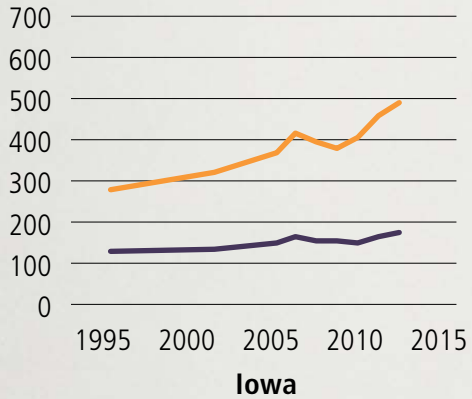
PRODUCTIVITY
(thousand dollars per employee per year)

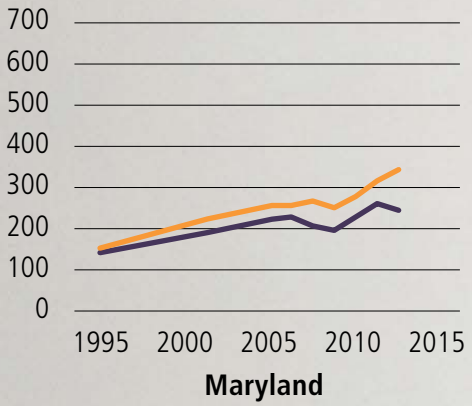
- Paper and paperboard manufacturing
- Wood products manufacturing

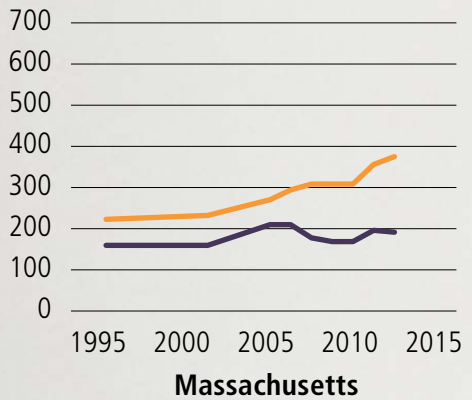


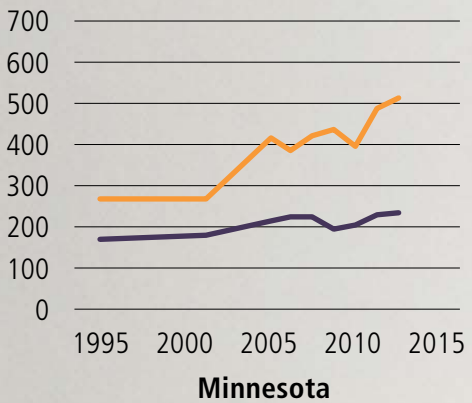












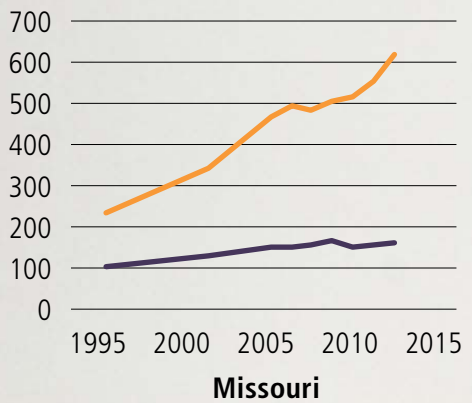
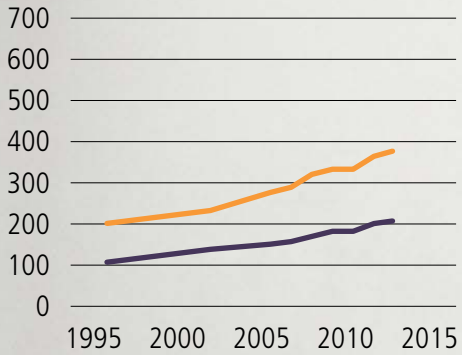
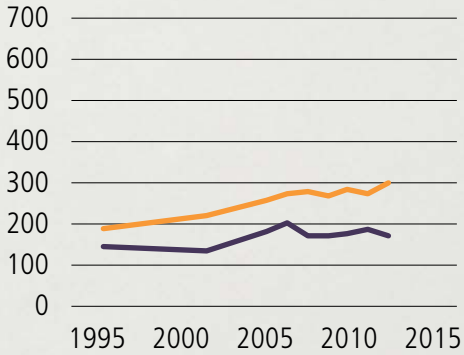


FIGURE 8.10

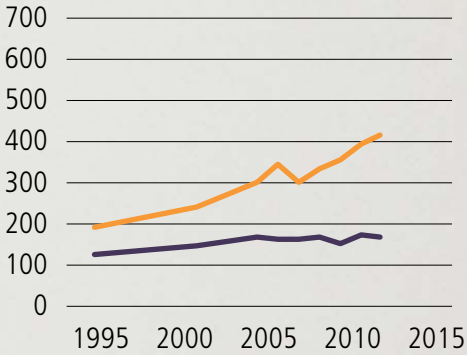
Employee productivity (defined as shipment value per employee) by States in the North, 1997 to 2011, forest products industry and the paper and paperboard industry (U.S. Census Bureau 2012).



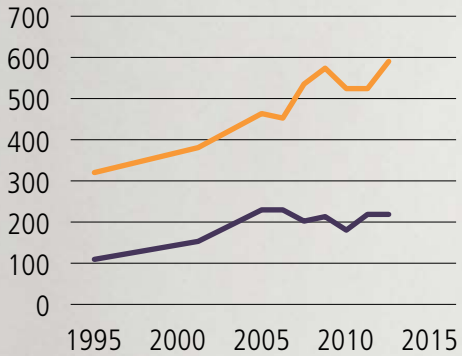
Illinois



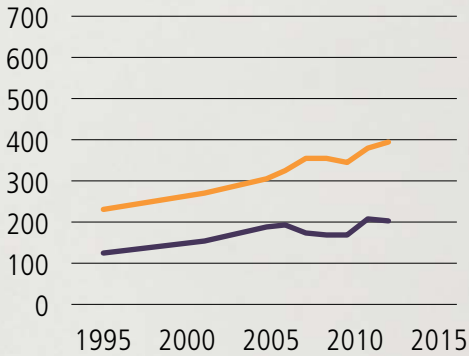
New Jersey



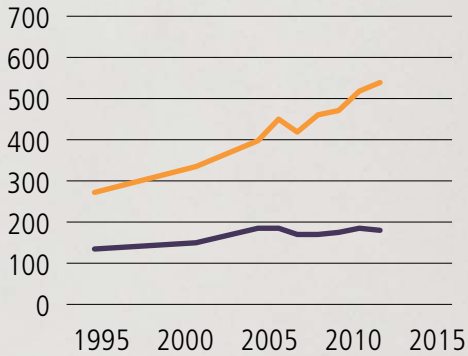
New York



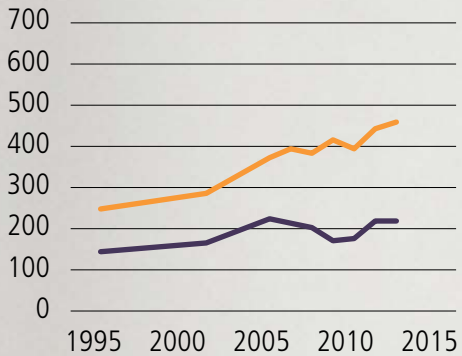
Maine



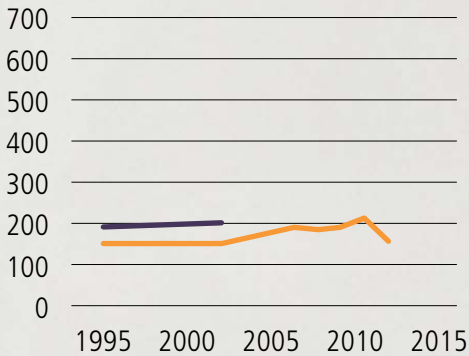
Ohio



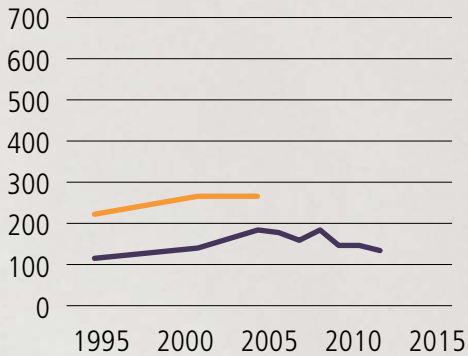
Pennsylvania



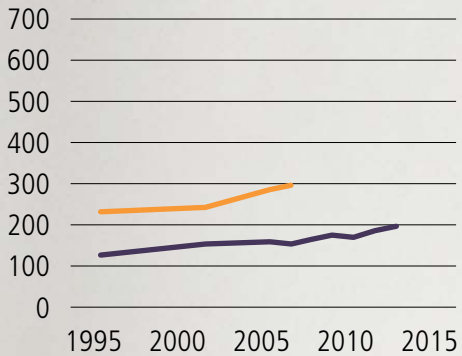
Michigan



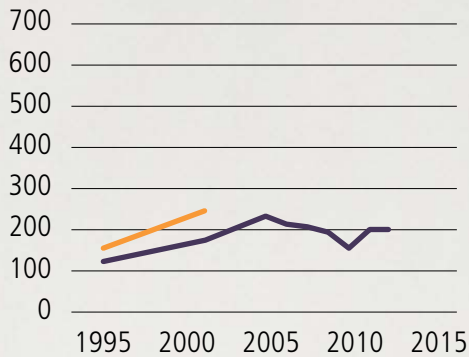
Rhode Island



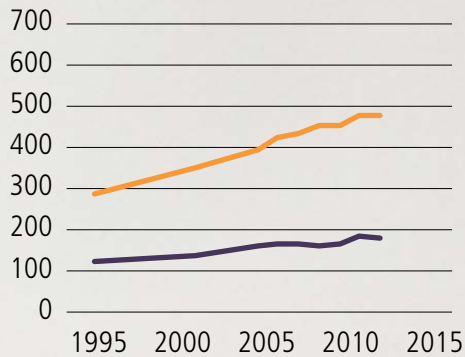
Vermont



New Hampshire



West Virgina



Wisconsin

The historical trends of increasing productivity and declining employment in manufacturing industries, where a majority of forest-related jobs were created, implies that future forest-related employment will decrease if wood demand and removals follow historical trends in the North (e.g., under scenarios A1B-C, A2-C, and B2-C). However, if biomass energy demand grows rapidly (e.g., under scenarios A1B-BIO, A2-BIO, and B2-BIO), wood removal will be much greater (Chapter 4), and gains in employment in woody biomass energy production can help offset a potential decline in the manufacturing sectors (Woodall et al. 2012) or result in increasing forest-related employment in the future. With bioenergy-feedstock demands being increasingly sourced from urban areas, employment in urban forestry is expected to increase. Parks and recreation jobs will also increase over time should the current trend in this industry remain.

Income

From 2001 to 2010, workers in the paper and paperboard industry earned on average $45,000 annually (in 2001 dollar value), the highest wage rate among the six forest related industries; workers in wood furniture and forest products manufacturing earned the second highest annual wages (about $30,000) and workers in other forest related industries earned <$30,000.

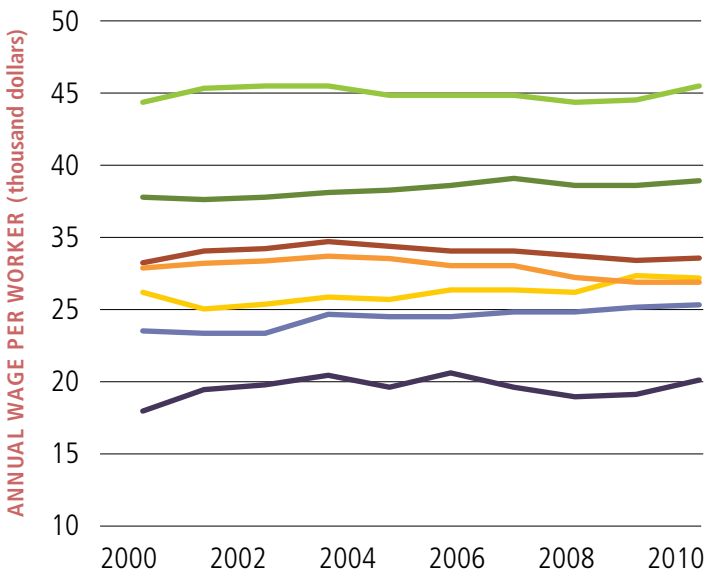
Despite the recent economic recession, the average wages of forest related production workers in the North increased by 1 percent (in real dollars discounted by consumer price index) from 2001 to 2010 (Fig. 8.11). The average annual wage rate, weighted by total workers in 2010, increased by $441 (in 2001 dollar value) in the same period. Although average nominal wage rates increased in five of the six job categories, the real value of the annual wage rate in the wood products category (NAICS 321) decreased by 4 percent from 2001 to 2010. In the same period, the real value of wage rates increased by 3 percent in paper and paperboard, 2 percent in wood furniture manufacturing, 5 percent in park and recreation services, 10 percent in forestry and logging, and 16 percent in hunting and trapping (Fig. 8.11). If the U.S. economy continues to grow as it did at the turn of the century, the average wage rate of forest production workers is expected to grow as well.

OUTDOOR RECREATION

Most public forests in the North are open to all, meaning that 44 million acres or 26 percent of northern forest land is available for recreation. In recent decades the area of publically owned forests has increased slightly, and that component of forest-based recreation land appears relatively stable. Private forests in the hands of families or individuals—approximately 100 million acres in total—are used for recreation primarily by their owners. An estimated 18 million acres (18 percent) of those forests are open for public recreation. In addition, most forest-based U.S. skiing facilities are in the North, as are the majority of forest-based nature parks. Most northern forest-based recreation, sightseeing, and tourism businesses are concentrated in the Northeast and the Great Lakes States (USDA FS 2011).

Cordell (2012) compared northern recreation trends and resources to those in other U.S. regions. That summary of participation rates and trends for 61 outdoor recreation activities describes the diversity of available recreation activities and participants, and it identifies activities in which participation rates have increased or decreased (Table 8.7).

Population demographics are expected to affect future participation in outdoor recreation. For example, the projected population increase from 2010 to 2060 in the North is expected to range from 15 to 50 million people (Chapter 2). This could result in a net increase in the total number of recreation participants, even for activities that are expected to experience constant or slightly decreasing participation rates. Increases in population would also reduce the area of potential recreation land and water per capita (Table 8.8). However, the per capita decreases in the North are expected to be lower than the national average because the rate of population increase will be lower.



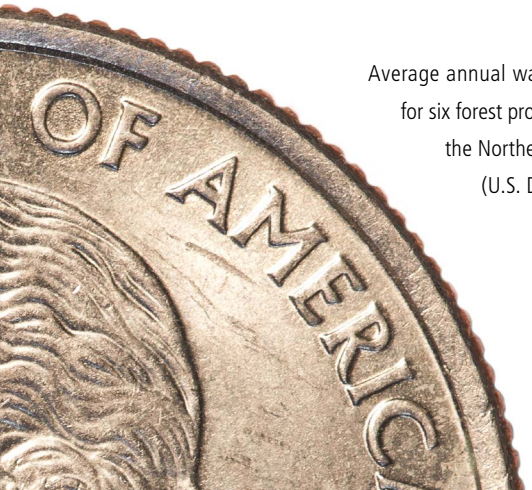


FIGURE 8.11
Average annual wage of workers in 2001 dollars for six forest production and service industries in the Northern United States, 2001 to 2010 (U.S. Department of Labor, Bureau of Labor Statistics 2012).

Table 8.7—Rates of participation in nature-based activities by people aged ≥16 years in the Northern United States (adapted from Cordell et al. 2012).

Activity	Proportion of population participating, 2007[a]	Change in total number of participants, 2000[b] to 2007
	(percent)	
More than 30 million participants		
Walking for pleasure	85	6
Attending family gatherings	75	7
Gardening or landscaping	67	3
Viewing or photographing natural scenery	64	12
Visiting an outdoor nature center or zoo	57	5
Picnicking	55	1
Viewing or photographing wildlife (other than birds and fish)	51	21
Viewing or photographing flowers or trees	51	23
Sightseeing	51	5
Driving for pleasure	50	4
Visiting beaches	45	15
Visiting historic sites	44	0
Swimming in lakes, ponds or streams	44	8
Swimming in outdoor pools	43	11
Bicycling	40	4
Viewing or photographing birds	38	18
Gathering mushrooms or berries	36	26
Visiting farm or agricultural settings	36	28
Day hiking	33	15
Visiting wilderness areas	31	11
10 to 30 million participants		
Viewing/photographing fish	25	13
Warm water fishing	25	17
Motor boating	24	5
Visiting watersides (besides beaches)	24	2
Sledding	21	5
Developed camping	21	-10
Mountain biking	20	-6
Participating in boat tours or excursions	19	-2
Visiting prehistoric sites	19	3
Off-road driving	18	25
Canoeing	12	8
Primitive camping	12	-3

Table 8.7 continued

Activity	Proportion of population participating, 2007[a]	Change in total number of participants, 2000[b] to 2007
	(percent)	
3 to 10 million participants		
Big game hunting	9	17
Backpacking	9	-2
Ice skating	8	-10
Saltwater fishing	8	2
Waterskiing	8	29
Horseback riding	8	6
Using personal watercraft	8	4
Downhill skiing	8	-15
Rafting	7	-13
Snowmobiling	7	-3
Kayaking	7	89
Small game hunting	7	15
Snorkeling	6	4
Horseback riding on trails	6	0
Snowboarding	6	36
Rowing	5	1
Sailing	5	-12
Mountain climbing	4	-12
Caving	4	30
Rock climbing	4	10
Cross country skiing	4	-21
Ice fishing	4	9
Anadromous fishing	4	6
Fewer than 3 million participants		
Orienteering	3	91
Snowshoeing	2	-17
Migratory bird hunting	2	13
Scuba diving	2	7
Surfing	1	43
Windsurfing	1	4

[a]*Spanned the years 2005 to 2009.*

[b]*Spanned the years 1999 to 2001.*

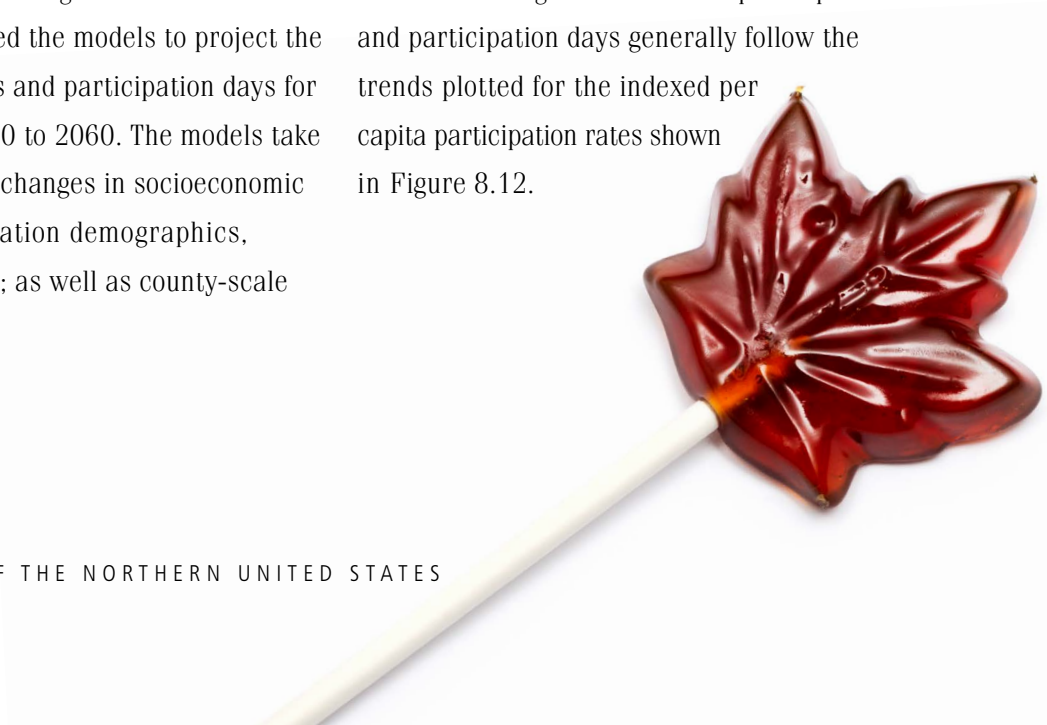
Table 8.8—Per capita park, forest, and water area in the United States and the North with projections to 2060 (Cordell et. al 2012); projected declines in acreage per capita result from a combination of increasing population and decreasing forest area, particularly for private forest land.

Category of land or water	Estimate, 2008[a]	Projected, 2060	Change from 2008 to 2060
	(acres per capita)		(percent)
Federal and state park land			
North	0.16	0.13	-19
United States	2.06	1.40	-32
Private forest land			
North	1.19	0.88	-26
United States	1.27	0.80	-37
Surface water[b]			
North	0.46	0.36	-22
United States	0.54	0.37	-31

[a] *2010 for private forest land, 2008 for all other categories.*

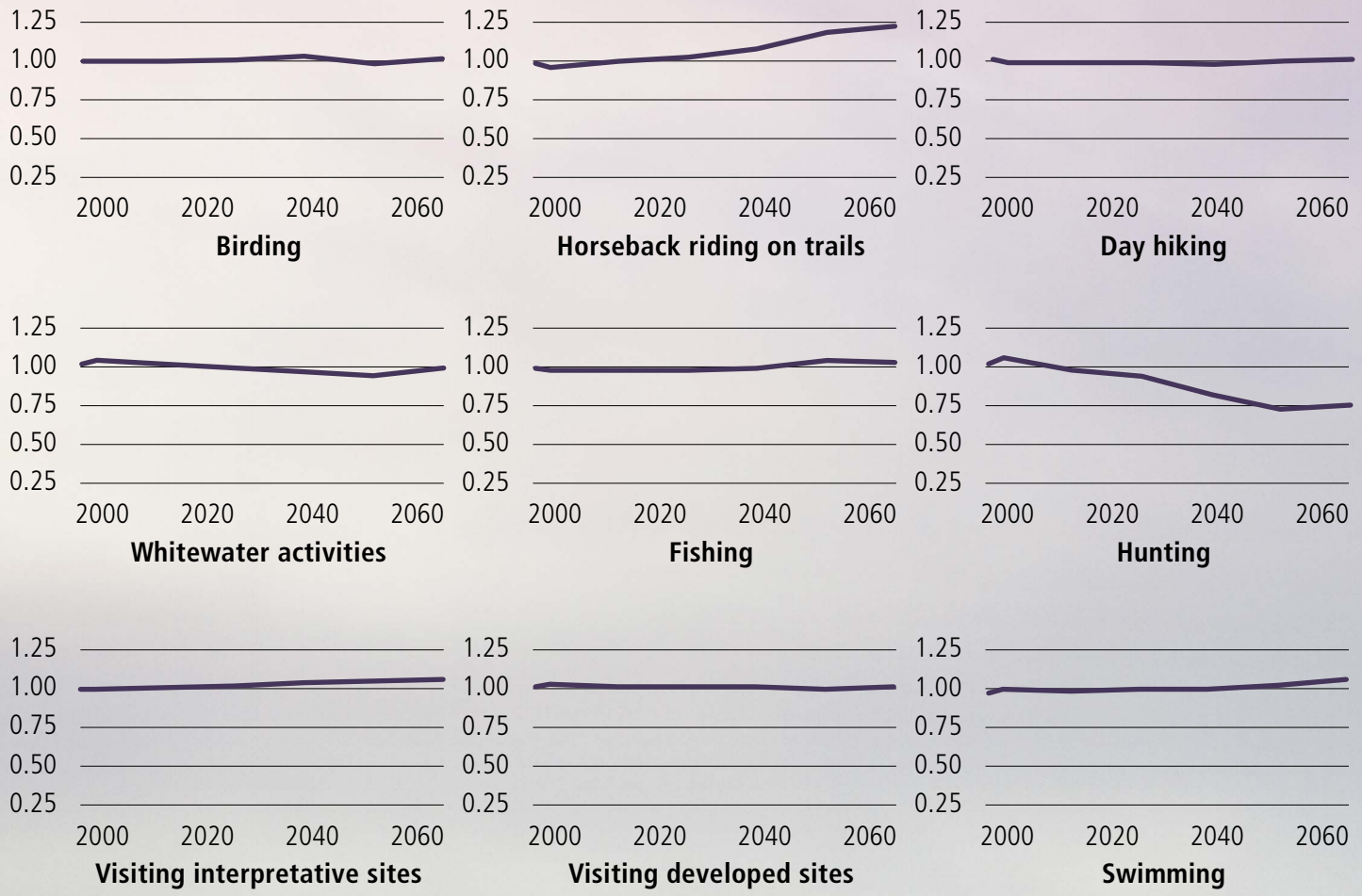
[b] *Includes inland, coastal, territorial, and Great Lakes water surface area.*

From 2000 to 2007, outdoor recreation participation increased for 48 activities and decreased for 13 activities in the North (Cordell 2012). Bowker and Askew (2013) modeled annual participation rates and participation days for 17 categories of recreation activities using data from 1999 to 2009. They then applied the models to project the number of participants and participation days for each activity from 2010 to 2060. The models take into account expected changes in socioeconomic factors such as population demographics, education, and income; as well as county-scale recreation supply indicators such as per capita public land, forest, water, and mountain acreage. Projected recreation participation rates were indexed as increases or decreases compared to observed participation rates for 2008 (Fig. 8.12). Predicted changes in number of participants and participation days generally follow the trends plotted for the indexed per capita participation rates shown in Figure 8.12.



Future changes to forest ecosystems may impact outdoor recreation activities and local economies. An example is the expected change to the maple-beech-birch (*Acer* spp.-*Fagus* spp.-*Betula* spp.) forest-type group. Because sugar maples are valued for their brilliant autumn color, they are a key resource for the tourism and outdoor recreation industries at many northern locations. Projected decreases in the future area of the maple-beech-birch group are variable across the region (Chapter 3), but the projections do not specifically address gains or losses of sugar maple trees. Other analyses focused specifically on sugar maple indicate that its range and relative abundance are likely to decrease across the region under a wide range of climate scenarios (Iverson et al. 2008, USDA FS 2014) with potentially negative consequences for recreation and tourism industries.

INDEXED PER CAPITA PARTICIPATION RATE



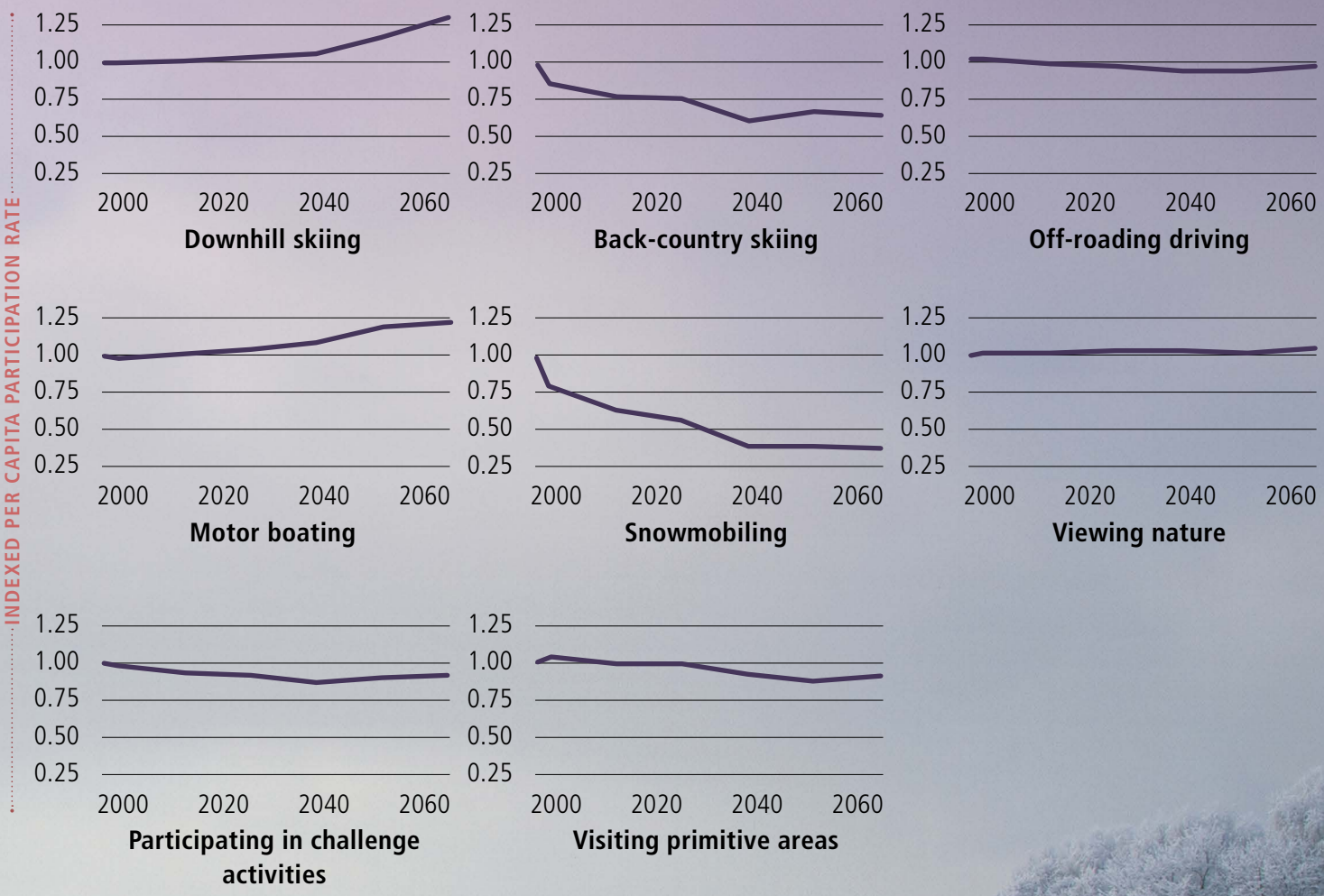


FIGURE 8.12

Change in per capita participation rates, 2008 to 2060, in the North for 17 categories of outdoor recreation activities under storyline A1B; a value of 1.0 was assigned to participation in 2008—values >1.0 indicate a relative increase and values <1.0 indicate a relative decrease (adapted from Bowker and Askew 2013).

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Legal, Institutional, and Policy Framework for Forest Conservation and Sustainable Management

9

Brett J. Butler

Introduction

ONE CONCLUSION FROM the 50-year forest projections described in Chapters 2 through 8 is that some of the most dramatic changes to the forests of the North will be the direct result of human activities, including land-use change, forest management, greenhouse gas emissions, and invasive species introductions. The tools that society will have available to influence the type and intensity of these and related human activities will draw from a complex mix of legal, institutional, and policy frameworks.

The concepts in this chapter provide a context for the prior chapters of this report and for future policies and decisions about forest conservation and management. As described by the Montréal Process Working Group (n.d.):

> Legislation, institutional capacity, and economic arrangements, with associated policy measures at both national and subnational levels, create an enabling environment for the sustainable management of forests. Reporting against these indicators contributes to raising public and political awareness of issues affecting forests and builds support for their sustainable management.

Unlike previous chapters, the indicators for the legal, institutional, and policy frameworks are largely descriptive (Table 9.1). For example, predicting how forest-associated laws, regulations, and policies will change with any degree of certainty is not possible. This chapter describes the forest ownership patterns that have a direct impact on legal, institutional, and policy frameworks, and then summarizes salient recent developments for each indictor and the trends that will likely influence their future direction.

Key Findings

- The impact of the legal, institutional, and policy framework differs enormously between publically managed forests and those held by private owners; three-quarters of the forest land in the North is privately owned, mostly by families and individuals.
- Numerous laws, policies, and regulations affecting forest-land management have been enacted at national and State levels; Best Management Practices, which are in place across the North, are periodically reviewed and updated.
- More than 30 million acres of forest land across the North are certified under one or more forest certification systems; the future of these programs depends on the demand for certified products, the requirements imposed by the various certification programs, and the willingness of landowners to participate.
- An estimated 7.2 million acres of forests and nonforested (primarily agricultural) land are enrolled in conservation easement programs across the North; enrolled acreage has been increasing substantially and will continue to do so as long as owners see this as a viable option and organizations see value in acquiring and holding the easements.
- Of all tax policies, those governing property taxes have the greatest potential to influence the behavior of family forest owners; although all Northern States have programs that can help defer or reduce annual property taxes on forest land, the future of tax policies is unknown and will likely hinge largely on issues that are larger than forestry.
- For owners that are primarily interested in financial gain, taxes can have an important impact—tax policies are one factor that led to the shift from vertically integrated forest companies (companies that own both forest land and the mills that processed timber from that land) to real estate investment trusts and timber investment management organizations.
- To augment the private natural resource professionals across the North, numerous programs and services have been established including cost sharing; technical assistance; financial incentives; and delivery of tools, training, and publications. For example, 9 percent of the nonindustrial private forest land—land not owned by forest products companies—is managed under a management plan associated with the Forest Stewardship Program of the U.S. Forest Service. Forestry assistance programs will continue to evolve to meet changing needs and the reality of decreasing budgets, continuing the trend of prioritizing where and how limited resources are spent.
- Partnerships among various institutions and organizations have become increasingly common for addressing large-scale, complex issues; this trend is likely to continue in the future.
- Public input on strategic-level forest management decisions is common on public lands and is increasingly common on large private holdings, especially those enrolled in certification programs; a continuing push for transparency in decisionmaking will likely cause an increases in public participation.

Table 9.1—Indicators of legal, institutional, and economic framework for forest conservation and sustainable management of temperate and boreal forests under Montréal Process Criterion 7 (Montréal Process Working Group 2015).

Indicator	Rationale
7.1.a Legislation and polices supporting the sustainable management of forests	This indicator provides information on legislation and policies, including regulations and programs, which govern and guide forest management, operations, and use. Legislation and policies designed to conserve and improve forest functions and values are prerequisite to achieving the sustainable management of forests.
7.1.b Cross-sectoral policy and program coordination	This indicator provides information on the extent to which policies and programs are coordinated across sectors to support the sustainable management of forests. Nonforest sector land use and development decisions may have a significant impact on forests and their use. Cross-sector coordination of forest and nonforest related policies and programs can promote improved forest management by helping to minimize adverse impacts and by strengthening the ability of countries to respond to national and global issues.
7.2.a Taxation and other economic strategies that affect the sustainable management of forests	This indicator provides information on the economic strategies that affect the sustainable management of forests. Government policies and strategies on investment, taxation, and trade may influence both forest management and the level of long-term investment in forestry.
7.3.a Clarity and security of land and resource tenure and property rights	This indicator provides information on land, forest, and resource tenure, laws, and rights. Clear title identifies rights and responsibilities under the law with respect to land and resources, while due process ensures that these rights can be protected or disputed. Lack of clear ownership or due process may hinder the active engagement of stakeholders in the sustainable management of forests, or leave forests vulnerable to illegal or unsustainable use.
7.3.b Enforcement of laws related to forests	This indicator provides information on the extent to which forest related laws and regulations are enforced. The ability to successfully prosecute offenders is essential in combating harmful activities that may threaten forests and their sustainable management (e.g., illegal forest conversion and illegal logging).

Table 9.1 continued

Indicator	Rationale
7.4.a Programs, services, and other resources supporting the sustainable management of forests	This indicator provides information on the capacity of both government and private organizations to deliver programs and services, to maintain and develop infrastructure, and to access the financial and human resources necessary to support the sustainable management of forests.
7.4.b Development and application of research and technologies for the sustainable management of forests	This indicator provides information on the capacity to develop and incorporate new science, research, and technologies into forest management. Continuous improvement in the depth and extent of knowledge and its application will help ensure advances in the sustainable management of forests.
7.5.a Partnerships to support the sustainable management of forests	This indicator provides information on partnerships and their contribution to the sustainable management of forests. Partnerships may help create a shared purpose and are important tools in building capacity; leveraging financial, technical, and human resources; strengthening political commitment; and in developing public support to advance the sustainable management of forests.
7.5.b Public participation and conflict resolution in forest-related decisionmaking	This indicator provides information on the processes that promote public participation in forest-related decisionmaking and reduce or resolve conflict amongst forest stakeholders. Public participation in decisionmaking processes and conflict resolution efforts can lead to decisions that are widely accepted and result in better forest management.
7.5.c Monitoring, assessment, and reporting on progress toward sustainable management of forests	This indicator provides information on the capacity to monitor, assess, and report on forests. An open and transparent monitoring and reporting system that provides up-to-date and reliable forest-related information is essential for informed decisionmaking, in generating public and political awareness of issues affecting forests, and in the development of policies to underpin the sustainable management of forests.

INFLUENCE OF FOREST OWNERSHIP PATTERNS *Current Status*

The impact of the legal, institutional, and policy framework differs enormously depending on whether one is considering public or private forest lands. Expectations for lands within these two broad ownership categories are different, and often different laws and regulations apply to each. Indeed, the legal, institutional, and policy framework is a major influence on the distribution of forest land between public and private ownerships and the protection of basic private ownership rights. As discussed in Chapter 3, these ownership patterns also influence, among other patterns and processes:

- Which lands are protected from development
- Areas where timber harvesting is prohibited
- Forest parcellation and fragmentation patterns
- The location and makeup of the wildland-urban interface.

As described in Chapter 3, forest ownership patterns vary substantially across the United States (Butler 2008) and across the North (Fig. 9.1). Three-quarters (128 million acres) of forest land in the Northern United States is privately owned; families and individuals are the dominant, private ownership category (Fig. 9.2). Other private ownerships include forest products companies and other corporations, Native American tribes, and other private groups, such as conservation organizations. Of the 44 million acres of public forest land across the region, half are managed by State governments, usually within forestry, wildlife, parks, or water agencies; a third by Federal agencies, including the U.S. Forest Service, the U.S. Fish and Wildlife Service, and the U.S. National Park Service; and the remainder by county and municipal governments, often for water protection (Chapter 6) or recreation (Chapter 8).

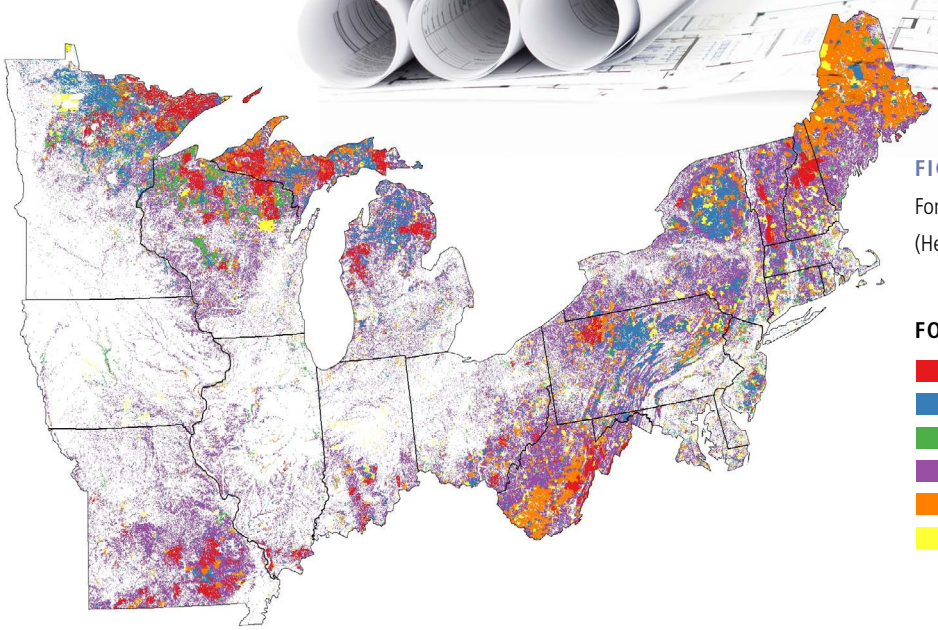


FIGURE 9.1
Forest ownership across the North (Hewes et al. 2014).

From 1977 to 2007, the net area of forest land across the North increased by 7 percent, but this increase was not evenly distributed among ownership categories (Fig. 9.3). Some States experienced net decreases in private forest land, even though total forest area increased. The largest percentage increase in forest land was for State and local governments that acquired additional forest land through purchases, donations, and other transfers.

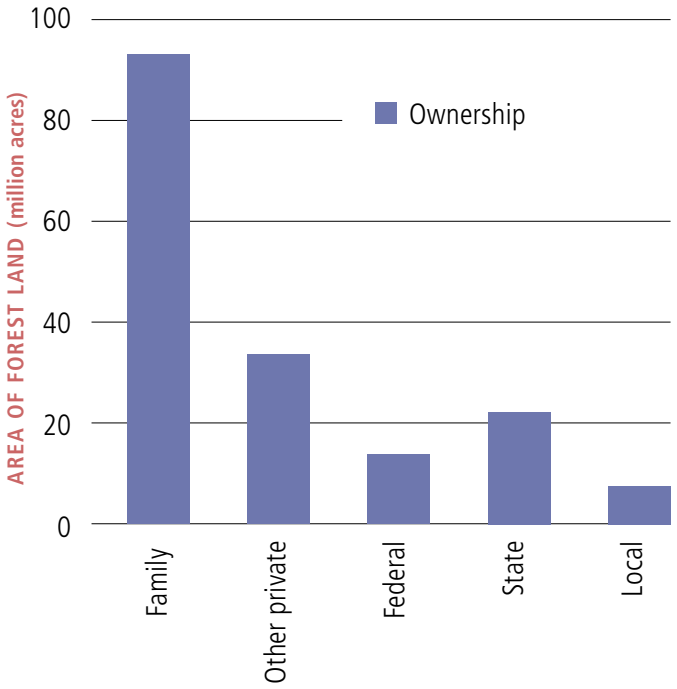
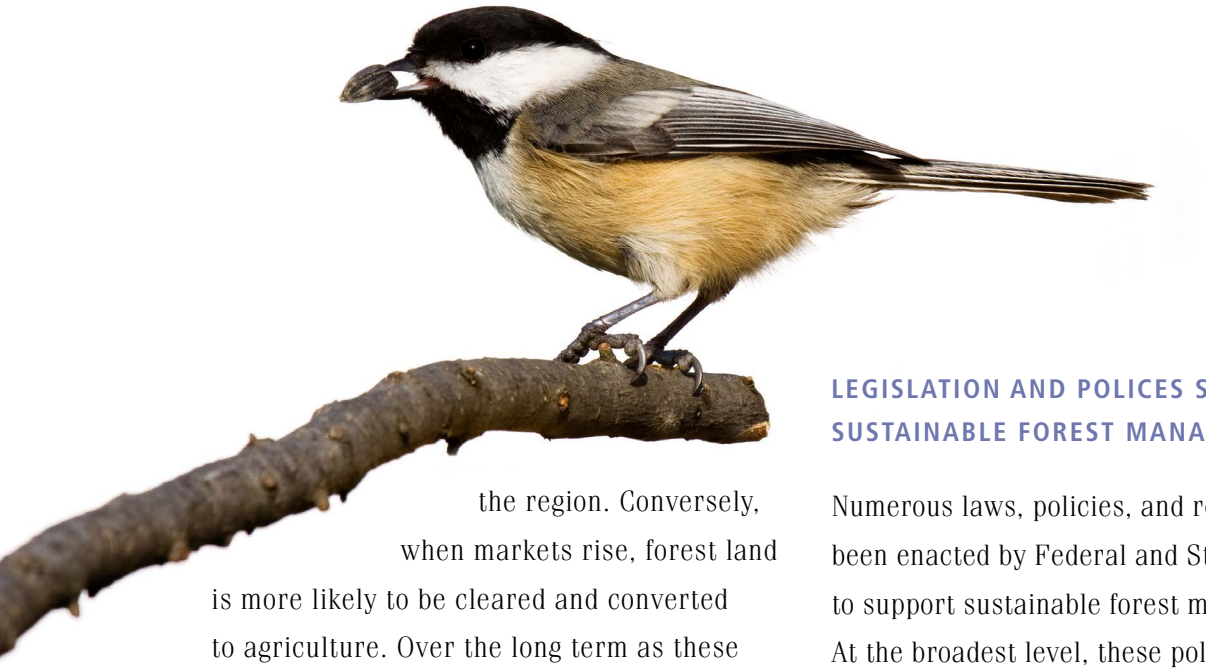


FIGURE 9.2
Forest land area by ownership category for the North, 2006 (Butler 2008).

Predicted Trends

Forest land area is projected to decrease between 2010 and 2060 (Chapters 2, 3, 4). The projection methods do not explicitly model changes in forest ownership, but they assume that future losses of forest land will be from the private rather than public ownership holdings. Indeed historical trends (Fig. 9.3), combined with pressures from development and other human activities (Mondal et al. 2013), suggest that any losses of forest acreage will be concentrated on private holdings. Divesture of public forest land has been rare, with recent trends showing increases, especially for State and local governments. An exception to the net loss in private forest land could occur in areas where continued conversion of marginal agricultural land to forest land offsets forest land lost to development (Chapter 2). The net forest gain from or loss to agricultural lands is heavily influenced by the relative prices of agricultural commodities (Alig et al. 2010). During periods when agricultural markets are depressed, unused cropland and pastureland will naturally revert to forests across most of



the region. Conversely, when markets rise, forest land is more likely to be cleared and converted to agriculture. Over the long term as these cycles occur, the specific location of forest and agriculture lands can shift even though total forest area remains relatively stable. And as the "green revolution" and other efforts have allowed more food to be produced on fewer acres, millions of acres have reverted (or been actively converted) to open space, often forest land—a primary driver of the increase in forest land observed in the United States over the past century.

LEGISLATION AND POLICES SUPPORTING THE SUSTAINABLE FOREST MANAGEMENT

Numerous laws, policies, and regulations have been enacted by Federal and State governments to support sustainable forest management. At the broadest level, these policies have influenced the distribution of forest land between public and private forest ownerships. Federal laws such as the Weeks Act have enabled governments to acquire forest land; and others, such as the National Forest Management Act, have prescribed how Federal forest holdings can be managed and used (Brown 2004, Cubbage et al. 1993). Analogous state-level laws or executive orders are in place for most, if not all, of the 20 Northern States.

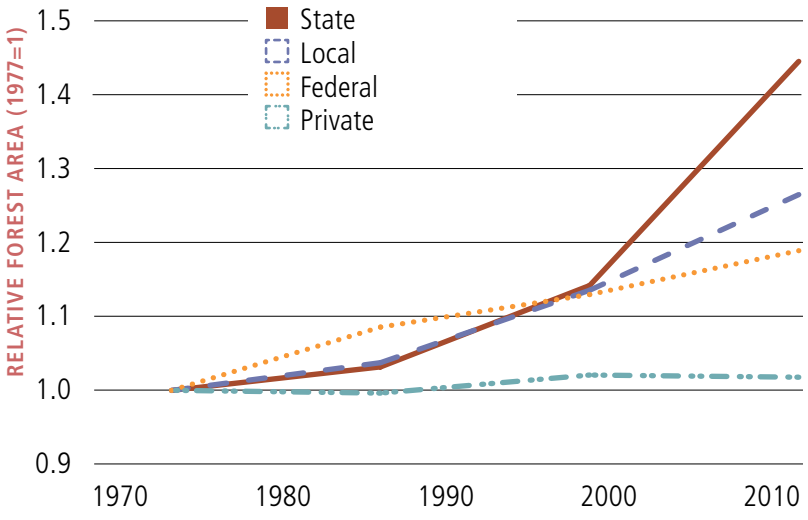


FIGURE 9.3
Relative changes in forest ownership for the North, 1977 to 2007 (Smith et al. 2009).

Current Status

Best management practices—Best management practices (BMPs) are common tools used by States to outline acceptable practices for forest operations. Many guidelines are focused on minimizing soil erosion and sustaining water quality (Chapter 6), but they can also include guidance on timber harvesting practices, forest regeneration, wildlife habitat, and aesthetic values. The specifics vary by State as to whether BMPs are voluntary or mandatory (Ellefson et al. 2001, Shifley et al. 2012). Shifley et al. (2012) summarize the general attributes of such management standards and guidelines for State and private ownerships across the region. In addition to BMPs, some States (such as Maine and Connecticut) have implemented more comprehensive forest practices laws.

Certification—Through forest certification, the private sector has initiated its own incentives for encouraging sustainable forest management. Voluntary certification programs require forest owners and managers to adhere to specific protocols intended to ensure sustainable management and to submit to periodic audits to ensure compliance. They include programs sponsored by the Forest Stewardship Council covering 27.7 million acres[1], the Sustainable Forestry Initiative covering 25.2 million acres (Sustainable Forestry Initiative, n.d.), and the American Tree Farm System covering 7.8 million acres[2] (Fig. 9.4), with some acres certified under more than one program. In addition to regulating field operations, required protocols can include long-term planning, monitoring, consideration of endangered species, mitigation of invasive species, and sustaining aesthetic and cultural resources. Participation affords forest owners assurances and recognition that they are managing sustainably as well as the opportunity to market their products as such. Research has shown that these systems are making a significant difference in how forest owners manage their land (Moore et al. 2012). Although few direct market incentives, such as price premiums for certified forest products, have been received, certification can provide access to markets that require certified wood and assurances to investors that corporations are managing sustainably.

Easements and land trusts—Conservation easements are another voluntary tool for influencing the uses of private lands. Each easement can have unique features, but in general, they are crafted to ensure that natural environments are protected from future development. The owner retains the rights to sell the land and use it within the confines of the agreement, and the easement is held by a government agency or a nongovernmental organization such as a land trust, defined as a nonprofit organization that, as all or part of its mission, actively works to conserve land by undertaking or assisting in land or conservation easement acquisitions, or by its stewardship of such lands or easements (Byers and Marchetti Ponte 2005). An estimated 902 State and local land trusts operate across the region

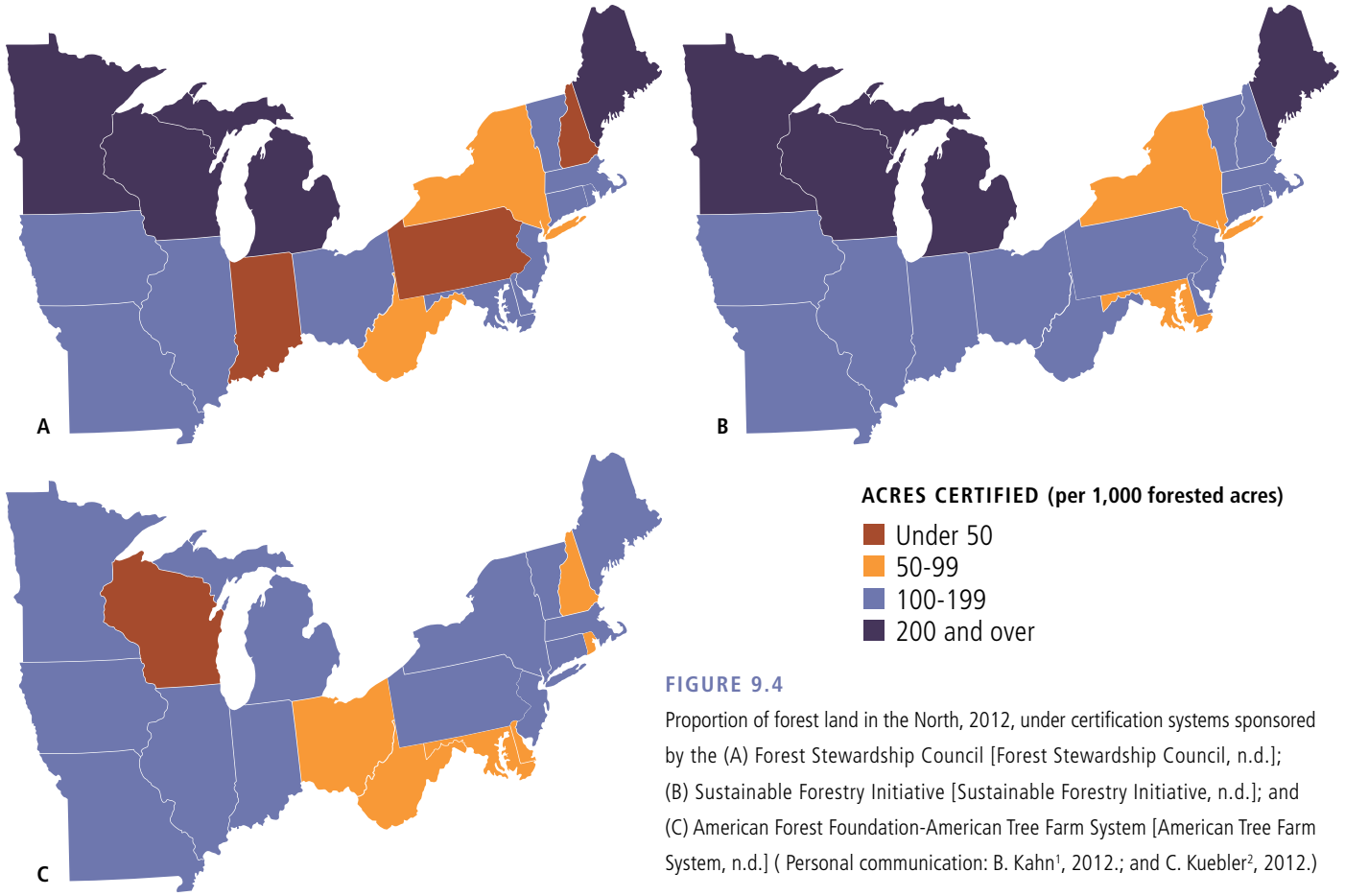
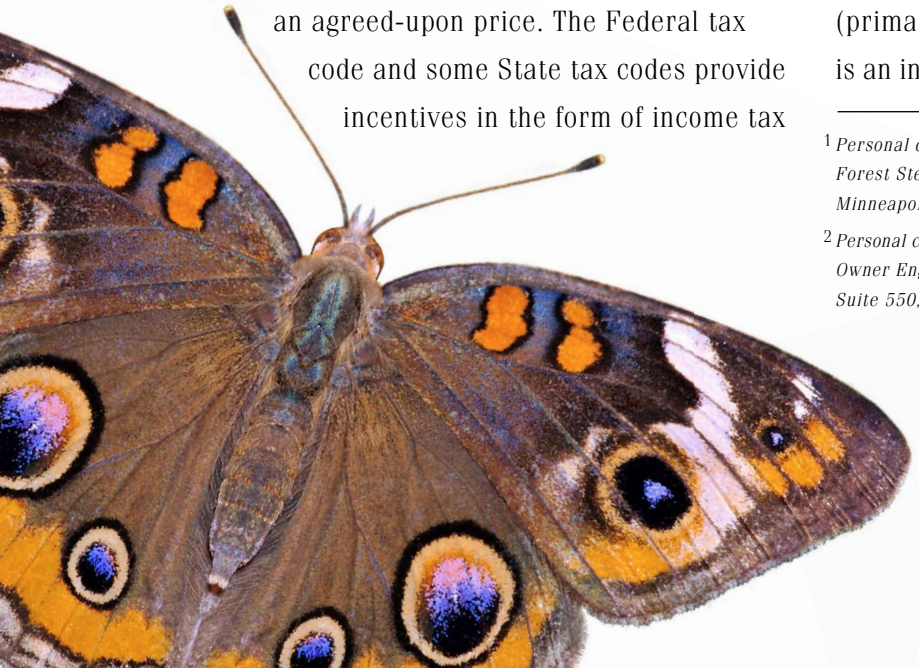


FIGURE 9.4

Proportion of forest land in the North, 2012, under certification systems sponsored by the (A) Forest Stewardship Council [Forest Stewardship Council, n.d.]; (B) Sustainable Forestry Initiative [Sustainable Forestry Initiative, n.d.]; and (C) American Forest Foundation-American Tree Farm System [American Tree Farm System, n.d.] (Personal communication: B. Kahn[1], 2012.; and C. Kuebler[2], 2012.)

(Chang 2011), each attached to a property deed and remaining effective in perpetuity, although some groups are experimenting with term easements. Owners can donate the development rights or can sell them for an agreed-upon price. The Federal tax code and some State tax codes provide incentives in the form of income tax deductions for donating conservation easements (Butler et al. 2012). Currently, thousands of conservation easements across the region cover an estimated 7.2 million acres (1.7 percent of the total area) of forests and nonforested (primarily agricultural) land (Fig. 9.5), which is an increase of 48 percent over the last decade.



[1] *Personal communication: B. Kahn. 2012. Communications Director, Forest Stewardship Council U.S. 212 Third Avenue North, Suite 445, Minneapolis, MN 55401.*

[2] *Personal communication: C. Kuebler, 2012. Senior Manager of Woodland Owner Engagement, American Forest Foundation. 2000 M Street, NW, Suite 550, Washington, D.C. 20036.*

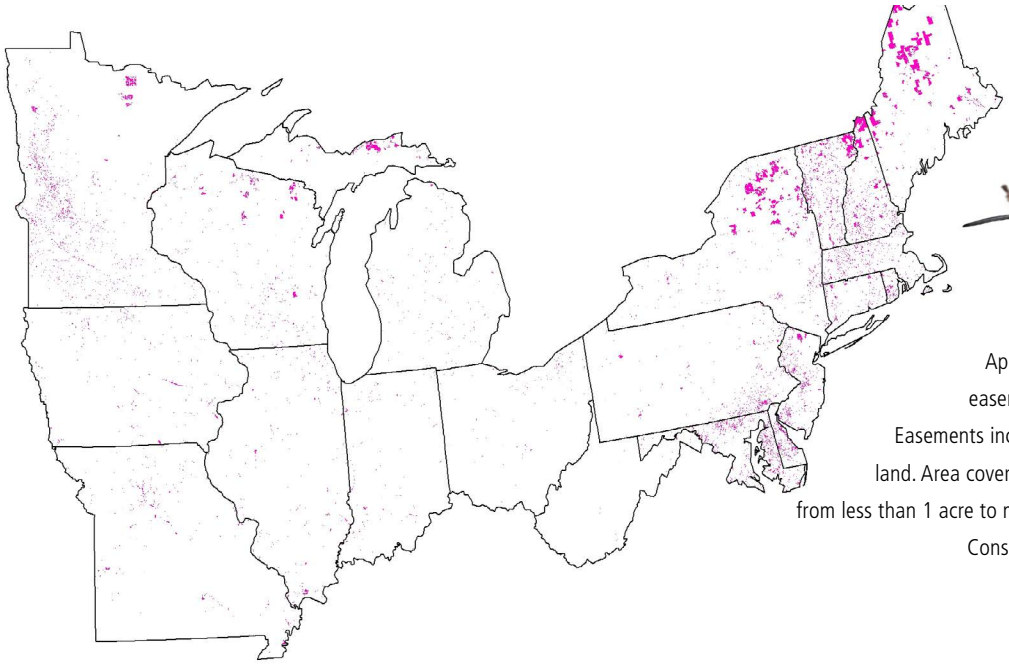


FIGURE 9.5

Approximate location of conservation easements across the U.S. North, 2012. Easements include both forests and nonforested land. Area covered by individual easements ranges from less than 1 acre to more than 100,000 acres (National Conservation Easement database, n.d.).

Through the Forest Legacy Program, the U.S. Forest Service provides funding to encourage the establishment of conservation easements (USDA FS 2013b). From 1993 (the first year of activity in the North) to 2012, a total of 458 tracts covering 1.6 million acres have been protected across the region. In addition, several state-level programs foster the establishment of conservation easements. For example, in 2008 Minnesota passed the Clean Water, Land, and Legacy amendment that added 0.375 percent to the sales tax, a third of which is dedicated to protecting, restoring, and enhancing lands and waters through conservation easements and other activities (Minnesota Legislative Coordinating Commission, n.d.).

Other government activities—Numerous laws and regulations have been enacted that hinder, intentionally or unintentionally, the implementation of forest management practices. For example, some municipalities require permits that some foresters and loggers consider overly onerous and choose to not operate in those areas. In response, some States have passed "right to practice forestry" legislation.

Predicted Trends

BMPs are subject to periodic reviews and updates. For example, many State BMPs have recently incorporated guidelines for biomass harvesting. The technical specifications in BMP guidelines and implementation strategies are influenced by professional resource managers. However, anything more stringent than voluntary BMP implementation ultimately depends on the will of the public officials and the influence exerted by their constituents.

Private sector solutions, such as certification and conservation easements, are influencing management on an increasing number of acres and are likely to continue to do so in the future. The ultimate fate of certification depends on the demand for certified products, the requirements imposed by the various certification programs, and the willingness of landowners to participate. Few, if any, price premiums have been obtained for certified wood produced in the United States to date, but certification has provided added market access (e.g., being able to supply companies that sell certified paper, certified lumber, and other products). If price premiums emerge or market access increases, certification will likely expand as well.

The acreage under conservation easements has been increasing dramatically. Assuming private owners continue to accept easements as a viable option and that organizations continue to express interest in acquiring and holding them, the area under easements will likely increase, but at what rate is unknown. Tax policies and the availability of public and private funds to purchase easements will likely influence these rates. A lack of resources to monitor the easements is a growing problem that will be exacerbated by increased area in easements, unless more is done to address this issue.

Other policies currently being debated, such as those intended to increase carbon sequestration, could have important implications for forest management (Chapter 7). Mitigation of greenhouse gas emissions through carbon sequestration is a topic of international interest (Heath et al. 2011). Programs such as the Regional Greenhouse Gas Initiative (http://www.rggi.org) or the California Climate Action Registry (http://www.climateregistry.org) provide opportunities to quantify and sell carbon sequestered in forests. Some policies allow only carbon credits from afforestation, but others include incremental carbon sequestration from existing or modified practices. Although public trading of carbon credits in the United States ceased with the shuttering of the Chicago Climate Exchange (Gronewold 2011), voluntary over-the-counter trading still occurs as private corporations hedge future policies and "green" their portfolios.

CROSS-SECTOR POLICY AND PROGRAM COORDINATION

Agricultural policies have strong links with forest policies. For example, many agricultural policies affect agricultural commodity prices, and those in turn affect the propensity of farm owners to convert forest land to agricultural land (Alig et al. 2010). The agencies that deal with forestry and agriculture are often administratively separated, thus decreasing the potential for cross-communication and increasing the potential for competition for limited resources. Likewise, many individuals and corporations working in the agriculture community operate separately from those who work in the forestry community.

Some national cost-share programs such as the Conservation Reserve Program (CRP), which supported the planting, mostly in Southern States, of 2.8 million acres of trees in the 1980s (Moulton and Hernandez 2000), are aimed explicitly at converting unproductive or erosion-prone agricultural lands to forests. Federal landowner assistance programs have gradually merged through legislation commonly known as the Farm Bill[3], the most recent being formally titled the Agriculture Reform, Food, and Jobs Act of 2012. For example, the Environmental Quality Incentives Program (EQIP), overseen by the USDA Natural Resource Conservation Service, now contains more explicit instructions for inclusion of forestry activities in cost-share assistance (USDA NRCS, n.d.). Many state-level initiatives either operate on funding from or otherwise mirror those established at the Federal level.

The current trend within governments is for increased cross-sector cooperation. Recently, the America's Great Outdoors initiative was launched to unite all areas of conservation and strengthen public engagement with natural resources (Council on Environmental Quality, n.d.), but neither this initiative, nor few, if any, government initiatives aimed at cross-sector communication, has been fully implemented.

TAXATION AND OTHER ECONOMIC STRATEGIES

Policy tools that influence forest owners include technical assistance, educational programs, financial incentives, regulations, and delivery of tools and publications (Jacobson et al. 2009). Taxation is considered one of the most effective of these tools. Property tax policies, in particular, have a high potential to influence the behavior of family forest owners (Butler et al. 2012). This is partially due to the fact that property taxes are due regardless of how much, if any, revenue is earned from a piece of land, and revenues from forest land are few and sporadic for most family forest owners.

[3] *The Agricultural Act of 2014 (H.R. 2642; Pub. L. 113-79, also known as the 2014 Farm Bill).*

Current Status

All Northern States have programs that can help defer or reduce annual property taxes for landowners with forest holdings, with estimated enrollment rates ranging from <25 percent to >75 percent of eligible owners (Butler et al. 2012). Higher enrollment rates are likely a function of higher tax savings, lower barriers to enrollment, better alignment with owners' objectives, and better dissemination of information about the programs. Conversely, further expansion of programs is inhibited by enrollment barriers (such as minimum acreage requirements) and other requirements, and the "fog of low awareness, confusion, and misinformation that enshrouds tax policies" that render the programs either nonapplicable, unpalatable, or unknown to many family forest owners (Butler et al. 2012). In addition, legislation can change program requirements, benefits, and penalties, causing further confusion for landowners and administrators.

For owners whose primary ownership objective is financial gain—not the objective of most family forest owners but a paramount objective for most businesses—taxes can have an important impact. The treatment of profits is one factor that has created dramatic changes in the forest products industry. Historically, many large companies owned both forest land and the mills that processed timber from that land (hence the term, vertically integrated companies). Beginning in the late 1980s, many companies sold their forest holdings or converted their businesses into real estate investment trusts (REITs). Many of these lands were acquired by timber investment management organizations (TIMOS; often managed on behalf of pension funds or other institutional investors) or other REITs. The advantage for such groups is that the tax burden on earnings falls to its investors rather than the investment group itself. This, combined with new ways of assigning financial value to timber assets, increased globalization, increased corporate consolidations; thus changing business strategies has created an enormous shift away from industry-owned forest land (Butler and Wear 2013).

At a broader level, government policies that affect trade with other countries can have large impacts on U.S. timber markets and consequently on U.S. forests. The Softwood Lumber Agreement of 1996 is one such example (Zhang 2001). In this ruling, the World Trade Organization determined that Canadian timber production had an unfair competitive advantage over U.S. production, and therefore imposed trade restructuring and substantial fines.

Predicted Trends

Changes to tax policies are a perennial topic for legislators, but the changes that ultimately get enacted and the consequences of those changes are notoriously difficult to predict. Future policies depend on the goals of the elected officials and the pressure placed on them by the public and special interest groups.

RESOURCE TENURE AND PROPERTY RIGHTS

There are different ways of explaining land ownership in the United States, but one useful way to view it is as a bundle of rights (Fig. 9.6), with the degree of landowner control over a specific right varying by the resource being considered (Banner 2011). For example, private owners have the right to sell their land and the right of usage according to the general laws and any easements or specific property restrictions in effect; however, wildlife, whether found on private land or on land managed by any level of government, is considered State property, and the extraction rights for belowground mineral rights are often not included with land ownership.

Current Status

In general, land ownership rights are well established across the United States and are well supported by legal precedent. Among the handful of contentious topics is eminent domain,

Marcellus Shale rig and gas well operation in Butler County, PA.; Photo by WCN24/7 via flickr.com

Gas Drilling in the Marcellus Shale

Across much of the Alleghany Plateau of Pennsylvania and nearby States—Kentucky, Ohio, and West Virginia—extraction of natural gas from shale by hydraulic fracturing, also known as "fracking," has become a topic of much debate. For many years, two basic methods were available for extracting gas: (1) the traditional method involves the drilling of a vertical shaft; and (2) in some types of rock formations, liquid under high pressure is sent down the shaft to "fracture" the rock and release additional gas—this is a technology that has been in use for a long time.

Recently a new method, hydraulic fracturing, was introduced whereby a well is drilled first vertically, after which the drill makes a 90-degree turn and continues, sometimes for a mile or more. Gas developers then fracture along the horizontal pipes.

Hydraulic fracturing can yield large quantities of natural gas but has also raised concerns about water quality (Soeder and Kappel 2009) and the impacts on forests (Drohan et al. 2012). The shale formations being drilled across the Alleghany Plateau and other areas across the North often underlie private forest land, but the ownership of this subterranean resource is separate from aboveground resources. The policies that govern this type of extraction are being debated and will have important consequences for the forests and the people of the region.

the capacity of a government to take land (with some monetary compensation provided) if the land is deemed necessary to build a highway or satisfy some other public good.

The longest enduring land ownership conflicts in the United States are related to Native Americans (Banner 2011), who used large swathes of land before European settlement but did not have a land ownership system that mirrored that of the European colonists. Either voluntarily or involuntarily, tribes left their ancestral grounds and many were relocated to distant reservations. Many of their descendants have subsequently fought to regain access to ancestral lands, a fight that continues.

FIGURE 9.6
Land ownership rights conceptualized as a bundle with different owners possibly controlling different rights for the same parcel of land (King County, n.d.).

Predicted Trends

Land tenure is fairly secure in the United States and will likely remain so for the foreseeable future. Issues related to Native American land claims are the major exception. The rights to subsurface gas, oil, and minerals are well established, but issues related to access and environmental impacts of extraction will continue to be debated.

ENFORCEMENT OF LAWS RELATED TO FORESTS

Numerous laws are in place to prevent illegal activities, such as timber theft, trespassing, illegal dumping, arson, and poaching, in forests, but enforcement is often difficult. Units within Federal and State governments are specifically tasked with enforcing forest, fish, and game laws and ensuring public safety. Most efforts focus on public lands, with enforcement of laws on private lands often falling to local law enforcement officials. Enforcement is complicated by the vast area that forests cover and the relative difficulty of either identifying individuals who break the law

or obtaining sufficient evidence for a successful prosecution. Existing laws cover a wide range of forest related problems, but enforcement can be difficult, primarily because of the vast areas that enforcement officers oversee. New technologies may help to reduce the cost of some enforcement.

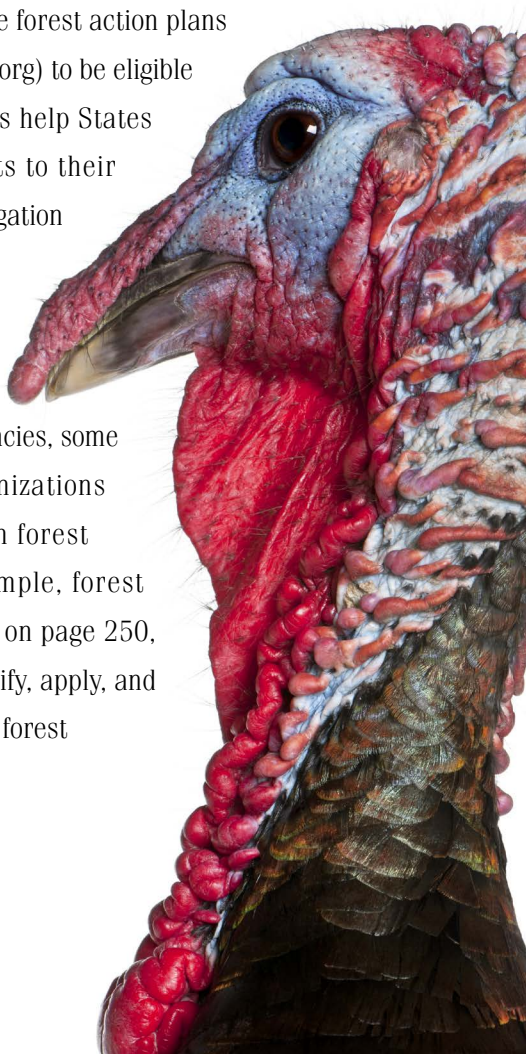
RESOURCES TO SUPPORT SUSTAINABLE FOREST MANAGEMENT

Current Status

To augment the private foresters, wildlife biologists, and other natural resource professionals, numerous public and nonprofit organizations and programs have been established in pursuit of sustainable forest management. Both publicly funded and private-sector resources are available to help forest owners and managers meet their needs and the needs of society. Public agencies offer technical assistance and financial incentives, enforce regulations, and deliver tools, training, and publications (Jacobson et al. 2009). Service foresters in many Northern States engage in one-on-one visits with private forest owners, help owners write management plans, and provide other management advice. Extension foresters implement programs to help owners, natural-resource professionals, and community leaders through workshops, master owner programs (akin to master gardener programs), and similar mechanisms. Cost sharing of management practices, such as developing management plans, planting trees, or improving timber stands, is periodically available through Federal and State programs.

The Forest Stewardship Program (Chapter 6) is an important source of U.S. Forest Service funding for many of these activities, particularly those implemented by State agencies. Although the funds can be used for various forms of landowner assistance, the cost sharing or full subsidization of forest management plans is a key component in many States. By 2011, stewardship plans were in place for 9 percent of northern nonindustrial private forest land (land not held by forest products companies), with individual State participation varying from <2 percent to nearly 30 percent of eligible forest lands (Fig. 9.7). The 2008 reauthorization of the Forest Stewardship Program required States to create forest action plans (www.forestactionplans.org) to be eligible for funding. These plans help States identify specific threats to their forests and develop mitigation strategies, including identification of priority forest landscapes.

In addition to public agencies, some nongovernmental organizations assist landowners with forest management. For example, forest certification, described on page 250, is a tool that helps identify, apply, and document sustainable forest management practices.



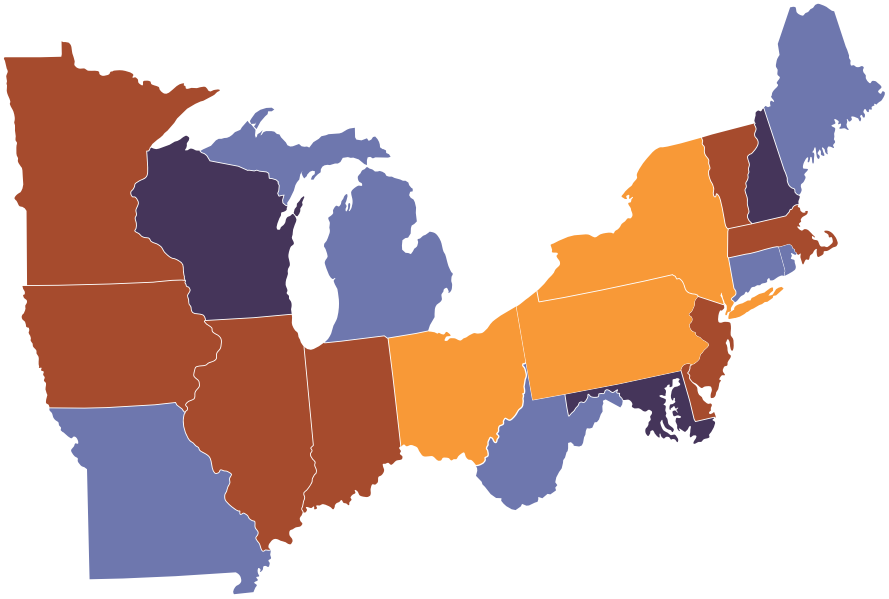


FIGURE 9.7

Proportion of nonindustrial private forest land (land not owned by forest products companies) in the North that is covered by management plans prepared with U.S. Forest Service funding in accordance with the Forest Stewardship Program (Butler et al. 2013).

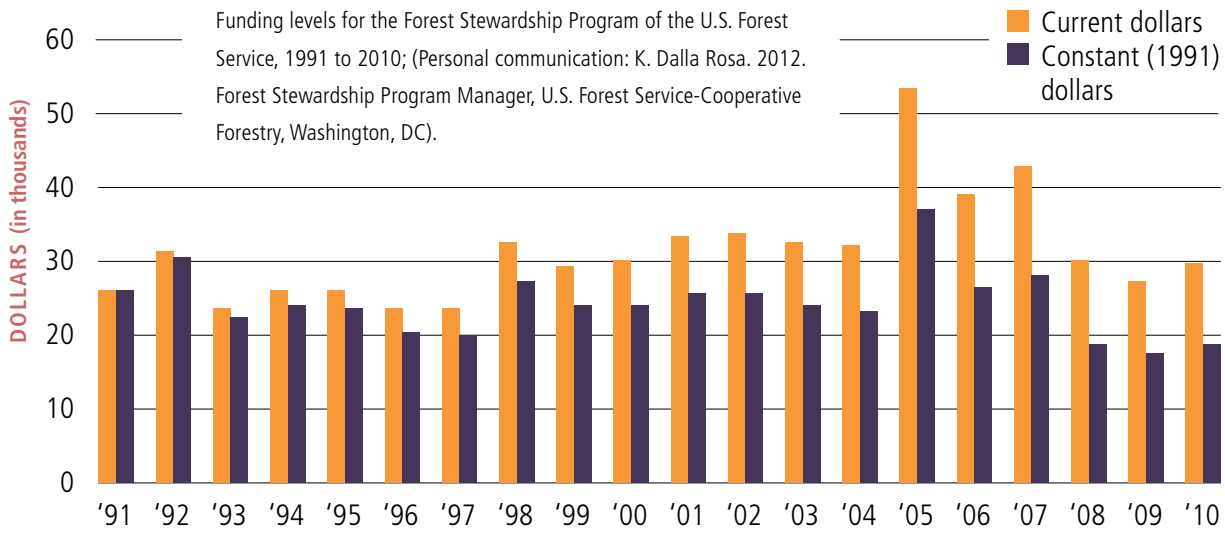
Predicted Trends

Funding levels for many public programs have been decreasing. For example, the Forest Stewardship Program, which supports many State agency activities including the writing of forest management plans, decreased 50 percent from 2005 to 2010 in terms of inflation-adjusted funding (Fig. 9.8).

Forestry assistance programs will continue to evolve to meet changing needs and the realities of budget changes. Some programs now take a more prioritized approach to place limited resources in those areas deemed to provide the greatest returns. Others are shifting the delivery of services to private providers and seeking alternatives to traditional one-on-one interactions.

FIGURE 9.8

Funding levels for the Forest Stewardship Program of the U.S. Forest Service, 1991 to 2010; (Personal communication: K. Dalla Rosa. 2012. Forest Stewardship Program Manager, U.S. Forest Service-Cooperative Forestry, Washington, DC).



RESEARCH AND TECHNOLOGIES FOR SUSTAINABLE FOREST MANAGEMENT

Research organizations throughout the North conduct studies and develop new technologies to improve sustainable management of forests throughout the region and beyond. The U.S. Forest Service, which employs the largest cadre of forest researchers in the world, has a strong presence across the region (USDA FS 2013a.) Scientists at land grant universities and other universities and colleges conduct research and train future generations of natural resource managers and scientists. Many nongovernmental organizations also employ experts to address specific natural resource issues. Traditionally, forest products companies had substantial research staffs, but with the forest land divestitures to timber management investment organizations and real estate investment trusts, many of those companies have lost their research capacities, and many of the new groups have opted to discontinue research on forest resources. Nevertheless some cooperative research programs that fund and direct private landowners and nongovernmental organizations remain intact and effective (e.g., University of Maine Cooperative Forestry Research Unit 2015).

The collective forest research budget across the region has been substantial; the average U.S. Forest Service annual research appropriation for the region has been $60 million over the past 6 years (Chapter 8). Anticipated near-term reductions in the Federal appropriations would likely diminish research capacity. Long-term, forest research funding levels in the region are unknown but would likely mirror national trends.

PARTNERSHIPS TO SUPPORT SUSTAINABLE FOREST MANAGEMENT

Current Status

Partnerships play a pivotal role in shaping and implementing the legal, institutional, and policy frameworks for sustainable forest management. Partnerships at the national level among Federal agencies and nongovernmental organizations help advance the collective forest policy agenda. Analogous partnerships at more local levels often form around specific topics or geographic locations. Some partnerships are temporary by design or circumstance, but others have proven to be long lasting.

Through partnerships, such as the Forests in the Farm Bill Coalition[4], the interests of forest owners and the forestry community are voiced. Many forestry programs are administered through collaborations among multiple groups that often include Federal and State agencies, universities, and nongovernmental organizations. For example, the Forest Stewardship Program involves funding from the Federal government that goes to State governments that in turn often contract with private consultants.

[4] *For a list of member organizations and more information on the Forests in the Farm Bill Coalition, see http://www.americanforests.org/wp-content/uploads/2012/01/fifb_coalition_web_version.pdf.*

Similarly, the North American Bird Conservation Initiative (www.nabci-us.org) brings together numerous agencies and nongovernmental organizations to identify regional activities needed to sustain diverse, viable bird populations.

Predicted Trends

As natural resource issues become more complex and oriented toward landscape-scale solutions, coordination among owners and cooperation across agencies will be increasingly important (Harper et al. 2006). A broad view of sustainable forests, as embodied in the criteria used to organize this report, requires increased reliance on effective partnerships to coalesce multiple interests as well as multiple fields of expertise to address the large-scale, long-term issues that affect forest conservation and sustainability. Because of increasingly scarce resources and other challenges mentioned throughout this chapter, cooperation among partners is more imperative than ever and is not expected to abate in the future.

The Wisconsin Driftless Network

The Wisconsin Driftless Network is an example of a group of partners coming together to address a common goal—increasing the engagement of family forest owners in forest conservation (http://mywisconsinwoods.org). The geographic focus of the partnership is an area of southwestern Wisconsin that is topographically and geologically distinct because it escaped the most recent episode of glaciation that smoothed the surrounding landscape. The partnership includes the Aldo Leopold Foundation, the American Forest Foundation, the Wisconsin Department of Natural Resources, the University of Wisconsin, the U.S. Forest Service, and others. Its approach is to develop collaborative, innovative, science-based methods that will increase the number of family forest owners who heed its conservation message and opt to participate in conservation activities. The breadth and diversity of its membership allow for coordinated outreach efforts, sharing of costs, and sharing of combined intellect. Plans are underway to document their experiences so that others can learn from what they have done.

PUBLIC PARTICIPATION AND CONFLICT RESOLUTION IN DECISIONMAKING

Current Status

The degree to which the public participates in forest-related decisionmaking depends on the policies being considered and on the ownership of land that will be affected. For most public lands, the public has many opportunities to offer input. For example, during national forest management planning, the public is encouraged to provide input, both on strategic issues and on proposed specific management activities. Day-to-day, on-the-ground decisions are typically the domain of natural resource professionals and only occasionally capture the interest of neighbors and visitors.

Some large, private forest ownerships, either by choice or by necessity (as when required by enrollment in a certification program), also interact with the general public, primarily local residents, on forest management issues. Formal public input for smaller scale private forest ownerships is uncommon, but neighbors often informally influence each other's management decisions.

Predicted Trends

The past several decades have been marked by efforts to make the decision processes of agencies more transparent and to increase public input into these processes. If this trend continues, options for public participation in forest management decisions on public lands are likely to increase. New technologies have improved communications with stakeholders. Increasingly, proposed forest plans are distributed electronically rather than as (often massive) printed documents. Maps, which are usually an integral component of forest plans, are now shared online with applications that allow readers to interactively adjust the map scale and to select and combine map layers.

On private lands, concern for ownership rights will continue to make public involvement optional. But as forest certification systems expand to encompass more acres of privately owned forest lands, increased public involvement appears likely on those lands. Right-to-practice forestry laws have been enacted across many areas to (1) recognize the benefits of forestry to the economy and ecology of the State, (2) provide protection from nuisance complaints against landowners conducting forestry operations, and (3) limit the power of local governments to enact ordinances and zoning regulations restrictive to forestry (Granskog et al. 2002). However in many places, local laws, norms, or attitudes make traditional forestry practices difficult to implement.

PROGRESS TOWARD SUSTAINABLE FOREST MANAGEMENT

Current Status

Monitoring, assessment, and reporting of progress occur at multiple scales. Nationally, regionally, and at individual State levels, the Forest Inventory and Analysis program (FIA) provides information on trends in forest resources that is valuable for strategic planning (Bechtold and Patterson 2005). FIA inventories, which have been conducted on a periodic basis since the 1930s, now provide annual updates for all Northern States. FIA data are readily available online as are tools that allow users to summarize the data for their individual situations (USDA FS 2014b). These data are reported in national and regional reports (Smith et al. 2009) and numerous FIA-produced State reports. They are also combined with other data in State forest action plans compiled by the National Association of State Foresters (http://www.forestactionplans.org); these plans provide snapshot assessments of forest resources, help identify key issues, and assist in setting forest policies and implementing management actions. Another important national monitoring effort, the Forest Health Monitoring Program of the U.S. Forest Service, facilitates the surveying and monitoring of forest pests and other threats (USDA FS, n.d.).

At a finer scale, most natural resource agencies and many large, private ownerships conduct their own monitoring, which provides information, often at the stand level, that is useful for writing specific treatment prescriptions. At present, these data cannot be easily combined nor summed to draw conclusions beyond the boundaries of the lands on which the inventories are conducted because of differences in data collection protocols and issues related to data sharing.

Predicted Trends

The fate of public inventory and analysis programs depends on funding levels and the desire of governments and the public for this information. At the national level, forest inventory and forest health monitoring have had strong support, but funding has been flat in recent years; from 2007 to 2011, the FIA budget decreased by 0.5 percent in terms of inflation-adjusted dollars (USDA FS 2014a). Among individual States, support for inventory and monitoring varies significantly. Nevertheless, unless resource decisionmaking ceases to be data driven, the need for inventory data will continue.

New and emerging technologies will continue to influence the collection, analysis, and dissemination of inventory data. Remotely sensed data are now routinely combined with field inventories to decrease the cost and increase the utility and precision of inventory and monitoring products. Online tools, such as FIA's Forest Inventory Data Online tool (USDA FS 2014b) and EVALIDator tool (Miles 2014) have increased data access and utility.

Over the past few decades, the objectives of the inventories have shifted dramatically. Initially they were focused on estimating timber volume by species and location. However, in recognition of the vast array of goods and services that forests provide—ranging from the intrinsic value of biodiversity to the role that forests play in water recharge and purification—the scope of inventoried forest characteristics has expanded and will likely continue to do so.

CONCLUSIONS

The role of the legal, institutional, and policy framework in sustainable management of the forests of the Northern United States has been important in the past and is likely to become more so in the future. Ultimately the will of the people, as expressed through politicians, nongovernmental organizations, and markets, will determine the reach of those laws, policies, and institutions. As forest policy shifts (Schelhas 2003), understanding the complex, multifaceted issues and interactions affecting the region's forests has become more important. The availability of resources will continue to be a major issue that influences all aspects of the legal, institutional, and policy framework.

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10 Urban Forests

David J. Nowak and Eric J. Greenfield

Introduction

TREES AND FORESTS are resources that significantly affect the health and well-being of people who live in urban areas where more than 80 percent of the U.S. population resides. These trees within our cities and communities provide many ecosystem services and values to both urban and rural populations. Healthy urban and rural forests are critical for sustaining quality of life for people in urban areas, but many forces could change the quantity and quality of urban trees and forests in the coming decades.

Societal and Ecological Benefits from Urban Forests

Urban forests are all of the trees and forests found in urban areas. This includes forested stands as well as trees along streets, in residential lots, and in parks. These forests provide a range of public services, in cities and beyond (Nowak and Dwyer 2007) by:

- Sequestering and storing carbon
- Removing air pollution and improving overall air quality
- Reducing air temperature
- Reducing building energy use
- Absorbing ultraviolet radiation
- Reducing runoff from precipitation and improving water quality
- Reducing noise pollution
- Improving human comfort
- Increasing property values
- Improving human physiological and psychological well-being
- Improving aesthetics
- Improving community cohesion

Although urban forests may seem to be isolated, they actually have many links to rural forests across the landscape. For example, destructive insects, diseases, and invasive species (Chapter 5) affect both urban and rural forests. Sometimes these destructive agents spread from rural forest landscapes to urban centers. At other times, people inadvertently move insects, diseases, or invasive plants to urban centers where they escape and spread into surrounding rural forests. The predicted increases in urban area that would result from increasing human populations would convert millions of acres of rural forest land (Chapters 3, 4) to urban uses. In contrast to land valuation in rural areas, the proximity of trees and people in urban areas increases the value of those trees and forests but can also increase the cost of caring for individual trees.

This chapter describes the potential changes in urban area and the consequences for forest land area and tree cover that would likely result from urban expansion over the next 50 years. To assess the potential impact of future urbanization, four indicators are analyzed: (1) change in urban area, (2) conversion of forest area to urban land, (3) change in percentage of tree cover resulting from urban-land expansion, and (4) change in percentage of tree cover in urban areas. In addition, the potential impact of insects, diseases, and invasive species in urban areas is discussed.

CHANGE IN URBAN AREA

Urban land in the conterminous United States increased from 2.5 percent of total land area in 1990 to 3.1 percent in 2000 (Table 10.1), a small percentage increase that nevertheless added 11 million acres in urban land—an area about the size of Massachusetts and New Hampshire combined (Fig. 10.1).

Key Findings

- From 1990 to 2000, urban land increased from 2.5 percent to 3.1 percent in the conterminous United States, and from 4.9 percent to 5.9 percent in the North.
- By 2050, urban land is expected to increase to 8.1 percent in the conterminous United States and to 13.7 percent in the North.
- Most of the urban expansion across the conterminous United States occurred in forests (33 percent) or agricultural land (33 percent), compared to 42 percent in agricultural land and 37 percent in forests for the North.
- Based on projected land-use changes, overall tree cover would decrease by as much as 1.6 percent in 2060 in the conterminous United States and by as much as 1.9 percent in the North.
- Projected changes in tree cover resulting from land-use change would be variable across the conterminous United States, with decreases in forested areas and increases in deserts, grasslands, and agricultural areas.
- Although U.S. urban tree cover is estimated at 35 percent, a recent study revealed that 17 out of 20 cities have recently experienced statistically significant decreases in tree cover.

Table 10.1—U.S. urban land growth estimated for 1990 to 2000 and projected for 2050 (Nowak and Walton 2005, Nowak et al. 2005).

State and region totals	State land in urban use, baseline						State land in urban use, Projected 2050		
	1990		2000		Change				
	(thousand acres)	(percent of total)	(thousand acres)	(percent of total)	(thousand acres)	(percent)	(thousand acres)	(percent of total)	Ranking based on percent
Connecticut	975	30.6	1,135	35.5	159	5.0	1,942	60.9	4
Delaware	141	10.9	195	15.0	53	4.1	512	39.5	5
Maine	202	1.0	228	1.1	26	0.1	792	3.8	37
Maryland	957	14.3	1,157	17.3	199	3.0	2,512	37.5	6
Massachusetts	1,537	29.2	1,797	34.2	261	5.0	3,206	61.0	3
New Hampshire	259	4.4	362	6.1	103	1.7	1,018	17.1	13
New Jersey	1,552	31.2	1,805	36.2	253	5.1	3,167	63.6	2
New York	2,266	7.2	2,540	8.1	274	0.9	5,824	18.5	11
Ohio	2,205	8.3	2,568	9.7	364	1.4	6,058	22.9	8
Pennsylvania	2,175	7.5	2,730	9.4	555	1.9	6,408	22.1	9
Rhode Island	213	30.2	254	35.9	41	5.7	498	70.5	1
Vermont	81	1.3	95	1.5	14	0.2	328	5.3	31
West Virginia	292	1.9	361	2.3	70	0.5	1,193	7.7	26
All Northeast States	12,854	8.2	15,225	9.7	2,370	1.5	33,457	21.2	NR
Illinois	1,939	5.4	2,304	6.4	366	1.0	5,279	14.6	17
Indiana	1,136	4.9	1,424	6.1	287	1.2	3,857	16.7	14
Iowa	468	1.3	523	1.5	55	0.2	1,780	4.9	33
Michigan	1,797	4.8	2,179	5.8	382	1.0	5,111	13.7	19
Minnesota	859	1.6	1,010	1.9	151	0.3	2,577	4.8	34
Missouri	1,006	2.3	1,168	2.6	163	0.4	3,078	6.9	29
Wisconsin	875	2.4	1,061	3.0	186	0.5	2,980	8.3	25
All North Central States	8,079	3.0	9,669	3.6	1,590	0.6	24,662	9.2	NR
All Northern States	20,934	4.9	24,894	5.9	3,960	1.0	58,119	13.7	NR

Table 10.1 continued

State and region totals	State land in urban use, baseline						State land in urban use, Projected 2050		
	1990		2000		Change				
	(thousand acres)	(percent of total)	(thousand acres)	(percent of total)	(thousand acres)	(percent)	(thousand acres)	(percent of total)	Ranking based on percent
Florida	3,093	8.3	4,018	10.8	925	2.5	10,355	27.9	7
Georgia	1,702	4.5	2,397	6.4	695	1.8	5,392	14.3	18
North Carolina	1,624	5.0	2,278	7.1	654	2.0	6,140	19.1	10
South Carolina	907	4.6	1,194	6.0	287	1.4	3,647	18.3	12
Virginia	1,253	4.8	1,522	5.9	270	1.0	3,280	12.6	20
All Southeast States	8,580	5.6	11,409	7.5	2,829	1.8	28,815	18.8	NR
Alabama	910	2.8	1,141	3.4	231	0.7	3,533	10.7	22
Arkansas	469	1.4	582	1.7	114	0.3	1,972	5.8	30
Kentucky	644	2.5	779	3.0	135	0.5	2,271	8.8	24
Louisiana	902	3.0	1,066	3.5	164	0.5	3,348	11.1	21
Mississippi	491	1.6	600	2.0	109	0.4	2,135	7.0	27
Oklahoma	648	1.4	743	1.7	96	0.2	2,123	4.7	35
Tennessee	1,198	4.4	1,558	5.8	360	1.3	4,118	15.3	15
Texas	3,704	2.2	4,575	2.7	871	0.5	11,840	7.0	28
All South Central States	8,965	2.3	11,044	2.8	2,079	0.5	31,340	7.9	NR
All Southern States	17,545	3.2	22,453	4.1	4,908	0.9	60,154	10.9	NR
Kansas	464	0.9	554	1.1	90	0.2	1,682	3.2	39
Nebraska	251	0.5	293	0.6	41	0.1	902	1.8	44
North Dakota	80	0.2	93	0.2	13	0.0	442	1.0	45
South Dakota	95	0.2	108	0.2	13	0.0	481	1.0	46
All Great Plains States	890	0.5	1,048	0.5	157	0.1	3,507	1.8	NR

Table 10.1 continued

State and region totals	State land in urban use, baseline						State land in urban use, Projected 2050		
	1990		2000		Change				
	(thousand acres)	(percent of total)	(thousand acres)	(percent of total)	(thousand acres)	(percent)	(thousand acres)	(percent of total)	Ranking based on percent
Arizona	766	1.0	1,074	1.5	308	0.4	3,702	5.1	32
Colorado	650	1.0	815	1.2	165	0.2	2,609	3.9	36
Idaho	202	0.4	261	0.5	59	0.1	982	1.8	43
Montana	142	0.2	167	0.2	25	0.0	755	0.8	47
Nevada	216	0.3	348	0.5	132	0.2	1,578	2.2	41
New Mexico	352	0.5	482	0.6	130	0.2	1,611	2.1	42
Utah	352	0.6	442	0.8	90	0.2	1,379	2.5	40
Wyoming	96	0.2	108	0.2	12	0.0	401	0.6	48
All Intermountain States	2,776	0.5	3,696	0.7	921	0.2	13,018	2.4	NR
All Rocky Mountain States	3,666	0.5	4,744	0.6	1,078	0.2	16,525	2.2	NR
Oregon	539	0.9	658	1.1	119	0.2	2,199	3.5	38
Washington	1,092	2.5	1,368	3.1	276	0.6	4,018	9.2	23
All Pacific Northwest States	1,631	1.6	2,026	1.9	395	0.4	6,216	5.8	NR
California	4,349	4.3	5,086	5.0	737	0.7	15,160	15.0	16
All Pacific Southwest States	4,349	4.3	5,086	5.0	737	0.7	15,160	15.0	NR
All Pacific Coast States	5,980	2.9	7,112	3.5	1,132	0.5	21,376	10.3	NR
48 State total[a]	48,163	2.5	59,242	3.1	11,079	0.6	156,214	8.1	NR
U.S. total[b]	48,473	2.1	59,635	2.6	11,163	0.5	N.d.	N.d.	NR

NR = no ranking

N.d. = no data

[a]*Includes Washington, D.C.*

[b]*Includes Alaska, Hawaii, and Washington, D.C.*

In the Northern United States, from 1990 to 2000, urban area increased by 4 million acres or 1.0 percent of the land area. The States with the largest percentage increase were in the Northeast: Rhode Island (urbanization subsumed 5.7 percent of the State land area), New Jersey (5.1 percent), Connecticut (5.0 percent), and Massachusetts (5.0 percent).

Nationally, States with the largest acreage increase were Florida (925,000 acres), Texas (871,000 acres), and California (737,000 acres). Of the ten U.S. States with the largest percentage increase, seven were in the Northeast, and

FIGURE 10.1
Relative change in urban land area for the (A) conterminous United States and (B) the North (Nowak et al. 2005).

three were in the Southeast. In aggregate, from 1990 to 2000, the Southeast had the largest increase in area and percent of urban land: 2.8 million acres (1.8 percent of total land area). In comparison, the Northeast States added 2.4 million acres of urban land (1.5 percent of total land area) (Table 10.1).

Based on the urban growth patterns of the 1990s, the expectation is that urban land area in the conterminous United States will increase substantially—from 3.1 percent in 2000 to 8.1 percent in 2050 (Fig. 10.2, Table 10.1). In the Northern States, urban land is expected to more than double, from 25 to 58 million acres. As discussed in Chapter 3, roughly a third of the total urban area expansion would be into forest land, but the proportion of forest land affected would vary greatly depending on geographic location.

From 2000 to 2025, the area of developed land in the United States is expected to increase by 79 percent (Alig et al. 2004). The landscape changes resulting from urbanization and other types of development will have significant impacts on land management and efforts to sustain environmental quality in urban and urbanizing areas.

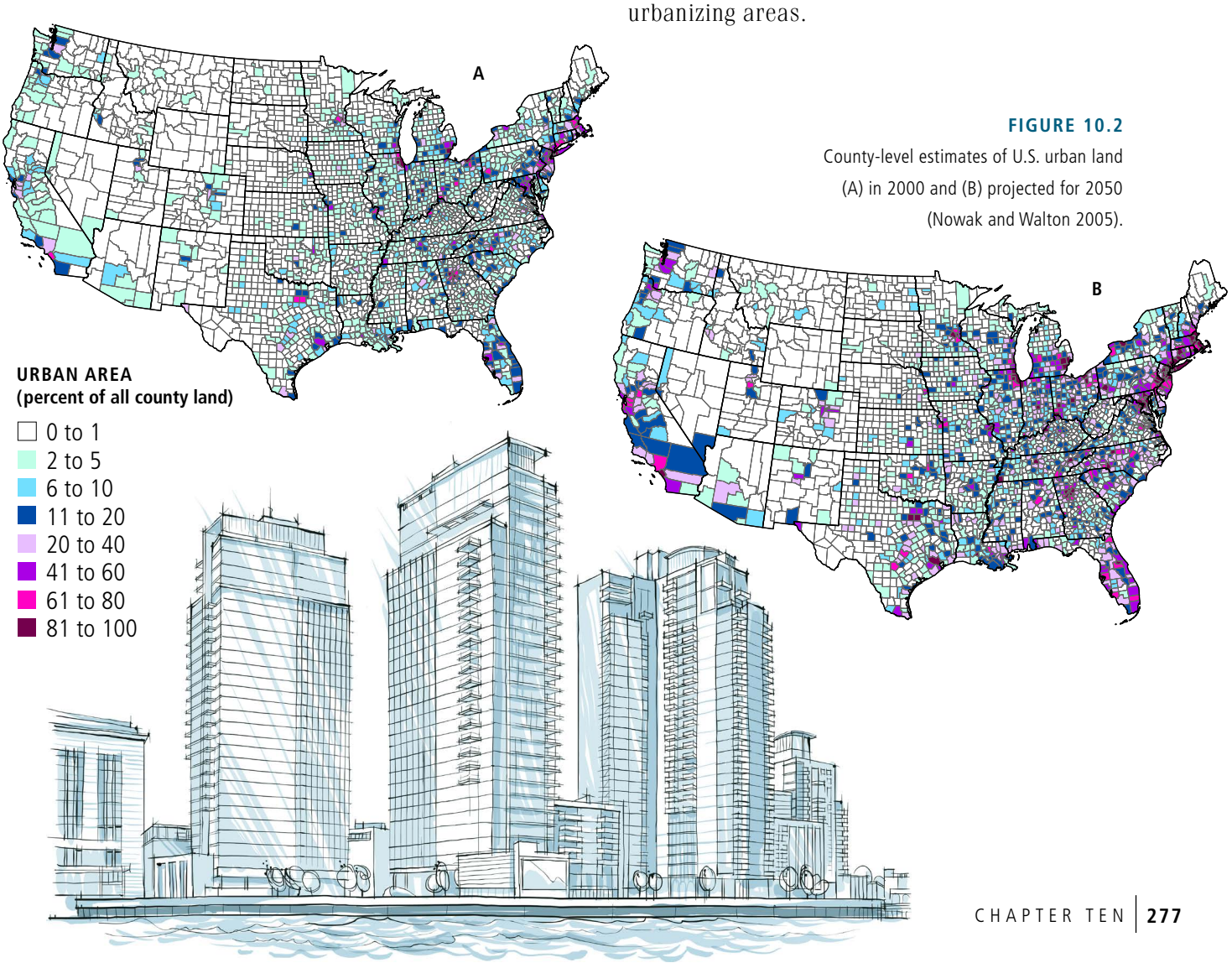


FIGURE 10.2
County-level estimates of U.S. urban land (A) in 2000 and (B) projected for 2050 (Nowak and Walton 2005).

Future urban growth patterns will be affected by population growth and other demographic shifts, changes in personal income, and other economic and socioeconomic factors (Alig et al. 2004). In the North, most urban growth is projected to occur around areas that are already heavily urbanized, with significant expansion expected along the east coast from Massachusetts to Maryland. In four States in the Northeast, more than half of the land area is projected to be urban by 2050 (Table 10.1): Rhode Island (71 percent), New Jersey (64 percent), Massachusetts (61 percent), and Connecticut (61 percent).

CONVERSION OF FOREST AREA TO URBAN LAND

Past Rates of Conversion

From 1990 to 2000, most of the urban expansion across the United States occurred in forests (33 percent of the expansion) or agricultural land (33 percent), with wide variations among States. In the Northern States (Appendix 10, Fig. 10.3), more urban expansion occurred in agricultural land (42 percent) than in forests (37 percent). The Northern States with the largest percentage of urban expansion into forests (Table 10.2) were Rhode Island (65 percent), Connecticut (64 percent), and Massachusetts (63 percent).

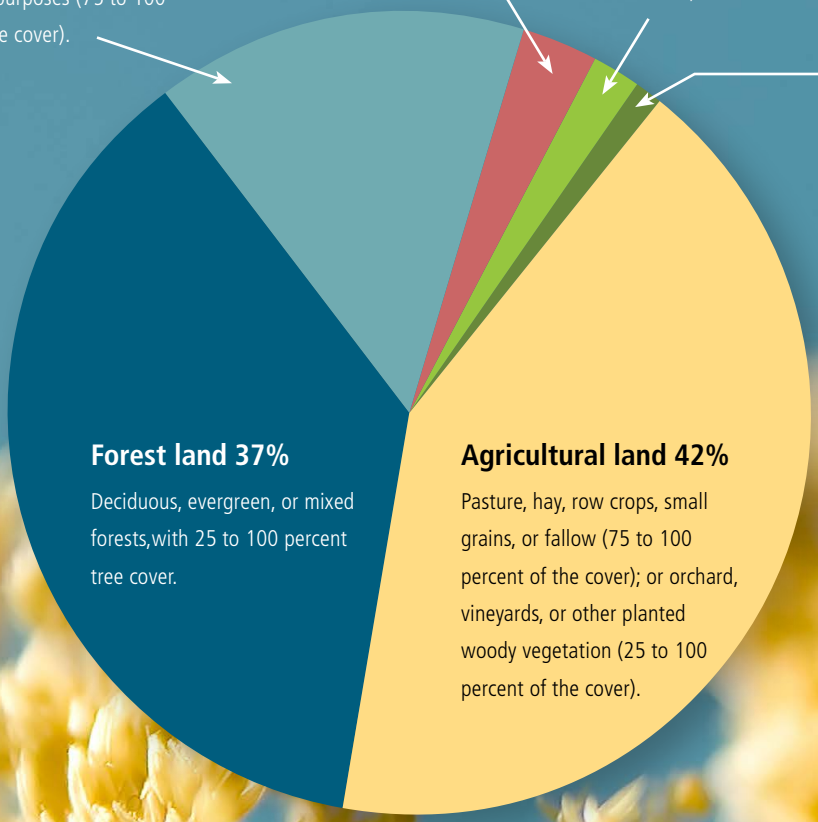
Developed versus Urban Areas

The National Resource Inventory (NRI) defines developed land as urban and built-up land and rural transportation land (USDA NRCS 2001). The developed land category includes: (1) large tracts of urban and built-up land; (2) small tracts of built-up land (<10 acres); and (3) land outside of these built-up areas that is used for roads, railroads, and associated rights-of-way (USDA NRCS 2001). NRI defines urban and built-up areas as land uses "consisting of residential, industrial, commercial, and institutional land" as well as several public infrastructure land-use categories such as railroads, landfills, and sewage treatment plants. Within NRI inventories of urban and built-up areas, highways and other transportation facilities are included if they are surrounded by urban areas (Alig et al. 2004).

Urban areas are defined as all the territory, population, and housing units that are located within either urbanized areas or urban clusters. Urban areas have a core population density of 1,000 people or more per square mile, but they also include some surrounding areas with lesser population density. As defined by the U.S. Census Bureau (2007), urbanized areas have a total population of 50,000 people or more and urban clusters have a population of 2,500 to 49,999 people.

FIGURE 10.3

Percentage of land within various land-cover categories converted to urban land in the North, 1990 to 2000 (Nowak et al. 2005).



Developed land 14.7%

Areas characterized by a high percentage (30 percent or more) of constructed materials or vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes (75 to 100 percent of the cover).

Woody wetlands 3.3%

Areas where forest or shrubland vegetation accounts for 25 to 100 percent of the cover and the soil or substrate is periodically saturated with or covered by water.

Other 1.7%

Bare, rock, sand, clay, quarries, strip mines, gravel pits, transitional areas, or shrubland (25 to 100 percent of the cover); or natural, seminatural grasslands and herbaceous plants (75 to 100 percent of the cover).

Herbaceous wetlands 1.4%

Areas where perennial herbaceous vegetation accounts for 75 to 100 percent of the cover and the soil or substrate is periodically saturated with or covered by water.

Forest land 37%

Deciduous, evergreen, or mixed forests,with 25 to 100 percent tree cover.

Agricultural land 42%

Pasture, hay, row crops, small grains, or fallow (75 to 100 percent of the cover); or orchard, vineyards, or other planted woody vegetation (25 to 100 percent of the cover).

Table 10.2—U.S. States with the greatest percentage and largest acreage of urban land expansion within various land-cover categories, 1990 to 2000 (Nowak et al. 2005, 2010).

Land-cover category	Top 5 States based on percentage gain				Top 5 States based on acreage gain			
	State	Urban land increase			State	Urban land increase		
		Area (thousand acres)	Change (percent[a])			Area (thousand acres)	Change (percent[a])
Forests	Rhode Island	26	65		Georgia	444	64
	Connecticut	102	64		North Carolina	366	56
	Georgia	444	64		Pennsylvania	237	43
	Massachusetts	164	63		Texas	184	21
	West Virginia	43	62		Florida	174	19
Agricultural areas	Nebraska	28	69		Texas	357	41
	Indiana	192	67		Pennsylvania	252	46
	Illinois	237	65		Illinois	237	65
	Wisconsin	116	62		Indiana	192	67
	Idaho	32	55		Ohio	185	51
Woody wetlands	Florida	133	14		Florida	133	14
	New Jersey	22	9		North Carolina	33	5
	Rhode Island	3	8		Georgia	28	4
	Massachusetts	16	6		Michigan	23	6
	Michigan	23	6		New Jersey	22	9
Herbaceous wetlands	Minnesota	11	7		Florida	57	6
	Maine	2	6		Minnesota	11	7
	Florida	57	6		Massachusetts	11	4
	Massachusetts	11	4		Georgia	9	1
	Delaware	2	4		Texas	8	1

[a]*Percent of total urban expansion within land-cover type.*

The Northern States with the largest total acreage of urban expansion into forests (Table 10.2) were Pennsylvania (237,000 acres) and Massachusetts (164,000 acres), States already known for their vast forests and large urban areas. In other States, urban areas expanded into other land-use types in differing proportions.

Projected Rates of Conversion

Nationwide by 2050, about 5.3 percent of forest land that is currently outside urban areas is projected to be subsumed by urban growth. This amount can be substantially higher at the individual State level, with Rhode Island (48 percent), New Jersey (40 percent), Massachusetts (37 percent), Connecticut (36 percent), and Delaware (33 percent) projected to lead all States (Fig. 10.4).

Although the Northeastern States are expected to have the highest percentage of forest land converted to urban uses, the Southern States would have more total acreage converted to urban areas (Fig. 10.5): 2.2 million acres in North Carolina, followed by 1.9 million acres in Georgia, 1.7 million acres in New York, 1.6 million acres in Pennsylvania, and 1.5 million acres in Texas. The total additional U.S. forest land projected to be subsumed by urbanization from 2000 to 2050 would be about 29 million acres, an area about the size of Pennsylvania (Fig. 10.6).

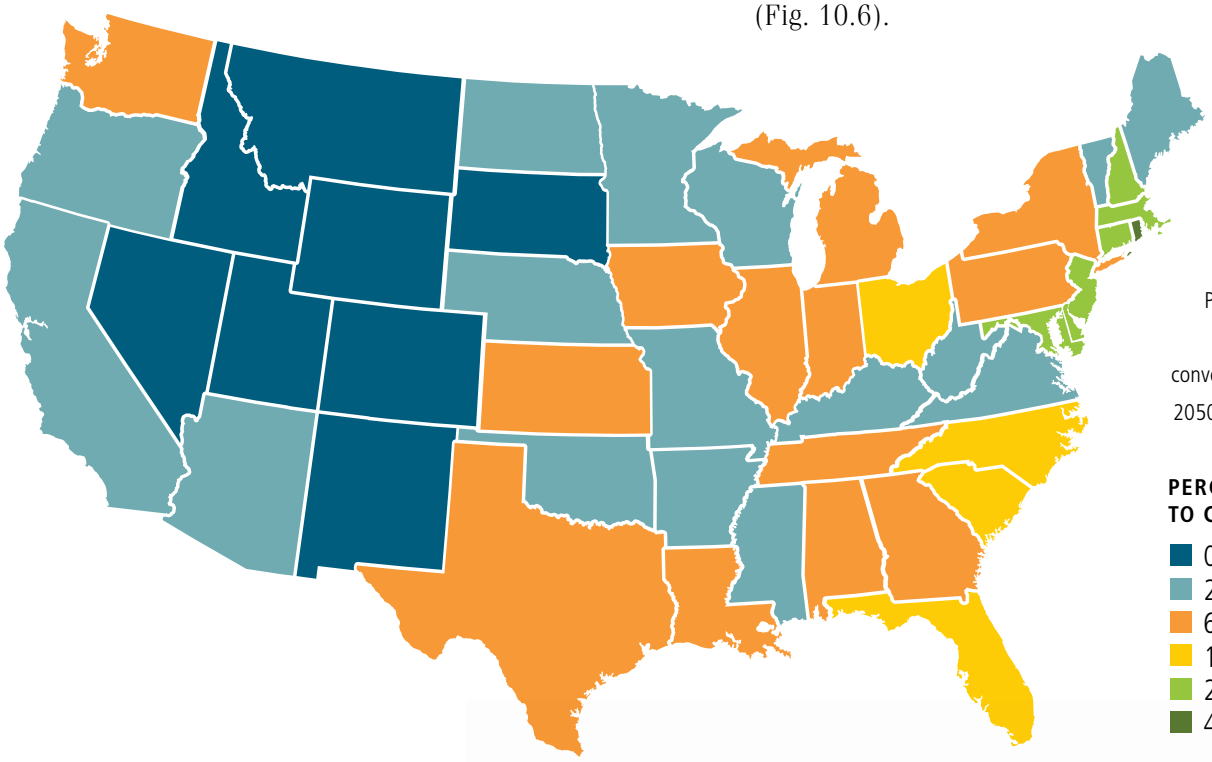


FIGURE 10.4
Percentage of U.S. non-urban forest land projected to be converted to urban land, 2000 to 2050 (Nowak and Walton 2005).

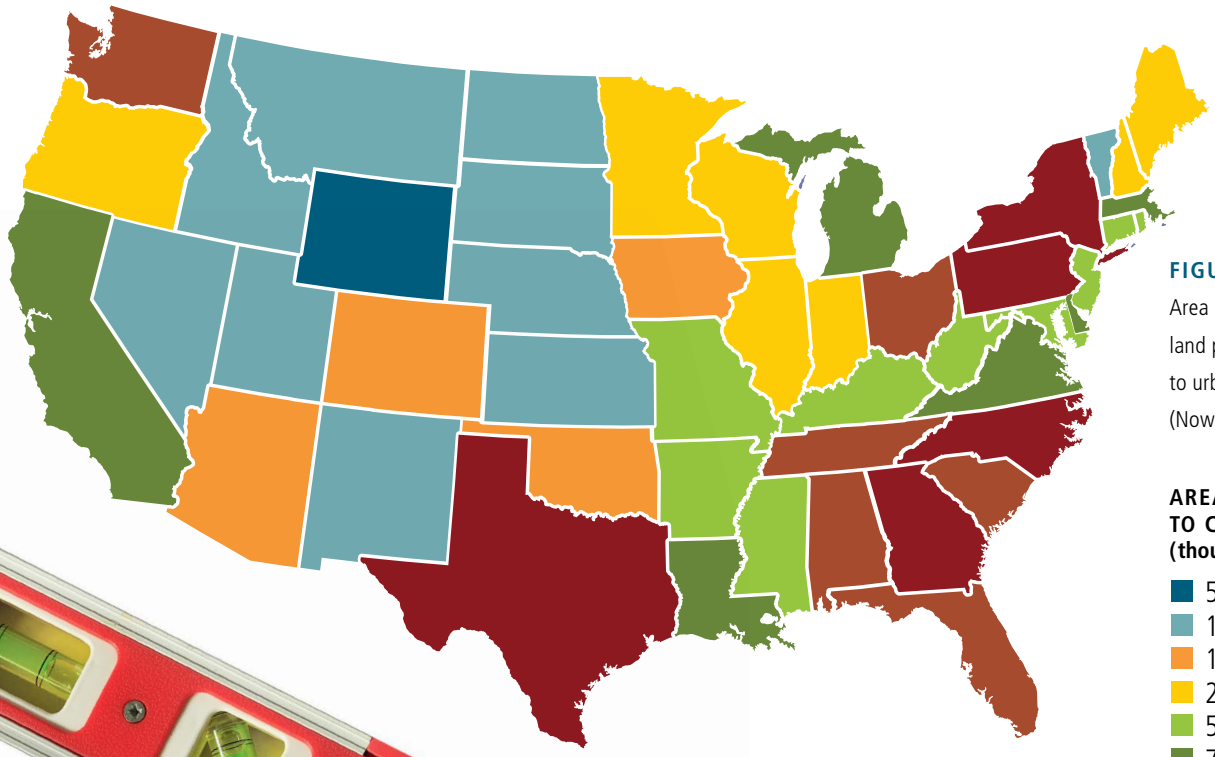
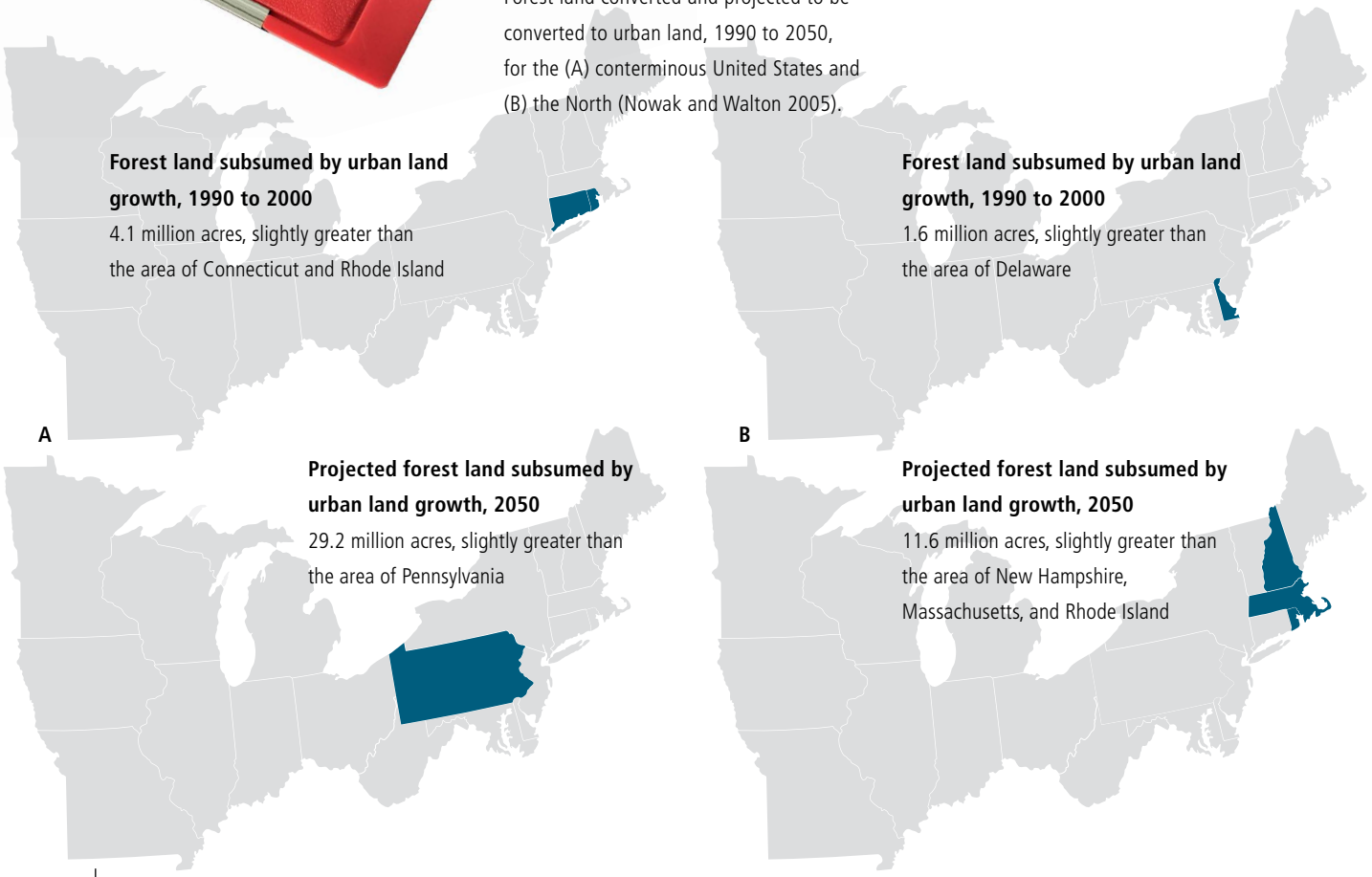


FIGURE 10.5
Area of U.S. non-urban forest land projected to be converted to urban land, 2000 to 2050 (Nowak and Walton 2005).

FIGURE 10.6
Forest land converted and projected to be converted to urban land, 1990 to 2050, for the (A) conterminous United States and (B) the North (Nowak and Walton 2005).



EFFECTS OF URBAN LAND EXPANSION ON TREE COVER

Expansion of urban land affects the tree cover in a landscape, but not always as one would imagine. For example, although expansion of urban areas into forests reduces tree cover as roads and buildings are constructed, substantial tree cover often still remains. Urban expansion into agricultural areas can increase tree cover as trees are planted in proximity to new homes or as trees naturally migrate into former agricultural fields that have not yet been developed.

Land-use change forecasts were used to estimate potential changes in tree cover for counties of the conterminous United States through 2060 (USDA FS 2012, Wear 2011). Tree cover predictions under three storylines (Fig. 10.7, Table 10.3) were developed by applying the land-use change forecasts to adjusted tree cover values in the 2001 National Land Cover Database (Nowak and Greenfield 2010) and then projecting estimated tree cover forward to 2060 (Greenfield and Nowak 2013).

FIGURE 10.7

Change in U.S. tree cover, 2000 to 2060 under three greenhouse storylines (IPCC 2007)—(A) A1B assumes moderate greenhouse gas emissions, moderate gains in population growth with large gains in income and energy consumption, but with a balanced renewable/fossil fuel portfolio; (B) A2 assumes moderate greenhouse gas emissions, large gains in population growth and energy consumption with moderate gains in income; and (C) B2 assumes low greenhouse gas emissions, moderate gains in population growth, income, and energy consumption (USDA FS 2012).

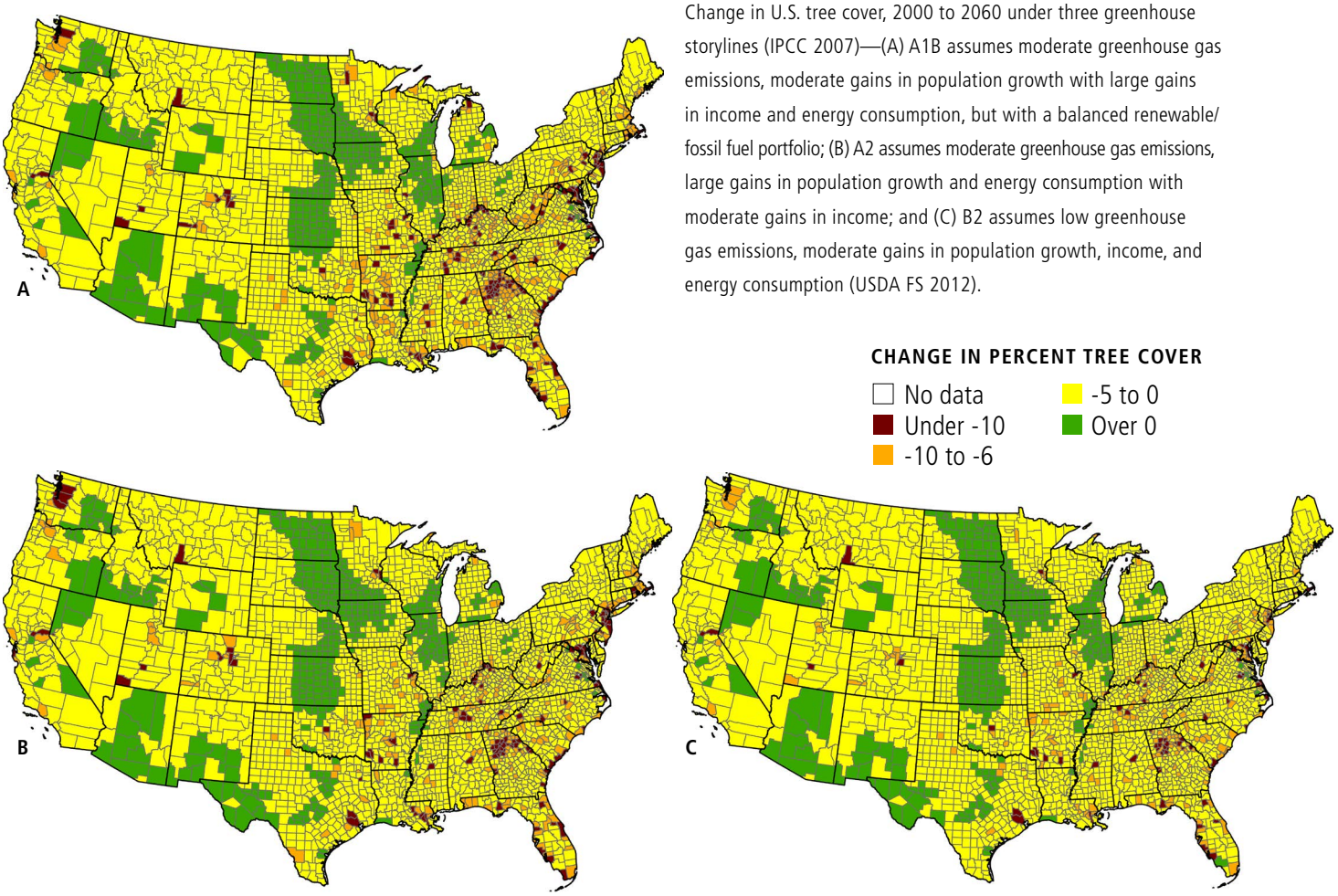


Table 10.3—Projected change in U.S. tree cover, by State, under three greenhouse gas emissions storylines (IPCC 2007), 2000 to 2060 (Greenfield and Nowak 2013, USDA FS 2012).

State and region	Storyline A1B[a]		Storyline A2[b]		Storyline B2[c]	
	Change	Relative change	Change	Relative change	Change	Relative change
	(percent[d])					
Connecticut	-2.8	-3.9	-3.3	-4.5	-1.7	-2.3
Delaware	-2.4	-5.9	-2.6	-6.4	-1.6	-4.0
Maine	-1.5	-1.7	-1.2	-1.4	-0.9	-1.0
Maryland[e]	-6.3	-12.2	-5.9	-11.6	-4.5	-8.8
Massachusetts	-4.1	-5.9	-4.4	-6.4	-2.7	-3.9
New Hampshire	-3.4	-4.0	-3.0	-3.6	-2.3	-2.7
New Jersey	-7.3	-13.1	-8.4	-15.1	-4.9	-8.8
New York	-1.4	-2.1	-1.2	-1.8	-0.8	-1.1
Ohio	-0.9	-2.3	-0.8	-2.0	-0.5	-1.3
Pennsylvania	-2.6	-4.0	-2.2	-3.4	-1.4	-2.2
Rhode Island	-9.2	-14.8	-10.0	-16.1	-5.5	-8.9
Vermont	-3.5	-4.5	-2.5	-3.2	-2.3	-3.0
West Virginia	-4.6	-5.6	-2.9	-3.6	-2.7	-3.3
All Northeast states	-2.6	-3.9	-2.2	-3.4	-1.6	-2.4
Illinois	-0.5	-3.3	-0.3	-1.9	-0.4	-2.6
Indiana	-2.4	-8.6	-1.6	-5.7	-1.4	-5.2
Iowa	-0.2	-1.5	-0.1	-0.8	-0.1	-1.1
Michigan	-1.9	-3.3	-1.6	-2.7	-1.2	-2.1
Minnesota	-1.6	-4.6	-1.3	-3.7	-1.0	-3.1
Missouri[f]	-3.0	-7.1	-2.2	-5.3	-1.9	-4.7
Wisconsin	-0.9	-1.9	-0.7	-1.5	-0.6	-1.2
All North Central States	-1.5	-4.4	-1.1	-3.3	-1.0	-2.8
All Northern States	-1.9	-4.1	-1.5	-3.3	-1.2	-2.6
Florida	-4.6	-8.5	-4.9	-9.1	-3.6	-6.7
Georgia	-6.6	-9.9	-5.1	-7.6	-4.5	-6.8
North Carolina	-3.9	-6.1	-3.3	-5.1	-2.7	-4.2
South Carolina	-4.3	-6.6	-3.7	-5.8	-2.9	-4.4
Virginia[g]	-3.1	-4.6	-2.4	-3.5	-2.2	-3.2
All Southeast States	-4.7	-7.4	-4.0	-6.4	-3.3	-5.2
Alabama	-3.2	-4.5	-2.4	-3.4	-2.0	-2.8
Arkansas	-4.7	-8.5	-3.6	-6.5	-3.2	-5.8
Kentucky	-5.0	-9.0	-3.9	-7.0	-3.1	-5.6
Louisiana	-3.0	-5.9	-2.3	-4.4	-1.9	-3.6
Mississippi	-3.0	-4.9	-2.2	-3.5	-1.9	-3.1
Oklahoma	-1.3	-4.8	-1.0	-4.0	-0.9	-3.3
Tennessee	-4.3	-7.3	-3.9	-6.5	-2.8	-4.7

Table 10.3 continued

State and region	Storyline A1B[a]		Storyline A2[b]		Storyline B2[c]	
	Change	Relative change	Change	Relative change	Change	Relative change
	(percent[d])					
Texas	-1.2	-5.4	-0.8	-3.6	-0.8	-3.8
All South Central States	-2.4	-6.1	-1.8	-4.6	-1.6	-4.0
All Southern States	-3.0	-6.6	-2.4	-5.3	-2.1	-4.5
Kansas	-0.1	-1.0	-0.1	-1.0	-0.1	-0.8
Nebraska	-0.2	-3.6	-0.1	-2.4	-0.1	-2.1
North Dakota	-0.1	-1.7	0.0	-1.5	0.0	-1.6
South Dakota	0.3	6.1	0.2	4.4	0.2	4.3
All Great Plains States	0.0	-0.3	0.0	-0.3	0.0	-0.2
Arizona	0.1	0.3	0.1	0.4	0.0	0.2
Colorado[h]	-1.7	-6.8	-1.5	-6.2	-1.2	-4.7
Idaho	-0.4	-0.9	-0.3	-0.7	-0.2	-0.5
Montana	-1.2	-4.5	-1.0	-3.6	-0.8	-3.0
Nevada	-0.4	-2.8	-0.3	-2.5	-0.3	-2.2
New Mexico	-0.2	-1.0	-0.1	-0.8	-0.1	-0.7
Utah	-1.2	-6.4	-1.2	-6.2	-0.9	-4.9
Wyoming	-0.2	-1.6	-0.2	-1.2	-0.2	-1.1
All Intermountain States	-0.7	-3.0	-0.6	-2.6	-0.5	-2.1
All Rocky Mountain States	-0.5	-2.8	-0.4	-2.4	-0.3	-2.0
Oregon	-1.0	-2.4	-1.0	-2.4	-0.7	-1.7
Washington	-1.6	-3.3	-1.7	-3.6	-1.1	-2.4
All Pacific Northwest States	-1.2	-2.8	-1.3	-2.9	-0.9	-2.0
California[i]	-1.4	-4.0	-1.5	-4.1	-1.0	-2.9
All Pacific Southwest States	-1.4	-4.0	-1.5	-4.1	-1.0	-2.9
All Pacific Coast States	-1.3	-3.3	-1.4	-3.4	-0.9	-2.4
48 State total	-1.6	-4.7	-1.3	-3.9	-1.1	-3.2

[a]*A1B-Moderate greenhouse gas emissions, moderate gains in population growth with large gains in income and energy consumption, but with a balanced renewable/fossil fuel portfolio.*

[b]*A2-High greenhouse gas emissions, large gains in population growth and energy consumption with moderate gains in income.*

[c]*B2-Low greenhouse gas emissions, moderate gains in population growth, income, and energy consumption.*

[d]*Change = percent tree cover in 2060 minus percent tree cover in 2000. Relative change = 100 X (tree cover in 2060 minus tree cover in 2000) divided by tree cover in 2000.*

[e]*Maryland analysis covers 23 of the State's 24 counties (Wear 2011).*

[f]*Missouri analysis covers 114 of the State's 115 counties (Wear 2011).*

[g]*Virginia analysis covers 97 of the State's 135 counties (Wear 2011).*

[h]*Colorado analysis covers 62 of the State's 63 counties (Wear 2011).*

[i]*California analysis covers 57 of the State's 58 counties (Wear 2011).*

The simulations were derived from demographic, macroeconomic, and climate change models and data compiled in the United States Forest Assessment System (Wear 2011). Forecasts of land-use allocations represent the competing economic values (land rents) of forests versus developed, agricultural, and other land uses as influenced by the storyline population and income dynamics. The assumptions and projection methodology for tree cover are consistent with, but separate from, those used to forecast change in forest conditions (Chapter 2).

All three projections predicted similar changes in percentage of tree cover from 2000 to 2060. Nationally, tree cover would decrease by 1.6 percent under storyline A1B, by 1.3 percent under A2, and by 1.1 percent under B2. Note that changes are expressed in absolute rather than relative terms; that is, if tree cover drops from 20 percent to 18 percent, the change would be expressed as 2-percent reduction.

With the exception of several countly-level increases in midwestern areas, tree cover is projected to decrease across all three storylines in the Northern States (Table 10.3). The largest decrease would be in Rhode Island: 5.5 percent under storyline B2, 9.2 percent under A1B, and 10.0 percent under A2. The State with the smallest decrease would be Iowa: 0.1 percent under storylines A2 and B2, and 0.2 percent under A1B.

The effects of expanding urbanization on surrounding rural land would be different for forests than for agricultural land. Tree cover would decrease in the more forested counties east of the Mississippi River and along the northwestern Pacific coast, but would increase in many agricultural, grassland, and desert counties of midwestern and western areas. Percentage tree cover tends to be greater in urban areas built on grassland, deserts, and agricultural land than in the rural areas that surround those urban areas; the opposite is true for urban areas built in counties dominated by forests (Nowak and Greenfield 2012b). The projected increases in tree cover for urban areas in counties dominated by desert, grassland, and agricultural areas are attributable to landscaping associated with urbanization. Projections of increases in these areas assume favorable conditions for sustaining tree populations; increases would not occur if necessary resources, such as water for irrigation, become scarce.

Providence, RI

CHANGE IN TREE COVER IN URBAN AREAS

Urban tree cover in the conterminous United States has been estimated at 27 percent (Dwyer et al. 2000, Nowak et al. 2001) based on Advanced Very High Resolution Radiometer data and Landsat thematic mapper data from the early 1990s (Zhu 1994). Urban tree cover tended to be greatest in urban areas that were developed in forested ecoregions (34 percent), followed by grasslands (18 percent) and deserts (9 percent). These results are consistent with earlier estimates of urban tree cover by ecoregion types (based on aerial photo interpretation of 58 U.S. cities), where tree cover averaged 31 percent in forest cities, 19 percent in grassland cities, and 10 percent in desert cities (Nowak et al. 1996). The percentage of tree cover in urban areas tends to decrease as population density increases and can vary within a city based on the distribution of land-use types and ecoregions; for example, vacant land in forested regions often supports tree cover, but vacant land in desert regions is often devoid of trees (Nowak et al. 1996, 2001; Nowak and Greenfield 2012b). Understanding the factors most associated with urban tree cover can improve projections of tree cover and inform policies that modify urban tree cover.

Based on photo-interpretation of the conterminous States from circa 2005, U.S. urban tree cover is estimated at 35 percent (Nowak and Greenfield 2012b). In the North

Table 10.4—U.S. urban tree cover, circa 2005, by State (Nowak and Greenfield 2012b).

State and region	Tree cover
	(percent of total urban area)
Connecticut	67
Delaware	38
Maine	54
Maryland	33
Massachusetts	65
New Hampshire	64
New Jersey	50
New York	41
Ohio	29
Pennsylvania	34
Rhode Island	54
Vermont	53
West Virginia	47
All Northeast states	44
Illinois	26
Indiana	22
Iowa	24
Michigan	35
Minnesota	31
Missouri	31
Wisconsin	29
All North Central States	29
All Northern States	38
Florida	35
Georgia	52
North Carolina	48
South Carolina	47
Virginia	35
All Southeast States	42
Alabama	53
Arkansas	43
Kentucky	27

Table 10.4 continued

State and region	Tree cover
	(percent of total urban area)
Louisiana	32
Mississippi	41
Oklahoma	19
Tennessee	39
Texas	32
All South Central States	35
All Southern States	39
Kansas	28
Nebraska	19
North Dakota	15
South Dakota	21
All Great Plains States	24
Arizona	16
Colorado	17
Idaho	13
Montana	9
Nevada	12
New Mexico	12
Utah	15
Wyoming	9
All Intermountain States	15
All Rocky Mountain States	17
Oregon	40
Washington	33
Alaska	38
All Pacific Northwest States	35
California	20
Hawaii	30
All Pacific Southwest States	20
All Pacific Coast States	25
48 State total	35
U.S. total	35

(Table 10.4), tree cover in urban areas is highest in Connecticut (67 percent) and Massachusetts (65 percent) and lowest in Indiana (22 percent) and Iowa (24 percent). Because of the different methods used and the limitations of the analyses, the increases in estimated urban tree cover in 2005 from previous years do not necessarily indicate a real increase or a temporal trend in urban tree cover. To measure temporal trends in city and urban tree cover more accurately, a paired-photo-interpretation was conducted in 20 U.S. cities (Nowak and Greenfield 2012a). Results revealed that urban tree cover is declining nationally by about 0.2 percent (4 million trees) per year and that eight of the nine northern cities analyzed had statistically significant declines in tree cover averaging about 0.9 percent per year (Table 10.5). Because tree cover is an indicator of the extent to which trees and forests are providing critical services to local urban residents, assessing the size of this resource and whether it is increasing or decreasing is critical. Even though tree cover seems to have declined, more data are needed to determine if this is a trend that will continue into the future.

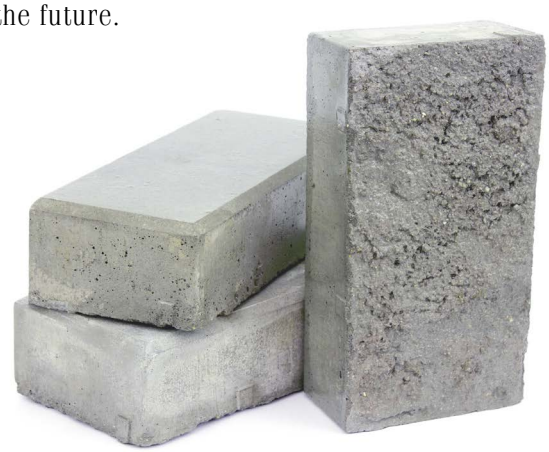


Table 10.5—Changes in tree and impervious cover change in 20 U.S. cities (Nowak and Greenfield 2012a). Values in boldface type indicate the change is statistically significant from zero at alpha=0.1.

City	Analysis period	Urban cover change for the analysis period			
		Absolute change[a]		Relative change[b]	
		Tree[c]	Impervious[d]	Tree[c]	Impervious[d]
		(percent)			
New Orleans, LA	2005 to 2009	**-9.6**	0.4	**-29.2**	0.9
Houston, TX	2004 to 2009	**-3.0**	**1.3**	**-9.8**	**3.5**
Albuquerque, NM	2006 to 2009	**-2.7**	**1.8**	**-6.6**	**5.1**
Baltimore, MD	2001 to 2005	**-1.9**	**2.1**	**-6.3**	**4.7**
Atlanta, GA	2005 to 2009	**-1.8**	**1.7**	**-3.4**	**6.5**
Miami, FL	2003 to 2009	**-1.7**	**1.0**	**-7.1**	**1.7**
Tacoma, WA	2001 to 2005	**-1.4**	**3.6**	**-5.8**	**8.9**
Kansas City, MO	2003 to 2009	**-1.2**	**2.0**	**-4.2**	**11.2**
Nashville, TN	2003 to 2008	**-1.2**	**1.1**	**-2.4**	**6.2**
New York, NY	2004 to 2009	**-1.2**	**1.4**	**-5.5**	**2.3**
Minneapolis, MN	2003 to 2008	**-1.1**	**0.8**	**-3.1**	**1.8**
Boston, MA	2003 to 2008	**-0.9**	**1.7**	**-3.2**	**3.6**
Los Angeles, CA	2005 to 2009	**-0.9**	**1.8**	**-4.2**	**3.4**
Detroit, MI	2005 to 2009	**-0.7**	**1.2**	**-3.0**	**2.6**
Portland, OR	2005 to 2009	-0.6	**1.5**	-1.9	**3.5**
Spokane, WA	2002 to 2007	-0.6	**2.0**	-2.5	**5.8**
Chicago, IL	2005 to 2009	**-0.5**	0.0	**-2.7**	0.0
Pittsburgh, PA	2004 to 2008	**-0.3**	0.0	**-0.8**	0.0
Denver, CO	2005 to 2009	**-0.3**	**1.4**	**-3.1**	**3.6**
Syracuse, NY	2003 to 2009	**1.0**	-0.5	**4.0**	-1.0
20 city average		-1.5	1.3	-5.0	3.7
18 city average[e]		-1.1	1.4	-3.8	3.9

Table 10.5 continued

City	Analysis period	Average change per year			
		Absolute change[a]		Relative change[b]	
		Tree[c]	Impervious[d]	Tree[c]	Impervious[d]
		(percent)			
New Orleans, LA	2005 to 2009	**-2.49**	0.09	**-8.27**	0.21
Houston, TX	2004 to 2009	**-0.60**	**0.26**	**-2.03**	**0.69**
Albuquerque, NM	2006 to 2009	**-0.91**	**0.60**	**-2.26**	**1.67**
Baltimore, MD	2001 to 2005	**-0.48**	**0.51**	**-1.62**	**1.16**
Atlanta, GA	2005 to 2009	**-0.46**	**0.43**	**-0.85**	**1.58**
Miami, FL	2003 to 2009	**-0.28**	**0.16**	**-1.22**	**0.27**
Tacoma, WA	2001 to 2005	**-0.36**	**0.89**	**-1.49**	**2.15**
Kansas City, MO	2003 to 2009	**-0.20**	**0.34**	**-0.71**	**1.78**
Nashville, TN	2003 to 2008	**-0.24**	**0.22**	**-0.48**	**1.21**
New York, NY	2004 to 2009	**-0.23**	**0.27**	**-1.13**	**0.45**
Minneapolis, MN	2003 to 2008	**-0.22**	**0.15**	**-0.63**	**0.35**
Boston, MA	2003 to 2008	**-0.19**	**0.35**	**-0.65**	**0.71**
Los Angeles, CA	2005 to 2009	**-0.23**	**0.45**	**-1.06**	**0.85**
Detroit, MI	2005 to 2009	**-0.18**	**0.30**	**-0.77**	**0.64**
Portland, OR	2005 to 2009	-0.15	**0.38**	-0.49	**0.87**
Spokane, WA	2002 to 2007	-0.11	**0.39**	-0.50	**1.14**
Chicago, IL	2005 to 2009	**-0.13**	0.00	**-0.69**	0.00
Pittsburgh, PA	2004 to 2008	**-0.08**	0.00	**-0.19**	0.00
Denver, CO	2005 to 2009	**-0.08**	**0.35**	**-0.78**	**0.88**
Syracuse, NY	2003 to 2009	**0.17**	-0.09	**0.65**	-0.17
20 city average		-0.37	0.30	-1.29	0.82
18 city average[e]		-0.27	0.31	-0.90	0.87

[a]*Absolute change = percent of city land in first year of analysis minus percent of city land in the last year.*

[b]*Relative percent change = absolute change (percent of city in first year minus percent of city in second year) divided by percent of city in first year.*

[c]*Tree and shrub cover includes shrub/scrub/chaparral cover in Albuquerque.*

[d]*Impervious surfaces include building, roads, and other impervious combined.*

[e]*Two cities were excluded from this average to factor out effects of losses associated with extreme disturbances: the storm damage from Hurricane Katrina in New Orleans and mortality from the emerald ash borer infestation in Detroit.*

Numerous natural and societal factors affect tree cover, both in positive and negative ways. For example, trees naturally regenerate and are planted, but they also succumb to storm damage, insects and diseases, old age, and land clearing for development. Continued monitoring of U.S. urban tree cover is needed to identify local and national changes. Because of numerous factors that can influence tree cover in cities and urban areas over the long term, the ability to predict future urban tree cover over the next 50 years is extremely limited. Nevertheless the recent, short-term trend is slightly downward.

Hartford, CT

POTENTIAL IMPACTS OF EMERALD ASH BORER AND INVASIVE TREE SPECIES

In addition to urban development and climate change, two other dominant factors will shape urban forests of the future: (1) insects and diseases, and (2) invasive tree species. Numerous insects and diseases are affecting tree health in urban areas across the United States (Chapter 5). One of the more recent and devastating insects introduced into the United States is the emerald ash borer (*Agrilus planipennis*), an exotic beetle that was discovered in southeastern Michigan near Detroit in 2002. This insect kills ash trees and has the potential to substantially alter urban forest composition in some cities in the North. The emerald ash borer is prevalent throughout much of the Northern States (USDA 2014) and may kill at least 50 percent of ash trees (*Fraxinus* spp.) within 15 years in infested areas (Krist et al. 2014). Based on field data from various northern cities collected between 1996 and 2009 (Nowak et al. 2013a), this insect could kill up to 11 percent of some city tree populations within the next 15 years, which will equate to millions of urban trees killed in northern cities (Table 10.6).

Boston, MA

Table 10.6—Estimated number of trees, percent of total tree population, percent carbon storage, and percent leaf area lost within the next 15 years due to emerald ash borer in select northern cities. All cities are within emerald ash borer infested areas except for New York (USDA 2014). For city sampling information, see Nowak et al. (2013a).

Philadelphia, PA

City	Number of trees	Tree population	Carbon storage	Leaf area
		(percent)		
Minneapolis, MN	105,900	11.0	5.1	12.4
Milwaukee, WI	286,650	9.2	5.7	6.9
Chicago, IL	201,350	6.0	4.2	5.8
Baltimore, MD	106,150	4.7	2.8	3.0
Philadelphia, PA	62,800	3.2	2.5	2.3
Morgantown, WV	15,350	2.9	0.9	1.3
Woodbridge, NJ	24,800	2.7	3.0	3.3
Boston, MA	15,550	1.3	0.9	0.5
Scranton, PA	13,000	1.3	1.4	0.9
Washington, DC	20,050	1.1	1.1	1.0
Hartford, CT	5,200	1.0	0.5	1.1
Moorestown, NJ	5,300	1.0	0.6	0.9
Freehold, NJ	450	1.0	0.4	0.4
Syracuse, NY	9,350	0.9	0.4	1.1
New York, NY	13,800	0.3	0.1	0.2
Jersey City, NJ	0	0.0	0.0	0.0

Chicago, IL

Invasive trees and shrub species (Chapter 5) also have the potential to substantially alter urban forest composition in the coming years through prolific regeneration. The invasive characteristics of some species pose problems associated with their spreading into the surrounding landscape, displacing native species and altering local ecosystems (e.g., Pimentel et al. 2000). In Syracuse, NY, only 35 percent of new trees (plantings or natural regeneration) occurring between 2001 and 2009 were native species, with 52 percent classified as invasive species (Nowak 2012). Regeneration was dominated by European buckthorn (*Rhamnus cathartica*), which tripled in population during this period (Nowak et al. 2013b). Species classified as invasive (based on State invasive species lists) can reach one-third of the total tree population in some northern cities (Table 10.7). These invasive species have and will continue to alter urban tree composition in the coming years, and thereby alter urban forest structure and ecosystem services derived from these forests.

Milwaukee, WI

Minneapolis, MN

Table 10.7—Characteristics of trees classified as invasive in select northern cities showing numbers of trees; numbers of species; and their relative proportion of the total population, carbon storage, and leaf area. For city sampling information, see Nowak et al. (2013a).

City	Number of trees	Number of tree species	Tree population	Carbon storage	Leaf area
			(percent)		
Milwaukee, WI	1,112,000	12	33.3	20.6	30.7
Syracuse, NY	326,300	5	29.8	13.9	21.4
Freehold, NJ	14,000	7	29.4	27.4	30.2
Jersey City, NJ	38,300	7	28.0	25.6	28.4
Boston, MA	267,400	5	22.6	14.6	25.5
Chicago, IL	570,400	10	16.1	17.6	14.7
New York, NY	778,600	2	15.0	9.3	10.7
Philadelphia, PA	294,300	6	13.8	10.4	12.4
Woodbridge, NJ	126,000	9	12.8	7.3	10.7
Hartford, CT	60,500	4	10.7	5.5	7.0
Moorestown, NJ	52,000	8	8.8	6.1	8.5
Baltimore, MD	178,900	4	7.2	4.1	4.8
Washington, DC	130,900	7	6.8	3.0	5.4
Minneapolis, MN	57,800	2	5.9	8.3	10.9
Scranton, PA	71,000	7	5.8	11.4	14.1
Morgantown, WV	19,500	1	3.4	1.2	1.7

CONCLUSIONS

Four trends are evident: (1) urban land is expanding at the expense of rural land, particularly forest and agricultural land; (2) urbanization will change tree cover nationally with results varying by region, with some regions gaining tree cover and others, including the Northern States, losing tree cover; (3) tree cover in urban areas has been on the decline in recent years; and (4) insects, disease, and invasive species will alter urban forest structure.

These trends indicate that urban land is subsuming rural forest land at the same time that the importance of urban trees and forests is increasing. Although urban forests will be a minor component of the forest landscape nationally, they are critical in terms of their influence on rural forests, both environmentally and politically. Many insects, invasive plants, pollutants, and human disturbances emanate from urban areas and spread into rural forests. In addition, because of their close proximity to more than 80 percent of the northern population, urban forests will directly affect the vast majority of people by influencing their perspectives, votes, and decisions about natural resources. Thus, urbanization will likely be the most dominant forest influence, and urban forests will be the most influential forest of the 21st century.

As populations and urban areas increase, urban forest benefits become more significant. From 1990 to 2000, urban land in the United States increased by 11 million acres and the urban population increased by 39 million people. Urban land is projected to almost triple in size by 2050 but will still remain a relatively small proportion of the total land area of the conterminous United States (8 percent). Northern urban land expanded by 4 million acres from 1990 to 2000, and it is projected to be 14 percent of total northern land area by 2050. The highest levels of urbanization have been and are projected to occur in Northeastern States, where much of the urban land is converted from forests and results in decreased tree cover. In the Northeast, 48 percent of the converted urban land from 1990 to 2000 came at the expense of forests. Urbanization in desert, grassland, and agricultural areas can increase tree cover relative to the surrounding landscape, but by 2060, a net decrease in tree cover for all land is predicted, ranging from 1.1 to 1.6 percent for the conterminous United States and from 1.2 to 1.9 percent for the Northern States.

Urban tree cover in the conterminous United States is currently estimated at 35 percent, with higher levels found in forested areas and lower levels found in deserts, grasslands, and agricultural areas. However, a recent study that included nine northern cities found that tree cover decreased in eight of them. Numerous natural and societal factors affect tree cover change, both positively and negatively. Continued monitoring and management of urban forests is necessary to sustain their essential benefits for current and increasing future urban populations.

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The Outlook for Northern Forests

11

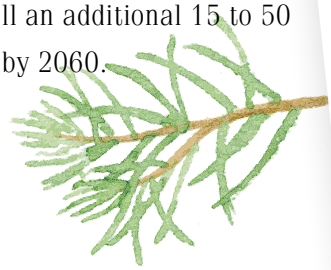
Stephen R. Shifley, W. Keith Moser, Sherri Wormstead, Francisco X. Aguilar

Introduction

THE FORESTS OF the Northern United States have been remarkably resilient to nearly four centuries of immigration and settlement with associated anthropogenic disturbances caused by farming, logging, burning, urbanization, trade, and many other factors. Although resilient, forests conditions have been significantly impacted by humans as is illustrated by the extent of forest land-use changes or the introduction of exotic, invasive species. Unquestionably, society has shaped the composition and structure of Northern Forests and will continue to do so in the future. The future holds many uncertainties, but identification of clear trends and analyses of alternative future scenarios can help managers, decisionmakers, and the public at large prioritize the most pressing challenges to sustaining healthy, resilient forests that produce a desirable blend of commodities and ecosystem services.

In many respects, northern forests are faring better than they did a century ago when widespread, exploitive logging was common. Although there are many reasons to celebrate the current conditions of northern forests, significant challenges lie ahead. This chapter focuses on the potential threats to northern forests and the opportunities that society has to shape these forests for the future. Large-scale, strategic analyses of future conditions can help focus attention on improving the resiliency, health, and diversity of northern forests, making them more economically, socially, and ecologically sustainable and able to continue supporting the quality of life for the 125 million people who live in the region now, as well an additional 15 to 50 million people expected by 2060.

Chapters 3 through 10 report details of projected forest conditions for future alternative scenarios. The material is organized using the Montréal Process Criteria and Indicators (Montréal Process Working Group, n.d.) in an effort to provide substantial breadth in the material presented and consistency with many other State, regional, and national assessments. Breadth of information, although essential, does not necessarily lead to clarity in identifying necessary management actions or policy decisions. That requires additional work by society.



ANTICIPATED CHANGES IN FORESTS AND SOCIETY

Previous chapters of this report analyzed future scenarios projected for northern forests. The scenarios were based on assumptions about changes in population, land-use patterns, public policy, demand for wood resources, and emissions of greenhouse gases and associated climate effects. The projections are not certainties, and to emphasize that point, alternative scenarios were compared. The future reality will differ from all the projections, and the further we look into the future, the more uncertainty we face from events that cannot be foreseen. Consider that 50 years ago, in the early 1960s, personal computing and cell phones were unknown, gasoline was about 30 cents a gallon, homes were commonly heated with coal, no one was concerned with greenhouse gas emissions, and the National Environmental Policy Act did not exist.

Drivers of Change

The next 50 years will be greatly affected by expected and unforeseeable changes in societies, economies, technologies, and regulations that will influence the interactions of people and forests. Populations in the United States and around the world are expected to increase, and the cumulative demand for forest products and services will accordingly grow. Despite many uncertainties, based on historical and recent tendencies, some dominant trends emerge for northern forests.

Relative to today, these projected trends and their consequent effects presented next seem fairly certain for the North over the next several decades.

More people, but a slower rate of population growth than for the United States as a whole, leading to:

- A larger proportion of people, up to 85 percent, living in urban areas
- Greater energy demand and likely more greenhouse gas emissions
- Increased fuelwood and energy consumption (even though per capita energy consumption is decreasing)
- More urban and suburban expansion into private forest land
- More forest fragmentation and parcellation, especially near urban areas
- Decreased size of private forest ownerships and increased number of owners
- Greater threat for the spread of invasive species
- A fundamental shift from the prior century-long trend of gradually increasing forest area to a trend of gradually decreasing forest area
- Fewer acres of forest per person with increased pressures on forests to provide ecosystem products and services, including recreation opportunities, diverse wildlife habitats, and watershed protection.

Increased attention to the effects of climate on forests and forests on climate, leading to:

- Increased emphasis on carbon sequestration as an ecosystem service provided by forests
- Improved methods to quantify forest carbon dynamics
- Increased emphasis on sustainable forest management though certification and other stewardship programs for private landowners
- Policy changes that reduce per capita greenhouse gas emissions, although total greenhouse gas emissions may continue to increase with increasing population
- Greater attention to managing forests for resilience to climate change impacts, including extreme weather events

Less emphasis on timber production for the majority of private forest owners and privately owned forest acres, leading to:

- Modest changes in forest tree species composition
- Increased global trade in wood products, with more reliance on imports
- Fewer jobs in the forestry, logging, wood products, and paper products industries, especially as productivity per worker increases
- Stagnant, slow, or even declining economic activity associated with wood product manufacturing, particularly in rural areas
- An aging forest resource resulting from low harvesting rates and limited capacity for private forest management
- Limited timber-derived revenues available to support proactive management goals such as increasing forest diversity and improving resilience to threats such as climate change

Forest growth and succession along with relatively low rates of management, leading to:

- Aging forests, with most forest area falling in the 60- to 100-year-old age class
- Low forest age-class diversity resulting in reduced habitat diversity for wildlife
- Fewer issues with water quality and quantity compared to other U.S. regions because of large water yields coupled with low rates of forest disturbance; localized water issues, particularly near urban areas or in watersheds with substantial loss of forest cover
- Reduced growth rate of wood volume and biomass
- Reduced net rate of carbon sequestration annually, since older forests accumulate carbon at lower rates than younger forests

Less Certain Future Outcomes

Impacts of a changing climate—Despite the broad scientific consensus that increased greenhouse gas emissions are changing the climate, uncertainty continues as to what the local and regional impacts will be on forests, wildlife, and people. Concern continues to mount about the potential for climate change—including increased frequency of extreme weather events—to cause declining forest health, increased tree mortality, decreased growth of wood, reduced output of timber and nontimber products (such as maple syrup), and loss of recreation opportunities (such as those due to loss of vibrant foliage from autumn landscapes and reduced snowpack for skiing).

How bioenergy and emerging wood-using industries will affect resource use—The North has high potential for future utilization of biomass for energy and advanced bio-based products (ranging from co-firing woody biomass with coal to cellulose nanotechnology); however, forest conditions, and social, financial, and logistical barriers have hindered large increases in wood-based energy production. Wood is a relatively low-value, widely-dispersed energy feedstock, and options for using it for energy production are unevenly distributed across the North. Electricity generation could use millions of tons of low-value wood annually, but the number of locations where electric production infrastructures coincide with economically advantageous supplies of woody biomass is limited.

Moreover, burning biomass to generate electricity is not the most efficient energy conversion path for woody biomass unless used in high efficiency systems (such as combined heat-and-power plants). In contrast, opportunities to use wood for residential and commercial heat are spatially dispersed (Song et al. 2012) and contemporary wood stove designs have energy conversion efficiencies that rival the best electric utilities (Alliance for Green Heat 2014). Residential wood heating in the United States has declined in recent years with little to no indication that consumption will grow in the future, but foreign markets could sustain local bioenergy projects as has been the case for wood pelletized and exported to Europe. The amount of woody biomass harvested for energy production or other products affects the amount of carbon retained in forests, the level of carbon emissions from competing fossil fuels, the associated quantity of roundwood harvest, and future forest age structure. The three scenarios with greatly increased woody biomass utilization for energy (A1B-BIO, A2-BIO, and B2-BIO) all predicted large reductions in forest volume by 2060.

How other factors will affect future forest conditions—Many other factors have the potential to affect the future trajectory of forest change or to be affected by future forest conditions, but the magnitude of those interactions is uncertain. Some of these uncertainties include:

- How expanding urban areas along with changes in tree cover will impact the ability for urban and community trees and fragmented forests to meet life-supporting ecosystem services of an increasing population
- How the forest products industry and forest-based rural economies will fare if rates of forest volume growth decrease as predicted; any significant changes in growth rates could accumulate to cause significant disruption in the current supply of wood resources to the industry
- How macroeconomic conditions will change and impact domestic and global demand for wood and other forest products
- How public policy changes and cumulative management decisions or indecision by millions of private forest owners will affect future forest diversity, fragmentation, and the impact of invasive species
- How attitudes and management priorities directed toward urban and rural forests will change; for example, a majority of all land area will be urban in several eastern States by 2060
- How effective public land managers and private conservation organizations, such as land trusts, will be in addressing landscape-scale conservation issues such as maintenance of forest biodiversity
- How forest certification will affect stand-scale and landscape-scale forest management practices
- How new or migrating invasive insects, diseases, and plants will affect tree composition and forest structure

Effects of Spatial and Temporal Scales on Findings

Projected (and past) forest changes are not uniform across the North. Differences among subregions and among states occur in:

- Forest area, vegetation types, and product utilization
- Forest resource policies, programs, and attention to forest-resource issues
- Spatial patterns of population density and land-use change (especially forest versus urban)

Thus, the forest resource problems anticipated for the North must be considered in the context of subregional, State, and local conditions as policy makers, landowners, and managers work to identify appropriate on-the-ground management actions. Throughout this report State-level and regional summaries are provided, because State natural resource agencies and legislatures will be at the forefront of coping with many of the potential problems and opportunities associated with northern forests. The appendices provide additional details. The Northern Forest Futures database (Miles and Wear 2015) and guide (Miles et al. 2015) (available on the DVD included with this book and available online) provide maximum flexibility to summarize projected forest conditions at State and subregional scales, for a number of scenarios, including those discussed in this report.

The natural processes of forest growth, mortality, regeneration, species succession, nutrient cycling, and water cycling are dominant forces that drive forest change. However, those processes can be greatly modified by human choices about forest land conversion, harvesting, habitat restoration, fire management, energy use, greenhouse gas emissions, forest policies, energy policies, economic policies, and more. Across large spatial scales, forests and the processes within them are subject to great inertia. Clear evidence that forests are responding to policy or management changes can take decades to become evident in State or regional statistics, simply because so many acres are involved. Nevertheless, current forest conditions in the North clearly bear the imprint of past human choices, and northern forests will gradually come to bear the imprint of future human choices.

Actions to Consider

- Strengthen people's connections to rural and urban forests
- Develop mutually beneficial partnerships among forest owners, managers, industry, and the larger society to support conservation goals
- Develop measurable state and regional goals for forest diversity and monitor progress toward achieving them
- Promote forward-looking forest management across all forest ownerships
- Estimate the types and number of forestry jobs that could be sustainably supported, now and in the future
- Work to understand the many dimensions of forest change

ACTIONS TO CONSIDER

The challenges facing northern forests are large, complicated, intertwined, and enduring. New challenges will emerge in the coming decades. The following actions (Shifley et al. 2014) are among many that will be needed to move from thoughtful consideration of the issues to on-the-ground management:

Strengthen people's connections to rural and urban forests

Forests and cities are intertwined across the northern landscape. Over time, the region is expected to become more populous and more urbanized; by 2060 urban areas will be the primary habitat for 85 percent of residents. Clearly, attention to the health and sustainability of urban trees and forests is important to human well-being. Rural forests near urban land will be heavily impacted by inevitable urban expansion. These forests provide critical ecosystem services to large numbers of people and can serve as places to foster greater appreciation for natural resources.

Nearly 12 million acres of forest land will likely be converted to urban uses by 2050. Although an enormous area, this still amounts to a loss of only about 7 percent of the region's current forest land. By 2060, rural forests will likely still cover about 40 percent of the land. Since there are already indications where urbanization will take place, it might be important to focus less on how much forest will be converted and more on how to accentuate potential benefits and mitigate undesirable consequences in the specific places where urbanization is most likely to occur.

By definition urban areas are heavily populated, but many also contain substantial tree and forest resources. Trees cover an estimated 38 percent of urban land in the North and are an essential component of human habitats. Current forest inventories separate rural forest descriptions from those for urban trees and forests, even though rural and urban forests fall along an ecological continuum that is characterized by a changing ratio of the number of trees to the number of people. Tree inventory, monitoring, and valuation methods that span the gradient from rural to urban areas could evolve with increasingly sophisticated, standardized, and informative forest resource inventory systems.

Urban forest managers have excelled in estimating the value of the ecosystem services that trees provide in terms of cooling neighborhoods, mitigating pollution, sequestering carbon, providing habitat, and contributing to overall human well-being. Valuation of those and other ecosystem services can be extended to rural forests where commodities have been the primary indicators of value. The net result would be better knowledge of the spatial distribution of the multiple values derived from rural and urban trees.

Develop mutually beneficial partnerships among forest owners, managers, industry, and the larger society to support conservation goals

Collaboration is required for planning and management to create forest landscapes that are diverse, that are resilient, and that are economically, socially, and ecologically sustainable. The long-term trends of an increasing number of forest owners coupled with decreasing forest parcel size adds to the complexity of managing for landscape-scale forest health and diversity across multiple ownerships. Large, publicly owned forest tracts with long-term management plans can serve as focal points for forest landscape management, but significant progress in landscape-scale management ultimately requires participation of private forest owners who collectively control 74 percent of the North's forest land. State forestry agencies, in cooperation with the U.S. Forest Service and other agencies, are leaders in identification of state-scale forest management priorities, but actual on-the-ground management demands the cooperation of public and private owners. Conservation easements can be effective mechanisms to coordinate management among private owners. Those instruments are well suited to implement forest management plans that will survive through ownership changes, intergenerational transfers, and parcellation. Other collaborative partnerships, such as the migratory bird joint ventures (USDI FWS 2014) and corporations that choose sustainably produced forest products or ecosystem services, are expected to continue to be highly influential in the future.

Some of the most widely applied practices used to regenerate, restore, or increase resilience in forest landscapes include monitoring and planning, writing prescriptions, harvesting, burning, planting, applying herbicides, controlling deer, and controlling invasive species. All management practices cost money and require labor to implement. Consequently, market values of forest products and services are an essential consideration in management decisions. Traditionally, the sale of forest products has been an economic engine that helped offset management costs for nontimber conservation goals. Shifting the management focus from forest products to other ecosystem services can alter the economic balance. Failure to adequately measure and monetize the value of ecosystem services can be a barrier to managing them. Forests that are valued for multiple commodities and services, such as timber, water, soil, carbon sequestration, and wildlife habitat, will be better positioned to cope with disruption in a single market (such as a housing slump) and therefore will more likely be sustainably managed and conserved over time. Effective partnering with foresters, loggers, and other woods workers will be essential to design and implement economically viable management prescriptions for ecosystem services as well as for forest products.

As a natural resource community, we are getting better at understanding how to manipulate forest ecosystems to favor a particular plant community or wildlife species. In addition, best management practices are available to guide protection of forest-associated soil and water resources during management activities.

We know much about restoring degraded habitats and adding diversity to forest landscapes. Still, the best laid plans for conservation can fail if they are not also socially acceptable and economically viable. As a natural resource community we need to ask new questions, such as:

- What configuration of forest products industries can effectively implement the on-the-ground forest management required to sustain healthy, diverse, and resilient urban and community trees and rural forested landscapes?
- What is the role that publicly owned forests should play to support timber markets in addition to nonconsumptive activities?
- What are the associated implications for economic sustainability of rural communities?
- Will society in general, and private forest land owners in particular, participate in collaborative management practices that result in desirable cumulative effects across large forest landscapes?
- How can we build stronger support for forward-looking forest management from the 5 million private forest owners and the 120 million other residents of the North that derive products and services from forests?

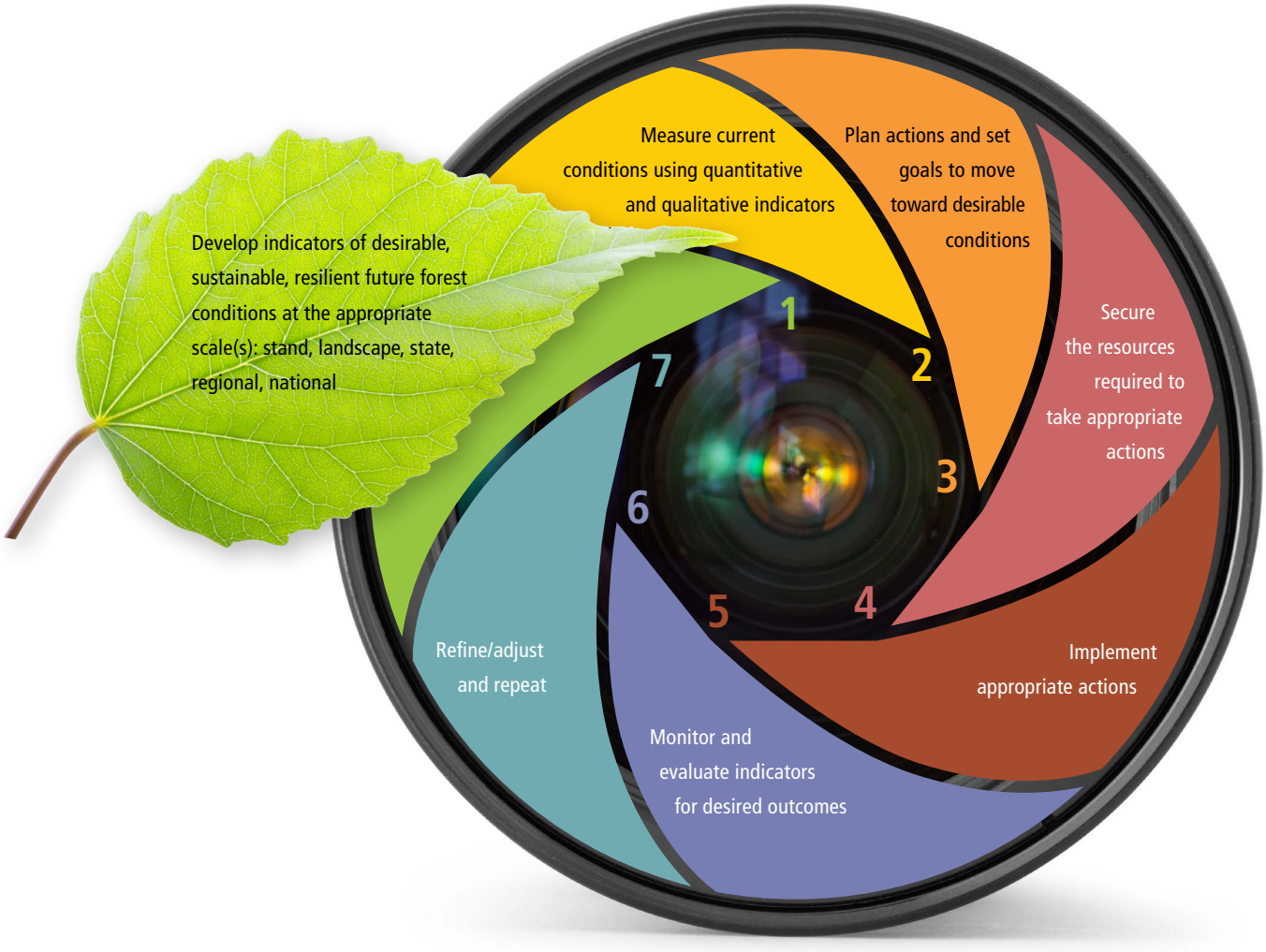
Develop measurable state and regional goals for forest diversity and monitor progress toward achieving them

Diversity of forest age classes is fundamental to sustaining resilience and long-term forest habitat diversity (Hunter and Schmiegelow 2011). Past disturbance history has resulted in low age-class diversity in northern forests with the majority of acres clustered in the 40- to 80-year age classes (Shifley et al. 2012, 2014). This is true for forest land in each State, as well as for the North as a whole. Efforts directed at increasing forest age-class diversity would increase other measures of forest diversity, expand habitat diversity for wildlife, and increase forest resiliency to undesirable consequences from stressors such as climate change and invasive species. Failure to address this issue has long-term implications for future forest diversity and resilience. Current deficits in the 10-year-old age class will eventually become deficits in the 20- and the 30-year-old age classes—creating a trend that will persist for decades. Although forests >100 years are also underrepresented in the North, the proportion of area in this age class would increase as existing forests mature if current disturbance regimes continue. Many other indicators of forest diversity are important, but forest age-class diversity is a simple indicator that provides a good starting point for discussions about increasing all aspects of forest diversity and resiliency. Forest age class diversity is typically evaluated at the scale of tens of thousands or even millions of acres. Making changes at those scales requires shared goals across multiple ownerships.

Promote forward-looking forest management across all ownerships

As is true for much of the United States, active forest management is a low priority among northern private forest owners, and management intensity is low on much—but not all—of the public land. Northern forests face significant challenges over the next 50 years: climate change, invasive species, decreasing diversity, decreasing productivity, decreasing area, and increased demands for commodities and ecosystem services. Some, like the infestation of emerald ash borer (*Agrilus planipennis*), present an immediate crisis; others, including declining diversity and species responses to climate change, build gradually but often inexorably.

The processes for dealing with future forest resource issues, individually or collectively, in forest ecosystems usually follow the same pattern (see diagram below):



This is forest management, plain and simple. The details of how to tailor management activities to achieve a desired outcome acre-by-acre may be complex and will certainly differ from place to place, but management procedures can generally be designed to avert or reduce the undesirable consequences of multiple stressors. Often, the limitation will not be a lack of understanding about which prescriptions will be successful in the woods, but rather the challenges of developing societal consensus and finding practical ways to invest in the selected treatments, monitor the outcomes, and repeat as needed. Many of the major stressors that will affect northern forests over the next 50 years—climate change, introduction of invasive species through global trade, and population growth—are largely outside the control of the natural resource community, but managing northern forests to be sustainable, productive, and resilient in the face of whatever comes along is squarely within the influence of the region's forest owners and the broader natural resource community.

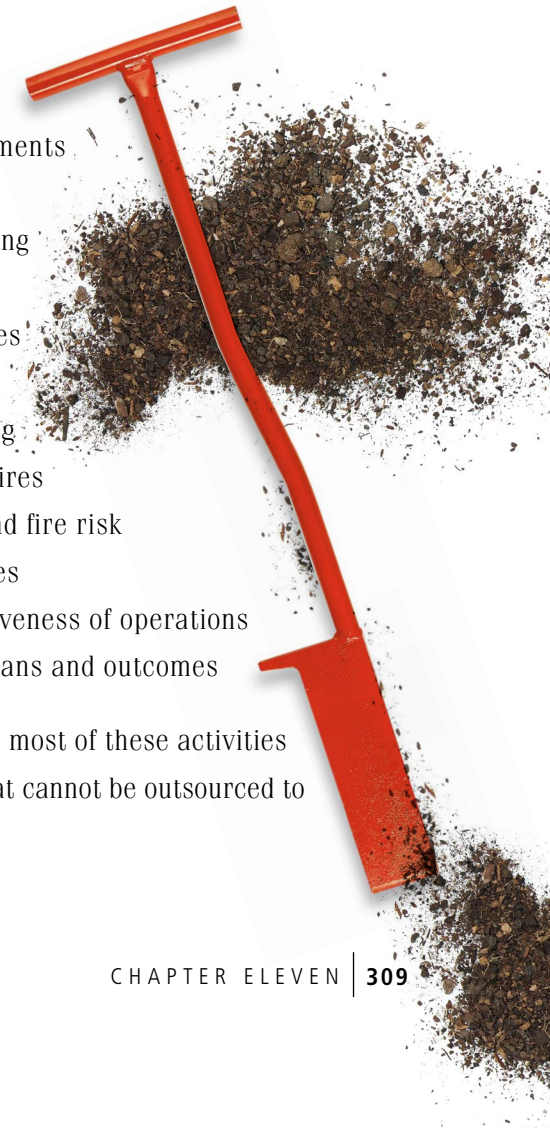
Estimate the types and number of forestry jobs that can be sustainably supported, now and in the future

The number of jobs has been decreasing steadily in the traditional fields of forestry and logging, wood products production, and pulp and paper production—in part caused by higher production efficiency of the remaining employees, either through technological enhancements or higher skilled workers—but the nature of woods work is also changing, as attention increasingly shifts to management of ecosystem services (including the provision of wildlife habitat), certification of sustainable timber production, and urban-tree management.

Despite centuries of timber harvesting in northern forests, there is a lack of understanding about the number of new jobs that would be supported for every additional 10 million cubic feet of timber that is sold and processed. Even less is known about the capacity of other rural and urban forest management activities to create jobs and generate economic activity. For example, how many people with what skills would be required for restoring and maintaining each additional 10,000 acres of woodland, or for managing the latest invasive species? The types of work activities would likely include:

- Planning
- Inventorying
- Prescribing treatments
- Planting
- Cutting and thinning
- Pruning
- Applying herbicides and pesticides
- Prescribed burning
- Suppressing wildfires
- Managing fuels and fire risk
- Managing invasives
- Monitoring effectiveness of operations
- Communicating plans and outcomes

By their very nature, most of these activities support local jobs that cannot be outsourced to other locations.



The forest products industry and public land management agencies in the northern region appear to be undergoing a period of realignment. Despite two decades of increased emphasis on landscape-scale conservation and decreased emphasis on timber production from public lands, the demand for raw materials and processing capacities of local forest products companies does not always align with the vegetation manipulation prescribed by forest managers. Woodland restoration is a case in point. Early stages of restoration can require harvesting of many small-diameter, virtually unmarketable trees, thereby creating an overwhelming management expense. In addition, repeated prescribed burning is used to encourage vegetation diversity but can degrade the quality of merchantable timber that could otherwise be sold to traditional timber markets. The forest management community is extremely adept at prescribing on-the-ground activities required to bring a stand or a landscape to a desired future condition, but less adept at forecasting the related implications in terms of jobs and economic activity.

Work to understand the many dimensions of forest change

Following the general outline of the Montreal Process Criteria and Indicators in this report forced a broad examination of the current conditions and expected changes for many elements of northern forests: biodiversity; productivity; health; soil and water resources; biomass and carbon; socioeconomic benefits; legal and institutional frameworks for sustainable management; and urban forest resources.

Our comprehensive format for reporting and discussing results provides a broad base for thinking about future forest conditions. Moreover, the modeling described in this report specifically addresses potential impacts of a changing climate. Given the broad consensus that climate will change in the North, the scenarios we examined were designed to capture the potential effects of those changes on northern forests in a way that complements past research conducted by U.S. Forest Service researchers and partners (e.g., Iverson et al. 2008, Prasad et al. 2007, Vose et al. 2012) and summarized by the Northern Institute of Applied Climate Science (USDA FS 2012).

One of the surprising results of the scenario analyses is the similarity of the projected forest outcomes for the three storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007) to estimate climate change associated with relatively low (B2), medium (A1B) or high (A2) greenhouse gas emissions. Differences were found to be modest until at least 2040 among the scenarios that continued with current rates of harvest, and there was no evidence that over this period the effects of climate change would overwhelm the changes resulting from forest aging, species succession, harvest, and land-use conversion. However, results from the scenarios assuming large increases in the amount of woody biomass that could be needed to satisfy increased demand for bioenergy (A1B-BIO, A2-BIO, and B2-BIO) confirmed that human influence through harvesting could substantially alter the trajectory of forest change in future decades.

Climate change will affect forest diversity, health, and ecosystem services in the North, but so will forest aging, species succession, logging, weather, fire, insects, disease, invasive plants, land-use change, recreation use, and management actions or inaction. Successful forest management requires society to consider which of these forces are most influential in the short-run and which are the most amenable to manipulation in pursuit of long-term, large-scale forest conservation objectives. We will learn more about climate effects on forests in the coming years and more about management practices necessary to increase resiliency and reduce unwanted consequences. Climate change appears to be a factor that will complicate—rather than dominate—change in northern forests over the next 50 years.

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Glossary

A1B storyline—a set of assumptions developed by the Intergovernmental Panel on Climate Change describing a future of robust growth: greenhouse gas emissions (medium); population growth (medium); gross domestic product increase (high); energy consumption growth (high, but with a balanced renewable/fossil fuel portfolio); loss of forest land (high); greenhouse gas emissions (medium); and pace of energy technology developments (fast); among other characteristics. See Chapter 2 for details.

A1B-BIO scenario—the combination of the assumptions from (1) the A1B storyline with (2) a general circulation model estimating future climate conditions based on expected greenhouse gas emissions for the A1B storyline, and (3) projected increasing harvest level based on a relatively high rate of woody biomass utilization for energy production. See Chapter 2 for details.

A1B-C scenario—the combination of the assumptions from (1) the A1B storyline with (2) a general circulation model estimating future climate conditions based on expected greenhouse gas emissions for the A1B storyline, and (3) projected future harvest rates that are a continuation of harvest rates observed for the prior 5 years. See Chapter 2 for details.

A2 storyline—a set of assumptions developed by the Intergovernmental Panel on Climate Change describing a future of asymmetric growth: greenhouse gas emissions (high); population growth (high), gross domestic product increase (moderate), energy consumption growth (high), loss of forest land (moderate), greenhouse gas emissions (high), and pace of energy technology developments (slow), among other characteristics. See Chapter 2 for details.

A2-BIO scenario—the combination of the assumptions from (1) the A2 storyline with (2) a general circulation model estimating future climate conditions based on expected greenhouse gas emissions for the A2 storyline, and (3) projected increasing harvest level based on a relatively moderate rate of woody biomass utilization for energy production. See Chapter 2 for details.

A2-C scenario—the combination of the assumptions from (1) the A2 storyline with (2) a general circulation model estimating future climate conditions based on expected greenhouse gas emissions for the A2 storyline, and (3) projected future harvest rates that are a continuation of harvest rates observed for the prior 5 years. See Chapter 2 for details.

A2-EAB scenario—a variation of the A2-C scenario that also models the death of all ash trees within the expanding zone of projected emerald ash borer infestation over time. See Chapter 2 for details.

activity day—a day that an individual (or a collective group of individuals) participates for any period of time in a particular recreational activity. This metric is commonly used to measure recreational activities. Multiple recreation activities (such as hiking, photographing nature, and fishing) can be recorded for one person on the same day.

afforestation—planting trees to establish a forest in an area where the prior land use was not forest (as in planting trees on former agricultural land).

annual growth—the average annual net increase in the volume of trees during the period between surveys. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year, and minus the net volume of trees that became cull trees.

B2 storyline—a set of assumptions developed by the Intergovernmental Panel on Climate Change describing a future of moderate growth: greenhouse gas emissions (low); population growth (medium), gross domestic product increase (medium), energy consumption growth (medium), loss of forest land (low), greenhouse gas emissions (low), and pace of energy technology developments (moderate), among other characteristics. See Chapter 2 for details.

B2-BIO scenario—the combination of the assumptions from (a) the B2 storyline with (b) a general circulation model estimating future climate conditions based on expected greenhouse gas emissions for the B2 storyline, and (c) projected increasing harvest level based on a relatively low rate of woody biomass utilization for energy production. See Chapter 2 for details.

B2-C scenario—the combination of the assumptions from (1) the B2 storyline with (2) a general circulation model estimating future climate conditions based on expected greenhouse gas emissions for the B2 storyline, and (3) projected future harvest rates that are a continuation of harvest rates observed for the prior 5 years. See Chapter 2 for details.

biomass—the weight of organic matter in a tree, stand, or forest. Biomass is commonly categorized into live or dead material and into bole, branch, bark, or root components. Weight can be reported in green tons (field weight at harvest) or dry tons (the oven-dry equivalent biomass). For a given sample, the green weight can be as much as twice the corresponding dry weight.

carbon emissions—quantity (typically tons or metric tons) of carbon emitted to the atmosphere from combustion of fuels, decomposition of organic matter, and other processes; often expressed as quantity of carbon dioxide (CO_2) with the mass of oxygen molecules included and sometimes expressed as carbon dioxide equivalent (CO_2e) where the quantity of greenhouse gasses other than carbon dioxide (for example methane) are included in the total by converting those gasses to the amount of carbon dioxide expected to have a comparable greenhouse effect.

carbon sequestration (in forests)—the quantity of carbon, or carbon dioxide (CO_2) equivalent, held in plant tissues and soils in a forest ecosystem. The amount of sequestered carbon is often estimated by components (including live trees, dead trees, aboveground tree parts, belowground tree parts, soil, or forest floor).

challenge recreation activities—physically challenging recreation such as caving, mountain climbing, and rock climbing. These activities are often associated with affluent young adults.

chlorosis—abnormal reduction or loss of the normal green coloration of leaves, typically caused by iron deficiency in lime-rich soils, by disease, or by lack of light.

climate change—long-term trends or fluctuations in temperature, precipitation, wind, and other climate variables. In contemporary usage, the term often is used to indicate changes and fluctuations associated with increased atmospheric carbon dioxide and other greenhouse gasses (Helms 1998).

community land—places that have geopolitical boundaries (such as cities, towns, or unincorporated named places) that may include all, some, or no urban land within their boundaries.

composite products—wood products composed of a resin matrix in combination with a wood fiber reinforcement. Composite wood pertains to, but is not limited to, particleboard, plywood, medium-density fiberboard, composite veneer, and oriented strandboard.

cull tree—a tree ≥5 inches d.b.h. that is unmerchantable as a saw log because it is rotten, poorly formed, or of an undesirable species.

d.b.h.—tree diameter at breast height; tree diameter at breast height measured as inches of tree diameter at a height of 4.5 feet above ground level.

d.o.b.—tree diameter outside the bark measured at a specified height (other than d.b.h.), often used to indicate the upper (or small) diameter of a merchantable tree bole.

early successional forest habitat—a young forest (typically no more than 10 years old) that has regenerated following a large disturbance (such as a regeneration harvest) or by planting or natural succession on other open land.

ecological region—see ecoregion.

econometric model—a statistical or mathematical model used to describe or predict economic quantities or relationships.

ecoregion—a contiguous geographic area with relatively uniform macroclimate, altitude, predominant natural vegetation, or other features that influence ecosystem function. Ecoregions can be split into finer divisions or aggregated into coarser categories based on macroclimate, landform, geology, hydrology, native vegetation, or other factors that affect plants and animals (Bailey 1995).

ecosystem services—the benefits that people derive from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth. Ecosystems provide food, clothes, fuels, and many of the commodities used to manufacture the products used in daily life. Ecosystems also purify and store water, help clean air, regulate climate, provide protection from natural hazards such as hurricanes, pollinate crops, and regulate pests. They can process and detoxify wastes, provide places to play and reflect, and contribute to a person's cultural, inspirational, and intellectual well-being by providing a sense of place.

edge—the transition between forest and nonforest land, between mature forest and young forest, or between two other contrasting forest conditions.

employees (number of)—all the full-time and part-time employees who are on the payrolls of establishments and worked or received pay for any part of a pay period that includes the 12th of March, June, September, or December. Included are employees on paid sick leave, paid holidays, and paid vacations; not included are proprietors and partners of unincorporated businesses. Employment data for prior years represent the average number of production workers for the payroll periods that include the 12th of March, May, August, and November. The "all employees" number is the average number of production workers plus the number of other employees in mid-March.

epicormic branching—branches growing from a previously dormant bud on the trunk or a limb of a tree.

family forest owners—families, individuals, trusts, estates, family partnerships, and other unincorporated groups of individuals that own forest land. This group is a subset of nonindustrial private forest owners.

FIA—see Forest Inventory and Analysis.

forest associated birds, mammals, and vascular plants—birds, mammals, and vascular plants that normally spend part of their lives in a forest habitat.

Forest Inventory and Analysis (FIA)—the U.S. Forest Service research and development group charged with conducting and reporting inventories of forest vegetation, soils, health, and product outputs.

forest land—land ≥120 feet wide and 1 acre in area with ≥10 percent cover (or equivalent stocking) by live trees of any size; includes land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between forests and nonforest lands that have ≥10 percent cover and forest areas adjacent to urban and built-up lands. Roadside, streamside, and shelterbelt strips of trees must have a crown width of ≥120 feet and continuous length of ≥363 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest land if they are <120 feet wide or 1 acre in area. Tree-covered areas in agricultural production settings, such as fruit orchards, or tree-covered areas in urban settings, such as city parks, are not considered forest land.

forest stand—a contiguous group of trees of similar age structure and size structure. In the North, stands are typically 5 to 40 acres in extent.

forest stewardship plan—a forest management plan that addresses the management objectives of the forest owner while maintaining the forest in a healthy condition for future generations.

forest type—a classification of forest land based on the tree species that presently form the plurality of live tree stocking, for example, the white oak (*Quercus alba*) forest type or the red pine (*Pinus resinosa*) forest type.

forest-type group—a combination of forest types that share closely associated species or site requirements and generally are combined for brevity of reporting, for example the oak-hickory (*Quercus* spp. – *Carya* spp.) forest-type group or the white-red-jack pine (*Pinus strobus – Pinus resinosa – Pinus banksiana*) forest-type group.

fragmentation (forest)—the process of breaking up contiguous forest cover into various nonforest land uses.

fuelwood—wood used for conversion to some form of energy.

GCM—see general circulation model.

general circulation model (GCM)—numerical models that represent the physical processes in the atmosphere, oceans, and land surface and have been applied to predict and map climate response to increased greenhouse gas emissions. The numerous GCMs are competing hypotheses about how climate will change in response to increased greenhouse gas emissions.

global circulation model—see general circulation model (GCM).

greenhouse gas (GHG) emissions—atmospheric emission of carbon dioxide (CO_2) and other gasses known to trap heat in the atmosphere.

growing stock—a classification of the timber inventory that excludes cull trees and includes live trees of commercial species meeting specified standards of quality or vigor. When associated with volume, growing stock includes only trees ≥5.0 inches d.b.h.

habitat restoration—returning forest species composition, size structure, or ecosystem processes to a desired range of conditions, typically conditions with increased diversity and/or resilience. In some cases the desired state may be representative of a former period of time (for example before European settlement).

hardwood—trees belonging to the botanical group Angiospermae. These broad-leaved trees typically drop their leaves in autumn. Examples include oaks (*Quercus* spp.), maples (*Acer* spp.), elms (*Ulmus* spp.), cottonwood (*Populus* spp.), quaking aspen (*Populus tremuloides*), and birch (*Betula* spp.). Although the wood of hardwoods physically ranges from hard or soft, it is usually hard compared to the wood of softwoods.

indicator—qualitative or quantitative variable that functions as a signal to relay complex ecological information in a simple and useful manner. Effective indicator variables must be indicative of a larger ecological process, easily measured, cost effective, and repeatable.

instar—a phase between two periods of molting in the development of an insect larva or other invertebrate animal.

integrated harvesting—a logging operation that combines harvesting of small-diameter trees for energy production with harvesting of large-diameter trees for pulping and milling.

Intergovernmental Panel on Climate Change (IPCC)—the international body established in 1988 by the United Nations Environment Programme and the World Meteorological Organization (WMO) and charged with providing a clear scientific view on the current state of knowledge about climate change and its potential environmental and socioeconomic impacts (http://www.ipcc.ch/ [accessed August 19, 2014]).

interior—locations within mature forest cover that are removed by some minimum distance (such as 50 yards) from a forest edge.

invasive plants and animals—see invasive species.

invasive species—a species whose introduction causes, or is likely to cause, economic or environmental harm or harm to human health. Only a small proportion of nonnative species are invasive.

IUCN protected status—see protected area.

land-use change—change in the classification of land; for example from forests to urban land.

lumber—timber sawn into boards, planks, or other structural members of standard or specified length.

national forest—an ownership class of Federal lands, designated by Executive Order or statute as national forests or purchase units, and other lands under the administration of the U.S. Forest Service.

net annual forest growth—the average annual net increase in the volume of trees during the period between surveys. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year, and minus the net volume of trees that became cull trees during the year.

nonindustrial private forest—all private forest owners excluding forest products companies.

nontimber forest products—products not commonly listed as outputs of the forest products industry, but that are used in the herbal medicine, culinary, crafts, and floral industries. They range from edible products (such as fruits, nuts, mushrooms, ramps, and maple syrup) to medicinal type products (such as ginseng and bloodroot) to ornamental products (such as pine cones, boughs, and grapevines) to landscape products (such as native plants) to specialty woods (such as burl and crotch wood for fine crafts) to wildgrown Christmas trees. As used here the category also includes post, poles, or residential fuelwood sold in small quantities.

old-growth forest—a subjective term describing forests that are relatively old for their forest cover type and relatively undisturbed by humans. Old-growth forests are characterized by the presence of large trees of late-successional (climax) species, multiple age cohorts, decaying trees, large snags, down wood in multiple stages of decay, and large-diameter down trees.

other Federal—an ownership class of Federal lands other than those administered by the Forest Service or Bureau of Land Management. This category includes land managed by the National Park Service, Fish and Wildlife Service, Department of Defense, and Department of Energy.

paper and paperboard products—products from pulp or recycled pulp and paper.

parcellation—the division of a property (individual ownership) into smaller parcels split among multiple owners.

phloem—the food-conducting tissues of a vascular plant that transport sugars produced by photosynthesis in the leaves. In trees the phloem is the innermost layer of the bark.

primary forest—see old-growth forest.

private forest—forest land held by private individuals, forest products companies, corporations, or other nongovernmental entities.

private forest owners—owners other than Federal, State, county, or municipal governments. This category includes private corporate (forest products industry and other incorporated) and private noncorporate entities.

private noncorporate owners—owners of private lands excluding lands owned by corporate interests. This category includes land owned by individuals, Native American lands, unincorporated partnerships, clubs, and lands leased by corporate interests.

protected area—an area that is especially dedicated to the protection and maintenance of biological diversity and natural and associated cultural resources, and is managed through legal or other effective means (see also reserved forest). Although all protected areas meet the general purposes contained in this definition, in practice the precise purposes for which protected areas are managed differ greatly. The International Union for Conservation of Nature (IUCN) has defined a series of six protected area management categories, based on primary management objective (DellaSalla et al. 2001, Dudley 2008, International Union for Conservation of Nature 2015).

Category I: an area possessing some outstanding or representative ecosystems, geological or physiological features, or species that is available primarily for scientific research or environmental monitoring; or a large unmodified or slightly modified area, which retains its natural character and influence without permanent or significant habitation, that is protected and managed so as to preserve its natural condition. Strict nature reserves (Ia) are distinguished from wilderness areas (Ib).

Category II: a natural area designated to (1) protect the ecological integrity of one or more ecosystems for present and future generations; (2) exclude exploitation or occupation inimical to the purposes of designation of the area; and (3) provide a foundation for spiritual, educational, recreational, and visitor opportunities, all of which must be environmentally and culturally comparable.

Category III: an area containing one or more specific natural or natural/cultural features that are of outstanding or unique value because of their inherent rarity, representative or esthetic qualities, or cultural significance.

Category IV: an area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species.

Category V: an area of land with coast and sea as appropriate, where the interaction of people and nature over time has created a distinct character with significant esthetic, ecological, or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance, and evolution of such an area.

Category VI: an area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while at the same time providing a sustainable flow of natural products and services to meet community needs.

protected forest—see protected area.

public forest land—forest managed by Federal, State, county, municipal, or other governmental entities.

pulpwood—roundwood, whole-tree chips, or wood residues that are used for production of wood pulp.

removals—the net volume of growing-stock trees removed from the inventory by harvesting, cultural operations such as timber stand improvement, or land clearing during a specified period of time (usually expressed as an annual average for a specified period of time).

reserved forest land—forest land withdrawn from timber extraction through statute, administrative regulation, or designation without regard to productive status. This is usually public forest land. See also protected area.

roundwood products—logs, bolts, and other round timber generated from harvesting trees for industrial or consumer use.

scenario—as used here it is the combination of the assumptions from (1) one of the IPCC storylines with (2) a general circulation model estimating future climate conditions based on expected greenhouse gas emissions for the selected storyline, and (3) an estimated pattern of future forest harvesting. In this study future harvest rates were modeled as either a continuation of harvest rates for the prior 5 years or one of three levels of increased biomass harvesting for energy production.

serotinous—able to release seeds in response to a fire or other disturbance.

softwood—trees belonging to the botanical group Gymnospermae. These needle-bearing trees typically produce seeds in cones. Examples include pines (*Pinus* spp.), spruces (*Picea* spp.), firs (*Abies* spp.), hemlocks (*Tsuga* spp.), and eastern redcedar (*Juniperus virginiana*). Although the wood of softwoods physically ranges from soft or hard, it is usually soft compared to the wood of hardwoods.

soil horizon—a specific layer in the land area that is parallel to the soil surface and possesses different physical characteristics from the layers above and beneath.

spatial scale—the degree of aggregation or disaggregation that one chooses to examine an issue. Spatial scales are hierarchical, and each scale can be split into finer units or combined into coarser units. Examples of spatial scale include national > State > county > township > section > woodlot (about 20 acres) < all woodlots along same south-facing ridge (about 100 to 500 acres) < small landscape (about 1,000 acres) < cluster of landscapes (thousands to millions of acres). Other relevant spatial scales might include the area around an individual tree, a forest stand, a group of forest stands, the typical home range of a wildlife species, an ecoregion, a watershed, a community, or an urban area.

statistical imputation—a process used to determine and assign replacement values for missing data or missing observations. As used here, future FIA plot conditions are "imputed" by drawing a replacement plot from a pool of candidate plots with the appropriate conditions. During a 10-year simulation time step, for example, an undisturbed 50-year-old oak-hickory (*Quercus* spp. – *Carya* spp.) forest plot would be replaced by a different 60-year-old oak-hickory forest plot chosen at random from among many dozens of candidate plots. But if the original plot were instead predicted to be harvested, it would be replaced by a newly regenerated forest plot, selected at random from a large pool of candidate plots. Imputation schemes can be quite complex. For example, climate change effects can be modeled by selecting future replacement plots from locations with warmer temperature regimes, similar to those expected in future decades.

stewardship—the administration of land and associated resources in a manner that enables their passing on to future generations in a healthy condition.

stewardship plan—see forest stewardship plan.

storyline—as used here, a set of assumptions about future changes in population, gross domestic product, land use, and greenhouse gas emissions. The projected forest conditions described in this report are based on the A1B, A2, or B2 storylines developed by the Intergovernmental Panel on Climate Change.

successional pathway—as a forest area progresses from pioneering community to climax community after a stand-replacing disturbance, the series of vegetation types that follow one another as the new stand matures (all depending on site and climate conditions).

susceptibility—the potential for introduction and establishment, over a 15-year period, of a forest pest within a tree species or tree-species group.

timberland—forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. Areas qualifying as timberland are capable of producing >20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.

total wages—the annual payroll or gross earnings paid in each calendar year to employees at the establishment. Total wage includes all forms of compensation (such as salaries, wages, commissions, dismissal pay, bonuses, vacation and sick leave pay, and compensation in kind) before such deductions as employees' Social Security contributions, withholding taxes, group insurance, union dues, and savings bonds purchases. The total includes salaries of officers of corporations; it excludes payments to proprietors or partners of unincorporated entities. Also excluded are payments to members of Armed Forces and pensioners carried on the active payrolls of manufacturing establishments. Also included are fringe benefits for employees, including the employer's costs for Social Security taxes, unemployment taxes, workmen's compensation insurance, State disability insurance pension plans, stock purchase plans, union-negotiated benefits, life insurance premiums, and insurance premiums on hospital and medical plans for employees. Also included are the employer's costs for benefits to individual employees such as stock purchase plans, deferred profit-sharing plans, and defined benefit and defined contribution retirement plans. Also excluded are such benefits as company-operated cafeterias, in-plant medical services, free parking lots, discounts on employee purchases, and uniforms and work clothing.

turbidity—a measure of water clarity measured by how much the material suspended in water decreases the passage of light through the water. Higher turbidity increases water temperatures because suspended particles absorb more heat. This, in turn, reduces the concentration of dissolved oxygen because warm water holds less dissolved oxygen than cold.

urban or community land—all territory, population, and housing units located within urbanized areas or urban clusters, which is based on population density (areas with core population density of 1,000 people per square mile) but also includes surrounding areas with lesser population density. Community lands are places that have geopolitical boundaries (for example, cities, towns, or unincorporated named places) and may include all, some, or no urban land within their boundaries. As urban land defines the more heavily populated areas (population density-based definition) and community land defines both urban and rural (nonurban) communities that are recognized by their geopolitical boundaries (political definition), both definitions provide information related to human settlements and the forest resources within those settlements. Because some urban land exists beyond community boundaries and not all community land is urban (communities are often a mix of urban and rural land), the category of "urban or community" was created to understand forest attributes accumulated by the union of these two definitions (U.S. Census Bureau 2015).

urban or community population—total population within a region that resides within urban or community land.

urban land—all the territory, population, and housing units located within urbanized areas or urban clusters, each with a core population density of 1,000 people per square mile and including surrounding areas that have lower population densities (U.S. Census Bureau 2015).

vertically integrated company—a company that is engaged in different parts of the production process, such as growing, transporting, and processing raw materials; and manufacturing, transporting, and marketing products.

volume of timber—the gross volume in cubic feet of wood for standing trees or for cut trees ≥4.0-inch top d.o.b. less deductions for rot, roughness, and poor form.

vulnerability—the potential for experiencing mortality of a tree species, over a 15-year period, if a forest pest were to become established.

watershed—as defined in nature by topography, the land area that drains to a waterbody and affects its flow, water level, loadings of pollutants, and other processes. In both a real and figurative sense, a lake or river is a reflection of its watershed. The U.S. Geological Survey has developed a hydrologic unit classification (HUC) system of watersheds at various scales and mapped these watersheds. The HUCs depicted in the figures of this report are at the "eight-digit scale" (USGS 2015).

wildland-urban interface—where houses meet or intermingle with wildland vegetation. The wildland-urban interface is composed of both interface and intermix communities. In both interface and intermix communities, housing must meet or exceed a minimum density of one structure per 40 acres. Intermix communities are places where housing and vegetation intermingle; wildland vegetation is continuous, covering ≥50 percent of the land, in areas >1 house per 40 acres. Interface communities are areas with housing in the vicinity of contiguous vegetation; they have >1 house per 40 acres, have <50 percent vegetation, and are within 1.5 miles of an area (made up of one or more contiguous census blocks) that is >1,325 acres (500 ha) and >75 percent vegetated (this minimum size limit ensures that areas surrounding small urban parks are not classified as interface).

witches' broom—dense twiggy growth in a tree caused by infection with fungus (especially rusts), mites, or viruses.

wood panels—engineered wood board such as plywood, veneer, oriented strandboard (OSB), particle board, medium-density board, and materials that are made from wood and glue.

xylem—the water conducting tissues of a vascular plant. Xylem transports water absorbed by roots throughout a tree.

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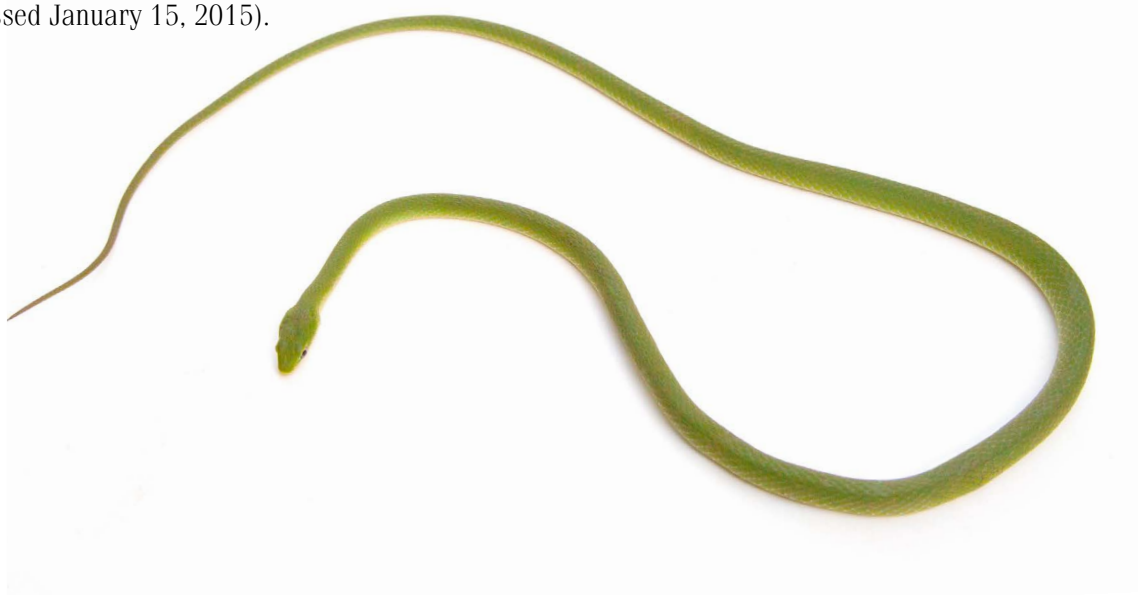


Appendices

The appendices consist of supplemental text and tables related to Chapters 2, 4, 7, 8, and 10. Content is organized by chapter and labeled to indicate the chapter from which it is introduced. For example, Tables A2.1 and A2.2, are introduced in Chapter 2. References in the appendices are listed with the citations in the related chapter.

DETAILS OF THE FOREST DYNAMICS MODEL AND SUBMODELS

The simulation algorithm links the Forest Dynamics Model (FDM) submodels together and produces predictions of future forest inventories, given a beginning inventory and assumptions about future land use and climate. In preparation for the simulation, the beginning inventory is screened for major forest-type groups that include less than 2 percent of the total plots established by the Forest Inventory and Analysis (FIA) Program of the U.S. Forest Service. Any such groups are considered too sparsely populated to model future forest type transitions directly, so a different method (described later in this section) is applied to those groups. The FIA plots in each remaining forest-type group form the bucket of suitable donor plots for that forest-type group. Plots are further subdivided by the partitioning submodel, which assigns each plot to a subgroup based upon the type of harvesting (none, partial, or full) that occurred on the plot in the previous inventory cycle.

Assuming that the beginning inventory of plots is a snapshot of forest conditions for 2010, the 2010-2015 simulation continues applying the harvest submodel to estimate the probability of each management level (unharvested, partially harvested, clearcut) for each plot in the screened 2010 inventory. A random draw from a uniform distribution assigns plots to the various management categories based on the probabilities programmed into the harvesting submodel.

Following assignment, the appropriate transition model for type of harvesting is applied. Change in the group assigned to each plot in 2015 is determined by another random draw from a uniform distribution applied to the correct group transition matrix (unharvested, partially harvested, clearcut). A plot designated as clearcut has its age reset to 2.5 years for 2015, and the other plots retain their plot age as of 2015. Based on the assumptions of future climate for each scenario, the plot location, and the forecast of plot age, each plot is assigned a climate profile for temperature, precipitation, and aridity. The predicted major forest-type group, harvesting type, forecasted age, and climate (along with the inventoried slope, aspect, and ownership) are then used to find the corresponding "bucket" of plots from which the partitioning submodel can randomly draw a replacement plot to represent that location's forest conditions for 2015.

The FDM submodels operate stochastically. Many modeled events in the transition, harvesting, partitioning, and imputation submodels (for example, whether or not a plot is harvested or shifts to a different forest type) draw a random number for the purposes of selecting a specific outcome from among all possible outcomes represented in a probability matrix (in effect, a computerized roll of the dice determines the outcome for numerous events modeled at each time step). Because of the random element in choosing outcomes at each time step, repeated projections based on the same scenario will differ in their outcomes.

Therefore, each scenario was repeated 26 times to produce a range of possible outcomes and to capture variations among simulations (limits of computing time restricted the number of repeated simulations). Wood volumes were summed for each of the 26 estimates for each time step, and an index that reflects the difference from the central tendency of growing-stock volume for each time step was calculated for each of the 26 inventory projections and summed over all time steps. For each scenario, the single inventory projection with the lowest summed index (the single inventory projection that is closest to the central tendency of growing-stock volume projected for all 26 runs of a single scenario) is the outcome summarized in subsequent analyses. The representative predicted inventory selected for each scenario has the same number of forested plots as the 2010 inventory.

The land-use submodel was used to forecast forest area. The assumed percentage of change in forest area for non-Federal land for each 5-year time step was applied to adjust the plot area expansion factors associated with each FIA plot. For example, in the first time step the plot area expansion factors in the 2010 beginning inventory were adjusted (e.g., reduced to indicate loss of forest land) to arrive at the 2015 expansion factors, and then were adjusted again in the next time step to arrive at the 2020 expansion factors, and so forth. Because the land-use submodel predicts change in forest area by county, every plot on non-Federal land within a county receives the same proportional change in forest area for a given 5-year time step. Plots on Federal land retain their 2010 expansion factors because Federal forest land area is assumed to be unchanged over the forecast period.

Harvesting removals, land-use removals (or additions), and growth and mortality can be calculated for each plot to arrive at a full bookkeeping of projected change in growing-stock volume on timberland. Harvesting removals were obtained by applying the removal intensities from the harvest submodel to the beginning inventory volume. Changes to volume resulting from land-use change (e.g., conversion of forest land to urban land) were calculated by multiplying the per-acre volume at the start of the period by the area of forest converted to other uses. Volume of total removals is the sum of harvesting removals and land-use change removals. Note that any increase in volume due to an increase in expansion factors is not included here. The FDM does not consider growth and mortality explicitly, but the net sum (net growth or other net change) can be estimated from the change in inventory. The total change in inventory between two periods is the ending inventory less the beginning inventory and is equal to the sum of harvesting removals and changes resulting from land use, growth, and mortality. Therefore, net growth = change in inventory + harvest removals + land-use removals. This formulation retains land-use additions in net growth. Subtracting land-use additions from the right-hand side of the equation accounts for net growth explicitly.

Note that total removals are divided by the time step of the simulation (5 years) to produce an annual removals estimate. Each element in this bookkeeping (beginning and ending volume, removals, and net growth) can be summed over all plots to obtain state-level totals.

SEPARATION AND SIMULATION OF HARVEST REMOVALS

The Northern Forest Futures Project relied on the removals forecasts provided by the Forest Dynamics Model for the 2010 Resources Planning Act (RPA) assessment (Wear 2011, Wear et al. 2013). These forecasts did not separate harvest removals (volume of cut trees) and land-use removals (volume of trees removed from the forest inventory when forest land is converted to other uses); only state-level total removals on an annual basis were available from the RPA assessment. A simple "top down" procedure was employed to split these state-level totals into separate estimates of land use removals and harvest removals. For a given time interval, subtracting ending timberland area from beginning timberland area provides an estimate of total forest area lost (or gained) through land use change, and a rough estimate of the sum, over all timberland plots, of the change in plot area expansion factors. Dividing the beginning inventory volume by beginning timberland area yields an approximation of per-acre beginning growing-stock volume on timberland.

Multiplying the change in timberland area by this per-acre volume gives an estimate of total removals resulting from land-use change over the 5-year time step (in these analyses projected forest area decreased in all time periods for all States). Dividing this estimate by the number of years in the time step produces an annual estimate of the removals volume due to land-use change. Subtracting this annual estimate of state land-use change removals from the total annual removals in the RPA assessment provides an estimate of annual harvest removals as the remainder.

Calculating change variables—The Forest Dynamics Model (Wear et al. 2013) was applied to calculate inventory summaries (volumes, number of trees, forest-type groups) based on imputed future inventories of tree species and tree size. The removals submodel is a component of the projection model that estimates the probability of a tree being harvested based on its species and diameter. This information aids in estimating annual harvest removals. The removals estimates were converted to an annual basis. An additional factor was included in the total removals estimate—the estimate of trees that are not harvested on forested parcels, but instead are removed from the inventory due to conversion of forest to other land uses.

Calculations for determining volume changes between succeeding periods are shown in Equations 1-3. This change in volume is made up of three components: growth, mortality, and removals. The Forest Dynamics Model does not model mortality directly. All of the change variables are modeled based on growing stock on timberland, so the volume equations do so as well.

$$\Delta Vol_{12} = Vol_2 - Vol_1 \quad (1)$$

$$\Delta Vol_{12} = Net\ growth_{12} - Removals(total)_{12} \quad (2)$$

$$Net\ growth_{12} = \Delta Vol_{12} + Removals(total)_{12} \quad (3)$$

Where:

Vol is growing-stock volume on timberland

ΔVol is periodic change in growing-stock volume

Net growth is growing-stock volume growth less mortality

Removals(total) is combined removals due to harvest and land-use change

subscript 1 represents variables from time period 1

subscript 2 represents variables from time period 2

subscript 12 represents change from the time period 1 to 2.

Calculating removals—Because two types of removals (removals resulting from harvesting and removals from land-use change [LUC]) are included in the total removals estimate, removals can be calculated as in Equation 4.

$$Removals(total)_{12} = Removals(harvest)_{12} + Removals(LUC)_{12} \quad (4)$$

where the removals component is indicated within the parentheses.

Periodic removals resulting from land-use change were calculated as the product of the land area converted from forest to another land use and the mean volume per acre as shown in Equations 5 and 6.

$$Vol/acre_1 = Vol_1/Area_1 \quad (5)$$

$$\Delta Area_{12} = Area_1 - Area_2 \quad (6)$$

Where:

Vol/acre is mean growing-stock volume per acre

Area is timber land area.

Multiplying the change in timberland area (acres) over a given time interval by the mean volume per acre produces an estimate of periodic total volume removals due to land use change. Dividing this estimate by the number of years in the interval gives an annual estimate of the volume removals due to land-use change (Eq. 7), and harvest removals were estimated by subtraction (Eq. 8).

$$Removals(LUC)_{12} = (Vol_1/Area_1 * \Delta Area_{12})/ Time_{12} \quad (7)$$

$$Removals(harvest)_{12} = Removals(total)_{12} - Removals(LUC)_{12} \quad (8)$$

where *Time* is the number of years in the specified interval.

Note that for forest area estimates (Eq. 6, 7), in all cases forest land area declined at the State level between two estimation periods, but at smaller spatial scales (which were not evaluated), forest land area may occasionally increase.

MODELING EFFECTS OF THE EMERALD ASH BORER

The effects of the emerald ash borer (*Agrilus planipennis*) on the number and volume of ash trees (*Fraxinus* spp.) were summarized for the broad category of forest-type groups and at the large scale of FIA inventory units. Our modeling results suggest that effects will contribute to a small decrease in the total number of trees and saplings in many FIA inventory units from 2010 to 2060, but changes in the elm-ash-cottonwood (*Ulmus* spp.–*Fraxinus* spp.–*Populus* spp.) forest-type group will vary among FIA inventory units. Forest species composition in forests measured by FIA will change when ash trees are killed by the emerald ash borer, but modeling results suggest that effects will not cause substantial changes in the number of plots in any given forest-type group.

For example, the area of forest in the elm-ash-cottonwood group is expected to show little change over time even though emerald ash borer is expected to kill all the ash trees in many locations. Some of the impacts of infestation on ecosystem functioning may be modest because associated non-ash species not prone to infestation have the potential to offset the loss of ash trees and their associated volume. Consequently, despite the assumption that emerald ash borer will cause 100 percent ash mortality, the transition from ash to other species may progress slowly as ash is replaced by a variety of associated species. However, the effects of infestation could lead to canopy gaps and facilitate an increase in native and nonnative invasive plant species (Gandhi and Herms 2010). Because changes were analyzed by forest-type groups, considering geographic differences in the composition of each forest-type group was important. For example, ash is not a significant component of any forest-type group in Maine FIA inventory units, but the elm-ash-cottonwood forest-type group in Minnesota FIA inventory units is composed mainly of green ash (*Fraxinus pennsylvanica*) and black ash (*F. nigra*). It is also important to keep in mind that this modeling may not apply to urban areas not measured by FIA, where the extensive distribution of planted ash trees could result in a greater impact.

Table A2.1—Projected population from 2010 to 2060 in North under three greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007, Zarnoch et al. 2010).

State	Storyline[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(1,000 people)						(percent)
Connecticut	A1B	3,535	3,654	3,792	3,947	4,115	4,281	21
	A2	3,606	3,768	3,959	4,188	4,481	4,836	34
	B2	3,524	3,634	3,681	3,690	3,738	3,802	8
District of Columbia	A1B	570	548	531	518	507	500	-12
	A2	581	566	554	549	553	565	-3
	B2	568	545	515	484	461	444	-22
Delaware	A1B	884	969	1,057	1,145	1,229	1,309	48
	A2	902	999	1,103	1,215	1,338	1,478	64
	B2	881	964	1,026	1,070	1,116	1,162	32
Iowa	A1B	3,005	3,100	3,212	3,339	3,473	3,613	20
	A2	3,065	3,197	3,353	3,543	3,781	4,082	33
	B2	2,996	3,083	3,118	3,121	3,155	3,209	7
Illinois	A1B	13,042	13,717	14,451	15,160	15,794	16,365	25
	A2	13,304	14,145	15,087	16,084	17,196	18,488	39
	B2	13,002	13,641	14,030	14,170	14,347	14,534	12
Indiana	A1B	6,402	6,698	7,025	7,383	7,758	8,148	27
	A2	6,531	6,908	7,334	7,833	8,447	9,205	41
	B2	6,383	6,661	6,820	6,901	7,048	7,236	13
Massachusetts	A1B	6,498	6,731	6,997	7,272	7,539	7,801	20
	A2	6,629	6,941	7,305	7,715	8,209	8,813	33
	B2	6,479	6,694	6,793	6,798	6,849	6,928	7
Maryland	A1B	5,877	6,579	7,290	7,964	8,571	9,120	55
	A2	5,995	6,785	7,611	8,450	9,332	10,303	72
	B2	5,860	6,543	7,077	7,445	7,786	8,100	38
Maine	A1B	1,342	1,407	1,479	1,562	1,654	1,756	31
	A2	1,369	1,451	1,544	1,657	1,801	1,983	45
	B2	1,338	1,399	1,436	1,460	1,503	1,559	17

Table A2.1 continued

State	Storyline[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(1,000 people)						(percent)
Michigan	A1B	10,165	10,465	10,821	11,236	11,688	12,173	20
	A2	10,369	10,792	11,298	11,921	12,725	13,753	33
	B2	10,134	10,407	10,506	10,503	10,617	10,811	7
Minnesota	A1B	5,358	5,884	6,423	6,962	7,483	7,988	49
	A2	5,465	6,068	6,706	7,387	8,147	9,024	65
	B2	5,342	5,852	6,236	6,508	6,798	7,094	33
Missouri	A1B	5,960	6,320	6,704	7,133	7,597	8,091	36
	A2	6,080	6,518	6,999	7,568	8,271	9,141	50
	B2	5,942	6,285	6,509	6,668	6,901	7,186	21
New Hampshire	A1B	1,379	1,549	1,722	1,900	2,078	2,256	64
	A2	1,406	1,598	1,798	2,016	2,263	2,548	81
	B2	1,375	1,541	1,672	1,776	1,888	2,003	46
New Jersey	A1B	8,948	9,601	10,287	10,928	11,484	11,969	34
	A2	9,127	9,901	10,740	11,594	12,503	13,522	48
	B2	8,921	9,548	9,987	10,215	10,432	10,630	19
New York	A1B	19,382	19,820	20,371	20,934	21,448	21,929	13
	A2	19,771	20,440	21,267	22,211	23,352	24,774	25
	B2	19,323	19,711	19,776	19,568	19,484	19,475	1
Ohio	A1B	11,484	11,653	11,893	12,183	12,491	12,811	12
	A2	11,715	12,017	12,416	12,926	13,599	14,473	24
	B2	11,450	11,589	11,546	11,388	11,347	11,378	-1
Pennsylvania	A1B	12,555	12,994	13,498	14,058	14,640	15,236	21
	A2	12,807	13,400	14,092	14,916	15,940	17,213	34
	B2	12,517	12,922	13,104	13,141	13,300	13,531	8

Table A2.1 continued

State	Storyline[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(1,000 people)						(percent)
Rhode Island	A1B	1,089	1,154	1,223	1,289	1,349	1,404	29
	A2	1,111	1,190	1,277	1,367	1,469	1,586	43
	B2	1,086	1,147	1,188	1,204	1,226	1,247	15
Vermont	A1B	643	696	751	813	881	956	49
	A2	656	717	784	863	960	1,080	65
	B2	641	692	729	760	801	849	32
Wisconsin	A1B	5,687	6,073	6,481	6,922	7,383	7,861	38
	A2	5,801	6,263	6,767	7,344	8,038	8,881	53
	B2	5,670	6,040	6,292	6,470	6,707	6,981	23
West Virginia	A1B	1,818	1,840	1,873	1,919	1,972	2,034	12
	A2	1,854	1,898	1,956	2,036	2,147	2,298	24
	B2	1,812	1,830	1,819	1,793	1,792	1,806	0
All Northern States	A1B	125,621	131,454	137,881	144,565	151,134	157,598	25
	A2	128,141	135,562	143,948	153,380	164,550	178,045	39
	B2	125,242	130,727	133,860	135,132	137,294	139,964	12
U.S. total	A1B	308,936	335,805	363,584	391,946	419,854	447,308	45
	A2	315,135	346,297	379,581	415,845	457,122	505,344	60
	B2	308,004	333,948	352,980	366,372	381,404	397,259	29

[a]*Storyline A1B assumes moderate greenhouse gas emissions associated with moderate population growth and large gains in income and energy consumption but with a balanced renewable/fossil fuel portfolio; storyline A2 assumes high greenhouse gas emissions associated with high population growth, high energy consumption, and moderate gains in income; and storyline B2 assumes low greenhouse gas emissions associated with moderate increases in population, income, and energy consumption.*

Table A2.2—Projected land use from 2010 to 2060 in the North under three greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007, Wear 2011); note that percentages may not sum to 100 due to rounding and that the total area is 413,586,000 acres or 646,228 square miles.

Storyline[a]	Year	Forest	Urban	Cropland	Pasture	Range
		(percent of total land area)				
A1B	2010	41	9	39	10	< 1
	2020	41	11	39	10	< 1
	2030	40	12	38	10	< 1
	2040	40	13	38	10	< 1
	2050	39	14	37	9	< 1
	2060	39	16	37	9	< 1
A2	2010	41	9	39	10	< 1
	2020	41	10	39	10	< 1
	2030	41	11	39	10	< 1
	2040	40	12	38	10	< 1
	2050	40	13	38	10	< 1
	2060	39	14	37	9	< 1
B2	2010	41	10	39	10	< 1
	2020	41	11	39	10	< 1
	2030	41	11	39	10	< 1
	2040	40	12	38	10	< 1
	2050	40	12	38	10	< 1
	2060	40	13	38	10	< 1

[a]*Storyline A1B assumes moderate greenhouse gas emissions associated with moderate population growth and large gains in income and energy consumption, but with a balanced renewable/fossil fuel portfolio; storyline A2 assumes high greenhouse gas emissions associated with high population growth, high energy consumption, and moderate gains in income; and storyline B2 assumes low greenhouse gas emissions associated with moderate increases in population, income, and energy consumption.*

Table A2.3—Projected forest area, 2010 to 2060, and percentage change in forest area in the North under three greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007, Wear 2011).

State	Storyline[a]	Year						Change (2010 to 2060)
		2010	2020	2030	2040	2050	2060	
		(1,000 acres)						(percent)
Connecticut	A1B	1,724	1,691	1,657	1,620	1,580	1,537	-11
	A2	1,724	1,689	1,653	1,613	1,567	1,512	-12
	B2	1,724	1,694	1,676	1,663	1,644	1,626	-6
Delaware	A1B	352	339	327	315	301	287	-18
	A2	352	340	328	315	301	285	-19
	B2	352	340	332	326	318	311	-12
Illinois	A1B	4,798	4,703	4,648	4,597	4,539	4,472	-7
	A2	4,798	4,722	4,683	4,651	4,614	4,570	-5
	B2	4,798	4,712	4,677	4,645	4,607	4,582	-5
Indiana	A1B	4,744	4,654	4,569	4,475	4,364	4,235	-11
	A2	4,744	4,678	4,617	4,554	4,478	4,388	-7
	B2	4,744	4,671	4,636	4,596	4,537	4,493	-5
Iowa	A1B	3,033	3,012	2,993	2,971	2,945	2,915	-4
	A2	3,033	3,018	3,005	2,991	2,974	2,953	-3
	B2	3,033	3,017	3,009	3,000	2,986	2,977	-2
Maine	A1B	17,657	17,598	17,541	17,477	17,404	17,319	-2
	A2	17,657	17,606	17,558	17,507	17,444	17,369	-2
	B2	17,657	17,607	17,580	17,554	17,515	17,481	-1
Maryland	A1B	2,493	2,314	2,142	1,977	1,826	1,680	-33
	A2	2,493	2,328	2,167	2,019	1,883	1,746	-30
	B2	2,493	2,330	2,216	2,119	2,022	1,952	-22
Massachusetts	A1B	3,019	2,941	2,861	2,779	2,700	2,627	-13
	A2	3,019	2,939	2,858	2,774	2,687	2,597	-14
	B2	3,019	2,949	2,904	2,870	2,831	2,796	-7
Michigan	A1B	19,821	19,624	19,431	19,219	18,977	18,701	-6
	A2	19,821	19,655	19,491	19,317	19,110	18,856	-5
	B2	19,821	19,655	19,559	19,466	19,337	19,225	-3
Minnesota	A1B	16,990	16,872	16,760	16,644	16,518	16,389	-4
	A2	16,990	16,888	16,793	16,697	16,591	16,487	-3
	B2	16,990	16,887	16,822	16,761	16,687	16,626	-2
Missouri	A1B	15,397	15,262	15,132	14,987	14,819	14,625	-5
	A2	15,397	15,290	15,186	15,075	14,941	14,774	-4
	B2	15,397	15,285	15,219	15,147	15,053	14,976	-3
New Hampshire	A1B	4,803	4,727	4,654	4,577	4,493	4,401	-8
	A2	4,803	4,736	4,671	4,604	4,529	4,441	-8
	B2	4,803	4,736	4,691	4,649	4,599	4,557	-5

Table A2.3 continued

State	Storyline[a]	Year						Change (2010 to 2060)
		2010	2020	2030	2040	2050	2060	
		(1,000 acres)						(percent)
New Jersey	A1B	2,002	1,859	1,722	1,597	1,483	1,379	-31
	A2	2,002	1,849	1,706	1,572	1,441	1,309	-35
	B2	2,002	1,869	1,778	1,717	1,658	1,611	-20
New York	A1B	18,951	18,804	18,681	18,547	18,394	18,219	-4
	A2	18,951	18,824	18,719	18,608	18,476	18,312	-3
	B2	18,951	18,826	18,770	18,717	18,647	18,591	-2
Ohio	A1B	8,044	7,964	7,887	7,802	7,703	7,591	-6
	A2	8,044	7,975	7,907	7,835	7,746	7,633	-5
	B2	8,044	7,978	7,943	7,911	7,869	7,835	-3
Pennsylvania	A1B	16,652	16,368	16,092	15,787	15,439	15,044	-10
	A2	16,652	16,418	16,191	15,949	15,661	15,310	-8
	B2	16,652	16,417	16,292	16,173	16,002	15,864	-5
Rhode Island	A1B	348	323	306	290	273	257	-26
	A2	348	323	305	288	269	248	-29
	B2	348	325	315	309	302	296	-15
Vermont	A1B	4,588	4,538	4,492	4,442	4,385	4,322	-6
	A2	4,588	4,551	4,518	4,484	4,446	4,400	-4
	B2	4,588	4,547	4,525	4,500	4,466	4,439	-3
West Virginia	A1B	11,974	11,802	11,642	11,463	11,249	10,992	-8
	A2	11,974	11,859	11,758	11,656	11,529	11,370	-5
	B2	11,974	11,840	11,784	11,713	11,601	11,524	-4
Wisconsin	A1B	16,697	16,562	16,432	16,291	16,126	15,936	-5
	A2	16,697	16,589	16,488	16,381	16,253	16,096	-4
	B2	16,697	16,584	16,522	16,456	16,366	16,291	-2
All Northern States	A1B	174,090	171,958	169,967	167,857	165,520	162,925	-6
	A2	174,090	172,276	170,601	168,891	166,938	164,656	-5
	B2	174,090	172,270	171,250	170,291	169,047	168,053	-3

[a]*Storyline A1B assumes moderate greenhouse gas emissions associated with moderate population growth and large gains in income and energy consumption but with a balanced renewable/fossil fuel portfolio; storyline A2 assumes high greenhouse gas emissions associated with high population growth, high energy consumption, and moderate gains in income; and storyline B2 assumes low greenhouse gas emissions associated with moderate increases in population, income, and energy consumption.*

Table A2.4—Underlying large-scale assumptions about future biomass consumption for bioenergy in the multi-national macro-region Organization for Economic Cooperation and Development (OECD 90) (Ince et al. 2011, USDA FS 2012b) under three greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

Source	Storyline[a]	Year						
		2000	2010	2020	2030	2040	2050	2060
		(1,000,000 tons)						
Roundwood fuelwood (forests)	A1B	93.1	105.3	240.4	405.3	628.9	1,022.5	1,297.1
	A2	93.1	98.8	154.4	356.8	544.2	748.2	746.1
	B2	93.1	98.9	133.0	67.1	45.7	145.4	263.8
Energy plantations	A1B	0.0	0.0	82.8	198.2	353.4	625.0	784.2
	A2	0.0	0.0	62.4	193.7	338.4	467.6	458.9
	B2	0.0	0.0	19.6	91.9	159.2	215.2	289.0
Cropland crops and residues	A1B	257.4	210.7	209.8	209.4	207.5	205.7	203.0
	A2	257.4	216.8	220.6	224.6	229.2	233.9	239.5
	B2	257.4	216.7	221.0	225.1	228.3	231.4	234.7

[a]*Storyline A1B assumes moderate greenhouse gas emissions associated with moderate population growth and large gains in income and energy consumption but with a balanced renewable/fossil fuel portfolio; storyline A2 assumes high greenhouse gas emissions associated with high population growth, high energy consumption, and moderate gains in income; and storyline B2 assumes low greenhouse gas emissions associated with moderate increases in population, income, and energy consumption..*

Table A2.5—Projected biomass production for bioenergy from roundwood and fuelwood, 2010 to 2060, under three greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

Source	Storyline[a]	Year					
		2010	2020	2030	2040	2050	2060
		(billion cubic feet)					
(Mill) fuel residue	A1B	2.0	2.6	2.8	3.5	3.4	3.4
	A2	2.4	2.3	2.2	2.3	2.1	1.2
	B2	2.4	2.4	2.4	2.3	2.4	2.6
(Recovered) harvest residue	A1B	0.0	3.6	5.9	8.9	12.5	16.3
	A2	0.0	2.8	4.1	5.8	7.7	10.0
	B2	0.0	1.6	3.7	4.2	4.7	5.6
Hardwood pulpwood	A1B	0.0	0.0	1.0	4.1	9.5	14.3
	A2	0.0	0.0	0.0	0.4	2.6	4.5
	B2	0.0	0.0	0.0	0.0	0.0	0.0
Mill (fiber) residue	A1B	0.1	0.3	0.5	1.3	2.2	3.3
	A2	0.1	0.4	1.0	2.1	2.1	1.2
	B2	0.0	0.0	0.2	0.6	1.7	2.4
Roundwood fuelwood harvesting	A1B	1.8	2.2	3.3	4.8	7.0	9.0
	A2	1.7	1.9	2.5	3.1	4.2	5.7
	B2	1.7	1.7	2.0	2.5	2.9	3.4
Softwood pulpwood	A1B	0.2	1.1	3.4	6.9	11.2	16.5
	A2	0.1	0.1	2.3	5.0	8.5	15.1
	B2	0.0	0.0	0.0	0.1	0.2	0.6

[a]*Storyline A1B assumes moderate greenhouse gas emissions associated with moderate population growth and large gains in income and energy consumption but with a balanced renewable/fossil fuel portfolio; storyline A2 assumes high greenhouse gas emissions associated with high population growth, high energy consumption, and moderate gains in income; and storyline B2 assumes low greenhouse gas emissions associated with moderate increases in population, income, and energy consumption.*

Please refer to the Literature Cited section at the end of Chapter 2 for the references.

Table A4.1—Projected forest land area by forest-type group for the North, 2010 to 2060, under three greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

Forest-type group and storyline[a]	Year					
	2010	2020	2030	2040	2050	2060
	(1,000 acres)					
Aspen-birch						
A1B	17,255	15,964	15,324	15,213	15,087	14,451
A2	17,255	16,012	15,365	15,280	15,182	14,203
B2	17,255	16,129	15,339	15,288	15,220	14,687
Elm-ash-cottonwood						
A1B	12,147	10,976	10,222	10,068	9,903	10,213
A2	12,147	10,923	10,503	10,363	10,205	9,966
B2	12,147	10,740	10,541	10,467	10,375	10,346
Maple-beech-birch						
A1B	44,982	46,104	46,668	46,216	45,704	46,441
A2	44,982	46,191	46,805	46,467	46,063	46,635
B2	44,982	46,703	47,339	47,147	46,882	47,623
Oak-hickory						
A1B	63,184	62,851	62,459	61,455	60,342	57,730
A2	63,184	63,125	62,276	61,463	60,538	59,329
B2	63,184	62,782	62,215	61,758	61,167	60,197
Other						
A1B	12,746	12,209	12,012	11,775	11,527	11,307
A2	12,746	12,347	12,128	11,917	11,695	11,556
B2	12,746	12,271	12,020	11,909	11,778	12,361
Spruce-fir						
A1B	15,279	15,037	14,342	14,276	14,199	13,659
A2	15,279	15,039	14,682	14,632	14,573	13,836
B2	15,279	14,839	14,763	14,732	14,688	13,676
White-red-jack pine						
A1B	8,497	8,817	8,940	8,855	8,758	9,123
A2	8,497	8,639	8,843	8,769	8,682	9,131
B2	8,497	8,806	9,033	8,991	8,937	9,163

[a]*Storyline A1B assumes moderate greenhouse gas emissions associated with moderate population growth and large gains in income and energy consumption but with a balanced renewable/fossil fuel portfolio; storyline A2 assumes high greenhouse gas emissions associated with high population growth, high energy consumption, and moderate gains in income; and storyline B2 assumes low greenhouse gas emissions associated with moderate increases in population, income, and energy consumption.*

Table A4.2—Projected volume of live trees on forest land in the North, 2010 to 2060, for seven future scenarios based on greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

State	Scenario[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(million cubic feet)						(percent)
Connecticut	A1B-C	4,127	4,232	4,669	4,564	4,450	4,065	-2
	A2-C	4,127	4,354	4,357	4,255	4,134	3,767	-9
	B2-C	4,127	4,080	4,024	3,990	3,944	4,101	-1
	A2-EAB	4,127	4,222	4,128	4,030	3,913	3,585	-13
	A1B-BIO	4,127	4,225	4,369	4,271	4,165	3,943	-4
	A2-BIO	4,127	4,247	4,308	4,205	4,083	3,914	-5
	B2-BIO	4,127	4,243	4,022	3,988	3,942	3,850	-7
Delaware	A1B-C	862	867	897	860	822	738	-14
	A2-C	862	876	841	808	771	766	-11
	B2-C	862	872	889	869	848	806	-7
	A2-EAB	862	888	765	734	700	744	-14
	A1B-BIO	862	835	857	821	783	675	-22
	A2-BIO	862	928	906	869	828	712	-17
	B2-BIO	862	858	841	823	803	825	-4
Illinois	A1B-C	8,652	9,238	8,830	8,735	8,627	8,308	-4
	A2-C	8,652	8,877	8,871	8,810	8,740	8,656	0
	B2-C	8,652	9,083	8,554	8,491	8,418	9,087	5
	A2-EAB	8,652	9,337	8,473	8,415	8,347	8,311	-4
	A1B-BIO	8,652	8,694	8,874	8,775	8,663	7,680	-11
	A2-BIO	8,652	8,804	8,966	8,896	8,817	7,829	-10
	B2-BIO	8,652	9,147	8,961	8,896	8,821	8,262	-5
Indiana	A1B-C	9,785	10,527	10,468	10,255	10,005	10,117	3
	A2-C	9,785	10,254	10,231	10,095	9,931	10,585	8
	B2-C	9,785	10,253	10,597	10,508	10,377	10,228	5
	A2-EAB	9,785	9,564	10,144	10,010	9,849	9,833	0
	A1B-BIO	9,785	10,383	10,139	9,926	9,676	8,799	-10
	A2-BIO	9,785	10,329	10,506	10,369	10,204	9,499	-3
	B2-BIO	9,785	10,136	10,793	10,703	10,571	9,840	1

Table A4.2 continued

State	Scenario[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(million cubic feet)						(percent)
Iowa	A1B-C	4,256	5,019	5,027	4,992	4,950	4,780	12
	A2-C	4,256	4,800	4,921	4,894	4,862	5,095	20
	B2-C	4,256	4,922	5,085	5,070	5,048	5,185	22
	A2-EAB	4,256	4,893	5,175	5,088	5,022	4,605	8
	A1B-BIO	4,256	4,708	4,679	4,646	4,607	3,747	-12
	A2-BIO	4,256	4,728	4,910	4,883	4,851	4,059	-5
	B2-BIO	4,256	4,724	5,003	4,986	4,962	4,569	7
Maine	A1B-C	25,474	26,738	27,130	27,013	26,877	26,046	2
	A2-C	25,474	26,551	27,544	27,446	27,329	27,043	6
	B2-C	25,474	26,804	27,084	27,035	26,965	27,191	7
	A2-EAB	25,474	26,632	26,933	26,367	26,070	25,980	2
	A1B-BIO	25,474	25,864	24,703	24,597	24,475	14,939	-41
	A2-BIO	25,474	26,168	25,782	25,686	25,571	18,810	-26
	B2-BIO	25,474	26,627	26,525	26,478	26,409	22,367	-12
Maryland	A1B-C	6,469	6,275	5,883	5,377	4,926	4,708	-27
	A2-C	6,469	6,248	5,802	5,373	4,990	4,576	-29
	B2-C	6,469	6,221	5,704	5,425	5,158	4,913	-24
	A2-EAB	6,469	6,466	6,050	5,606	5,216	4,531	-30
	A1B-BIO	6,469	6,044	5,399	4,952	4,563	3,735	-42
	A2-BIO	6,469	6,070	5,728	5,306	4,927	4,128	-36
	B2-BIO	6,469	6,404	5,751	5,486	5,227	4,617	-29
Massachusetts	A1B-C	7,754	7,863	7,359	7,175	6,991	6,630	-14
	A2-C	7,754	7,637	7,500	7,302	7,092	6,765	-13
	B2	7,754	7,577	7,490	7,418	7,331	7,021	-9
	A2-EAB	7,754	7,651	7,521	7,021	6,822	6,333	-18
	A1B-BIO	7,754	7,717	7,523	7,327	7,135	6,696	-14
	A2-BIO	7,754	7,700	7,494	7,291	7,077	6,422	-17
	B2-BIO	7,754	7,880	7,749	7,675	7,588	7,398	-5

Table A4.2 continued

State	Scenario[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(million cubic feet)						(percent)
Michigan	A1B-C	31,553	32,857	33,405	33,024	32,590	33,934	8
	A2-C	31,553	32,844	33,505	33,194	32,824	34,290	9
	B2-C	31,553	32,967	34,196	34,026	33,791	35,574	13
	A2-EAB	31,553	31,510	32,143	31,847	31,494	32,742	4
	A1B-BIO	31,553	32,515	32,146	31,787	31,379	25,620	-19
	A2-BIO	31,553	33,008	32,650	32,344	31,978	29,003	-8
	B2-BIO	31,553	32,791	33,930	33,763	33,533	32,368	3
Minnesota	A1B-C	18,099	19,232	20,498	20,314	20,116	22,013	22
	A2-C	18,099	19,569	21,021	20,843	20,649	22,403	24
	B2-C	18,099	19,292	20,487	20,387	20,268	20,968	16
	A2-EAB	18,099	19,767	20,874	19,812	18,847	20,901	15
	A1B-BIO	18,099	19,218	18,906	18,730	18,540	12,807	-29
	A2-BIO	18,099	19,520	20,591	20,428	20,253	18,504	2
	B2-BIO	18,099	19,340	20,361	20,261	20,142	17,933	-1
Missouri	A1B-C	20,143	21,930	22,529	22,309	22,054	23,298	16
	A2-C	20,143	21,625	22,161	21,996	21,798	23,451	16
	B2-C	20,143	21,075	22,396	22,290	22,152	24,064	19
	A2-EAB	20,143	21,489	22,396	21,972	21,609	23,341	16
	A1B-BIO	20,143	21,156	21,718	21,510	21,269	19,779	-2
	A2-BIO	20,143	21,707	21,859	21,700	21,507	21,649	7
	B2-BIO	20,143	21,402	22,430	22,325	22,187	22,731	13
New Hampshire	A1B-C	10,670	11,298	11,247	11,045	10,826	10,618	0
	A2-C	10,670	11,378	11,367	11,183	10,977	10,697	0
	B2-C	10,670	11,232	11,418	11,309	11,181	11,069	4
	A2-EAB	10,670	11,033	11,114	10,735	10,535	10,289	-4
	A1B-BIO	10,670	10,995	10,930	10,725	10,505	8,300	-22
	A2-BIO	10,670	11,203	10,944	10,768	10,571	9,409	-12
	B2-BIO	10,670	10,779	11,256	11,145	11,014	10,002	-6

Table A4.2 continued

State	Scenario[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(million cubic feet)						(percent)
New Jersey	A1B-C	3,919	3,835	3,557	3,308	3,078	2,768	-29
	A2-C	3,919	3,497	3,439	3,176	2,917	2,790	-29
	B2-C	3,919	3,878	3,842	3,707	3,579	3,253	-17
	A2-EAB	3,919	3,559	3,215	2,957	2,707	2,593	-34
	A1B-BIO	3,919	3,690	3,426	3,171	2,937	2,634	-33
	A2-BIO	3,919	3,726	3,668	3,399	3,134	2,567	-35
	B2-BIO	3,919	3,738	3,577	3,455	3,339	3,155	-19
New York	A1B-C	39,609	41,756	43,115	42,796	42,433	42,506	7
	A2-C	39,609	41,519	42,696	42,434	42,120	42,281	7
	B2-C	39,609	41,229	43,210	43,084	42,914	43,418	10
	A2-EAB	39,609	41,448	40,560	40,316	40,023	40,687	3
	A1B-BIO	39,609	40,856	42,585	42,276	41,924	40,247	2
	A2-BIO	39,609	40,999	42,463	42,206	41,899	41,474	5
	B2-BIO	39,609	41,208	43,145	43,021	42,854	42,156	6
Ohio	A1B-C	15,992	17,576	17,884	17,682	17,449	18,780	17
	A2-C	15,992	17,587	17,504	17,345	17,145	17,944	12
	B2-C	15,992	17,102	18,021	17,942	17,837	18,526	16
	A2-EAB	15,992	15,765	16,719	16,560	16,365	16,944	6
	A1B-BIO	15,992	17,007	16,884	16,696	16,478	13,948	-13
	A2-BIO	15,992	16,604	17,422	17,254	17,048	16,027	0
	B2-BIO	15,992	16,691	17,876	17,802	17,701	17,172	7
Pennsylvania	A1B-C	35,386	35,318	35,040	34,364	33,594	34,093	-4
	A2-C	35,386	34,921	35,469	34,922	34,269	34,847	-2
	B2-C	35,386	35,349	36,492	36,215	35,821	35,978	2
	A2-EAB	35,386	35,221	35,125	34,602	33,978	34,758	-2
	A1B-BIO	35,386	35,794	34,662	34,006	33,260	27,624	-22
	A2-BIO	35,386	35,806	35,770	35,244	34,615	31,090	-12
	B2-BIO	35,386	35,472	35,824	35,562	35,186	33,514	-5

Table A4.2 continued

State	Scenario[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(million cubic feet)						(percent)
Rhode Island	A1B-C	786	707	742	702	663	581	-26
	A2-C	786	778	695	658	616	573	-27
	B2-C	786	675	710	696	680	658	-16
	A2-EAB	786	735	725	672	629	560	-29
	A1B-BIO	786	748	812	769	726	613	-22
	A2-BIO	786	734	678	641	600	623	-21
	B2-BIO	786	739	701	688	672	633	-19
Vermont	A1B-C	10,174	10,540	10,558	10,438	10,303	10,346	2
	A2-C	10,174	10,266	10,727	10,644	10,548	10,770	6
	B2-C	10,174	10,705	10,786	10,727	10,645	10,366	2
	A2-EAB	10,174	10,404	9,908	9,834	9,750	9,830	-3
	A1B-BIO	10,174	10,544	10,473	10,352	10,217	8,288	-19
	A2-BIO	10,174	10,234	10,817	10,737	10,646	9,296	-9
	B2-BIO	10,174	10,526	10,688	10,629	10,547	10,561	4
West Virginia	A1B-C	27,102	26,327	26,897	26,487	25,995	25,546	-6
	A2-C	27,102	26,686	26,435	26,209	25,932	26,544	-2
	B2-C	27,102	26,092	26,286	26,133	25,892	26,299	-3
	A2-EAB	27,102	26,686	27,426	27,199	26,920	27,332	1
	A1B-BIO	27,102	26,534	25,579	25,198	24,740	20,069	-26
	A2-BIO	27,102	26,808	26,112	25,892	25,620	23,223	-14
	B2-BIO	27,102	26,032	26,338	26,181	25,934	24,856	-8
Wisconsin	A1B-C	23,242	25,818	27,208	26,973	26,699	28,378	22
	A2-C	23,242	25,810	27,293	27,114	26,899	28,855	24
	B2-C	23,242	25,673	27,102	26,995	26,847	28,895	24
	A2-EAB	23,242	25,608	25,402	25,236	25,038	27,074	16
	A1B-BIO	23,242	25,263	25,057	24,835	24,577	17,722	-24
	A2-BIO	23,242	25,695	26,403	26,226	26,014	22,068	-5
	B2-BIO	23,242	25,280	26,670	26,562	26,413	24,985	8

Table A4.2 continued

State	Scenario[a]	Year						Change 2010 to 2060
		2010	2020	2030	2040	2050	2060	
		(million cubic feet)						(percent)
All Northern States	A1B-C	304,055	317,951	322,940	318,412	313,447	318,255	5
	A2-C	304,055	316,077	322,381	318,700	314,544	322,699	6
	B2-C	304,055	315,081	324,374	322,317	319,695	327,599	8
	A2-EAB	304,055	312,877	314,795	309,013	303,833	310,974	2
	A1B-BIO	304,055	312,790	309,721	305,370	300,619	247,866	-18
	A2-BIO	304,055	315,018	317,979	314,345	310,242	280,307	-8
	B2-BIO	304,055	314,018	322,441	320,428	317,845	301,793	-1

[a]*There are seven scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.*

Table A4.3—Projected volume of total annual removals in the North, 2010 to 2060, for seven future scenarios based on greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Connecticut	A1B-C	54	22	18	16	18	15
	A2-C	54	24	17	18	20	18
	B2-C	54	17	13	5	6	8
	A2-EAB	54	31	17	11	16	15
	A1B-BIO	54	21	29	24	24	24
	A2-BIO	54	21	19	25	18	23
	B2-BIO	54	20	22	12	12	15
Delaware	A1B-C	7	6	7	12	7	9
	A2-C	7	10	7	7	9	11
	B2-C	7	9	8	7	10	7
	A2-EAB	7	8	9	6	7	10
	A1B-BIO	7	10	8	15	21	19
	A2-BIO	7	7	9	10	13	18
	B2-BIO	7	7	9	10	10	13
Illinois	A1B-C	58	49	39	64	48	50
	A2-C	58	54	38	30	57	43
	B2-C	58	54	36	71	53	39
	A2-EAB	58	51	44	33	52	55
	A1B-BIO	58	59	60	97	132	162
	A2-BIO	58	61	47	72	96	142
	B2-BIO	58	56	59	55	83	76
Indiana	A1B-C	80	115	106	142	143	115
	A2-C	80	113	115	89	111	132
	B2-C	80	97	90	104	126	110
	A2-EAB	80	94	89	95	93	133
	A1B-BIO	80	122	168	282	371	423
	A2-BIO	80	111	155	194	259	331
	B2-BIO	80	125	97	164	217	220

Table A4.3 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Iowa	A1B-C	46	39	50	69	47	48
	A2-C	46	47	64	40	39	46
	B2-C	46	48	74	56	86	69
	A2-EAB	46	39	50	53	35	42
	A1B-BIO	46	49	105	134	144	169
	A2-BIO	46	51	63	78	101	120
	B2-BIO	46	49	56	98	87	98
Maine	A1B-C	562	549	558	556	560	575
	A2-C	562	524	549	567	503	581
	B2-C	562	586	575	565	566	500
	A2-EAB	562	541	541	519	515	564
	A1B-BIO	562	630	890	1,106	1,172	1,157
	A2-BIO	562	631	709	830	1,020	1,079
	B2-BIO	562	574	645	718	836	880
Maryland	A1B-C	67	103	74	76	67	79
	A2-C	67	85	80	81	81	68
	B2-C	67	81	65	69	81	60
	A2-EAB	67	87	70	72	84	80
	A1B-BIO	67	107	126	113	144	125
	A2-BIO	67	96	90	113	118	120
	B2-BIO	67	104	75	72	105	104
Massachusetts	A1B-C	35	34	32	29	18	21
	A2-C	35	37	32	23	20	21
	B2-C	35	40	22	17	14	16
	A2-EAB	35	34	36	24	22	25
	A1B-BIO	35	53	40	34	36	36
	A2-BIO	35	46	42	29	30	31
	B2-BIO	35	41	27	24	20	19

Table A4.3 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Michigan	A1B-C	339	357	344	408	400	408
	A2-C	339	365	358	372	390	437
	B2-C	339	354	374	370	383	418
	A2-EAB	339	320	328	371	353	407
	A1B-BIO	339	399	650	845	1,114	1,188
	A2-BIO	339	363	490	615	803	939
	B2-BIO	339	389	427	508	668	725
Minnesota	A1B-C	297	249	288	291	289	321
	A2-C	297	241	303	275	318	338
	B2-C	297	230	250	298	293	293
	A2-EAB	297	257	294	295	274	348
	A1B-BIO	297	304	435	605	680	622
	A2-BIO	297	249	296	421	512	542
	B2-BIO	297	267	322	373	456	470
Missouri	A1B-C	175	142	171	179	171	170
	A2-C	175	156	143	141	160	172
	B2-C	175	153	169	170	176	190
	A2-EAB	175	157	179	183	135	178
	A1B-BIO	175	177	250	349	466	623
	A2-BIO	175	195	195	259	333	417
	B2-BIO	175	147	173	224	270	312
New Hampshire	A1B-C	92	113	103	121	144	110
	A2-C	92	90	99	108	130	125
	B2-C	92	111	90	134	127	126
	A2-EAB	92	109	108	113	104	132
	A1B-BIO	92	118	208	284	366	427
	A2-BIO	92	115	170	172	259	308
	B2-BIO	92	117	118	160	220	226

Table A4.3 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
New Jersey	A1B-C	29	35	61	50	51	40
	A2-C	29	52	44	41	46	39
	B2-C	29	44	32	31	42	33
	A2-EAB	29	47	46	38	48	42
	A1B-BIO	29	49	52	65	91	91
	A2-BIO	29	54	47	63	82	74
	B2-BIO	29	43	38	47	58	47
New York	A1B-C	300	172	181	234	219	263
	A2-C	300	170	192	180	227	234
	B2-C	300	175	169	188	197	248
	A2-EAB	300	161	206	188	210	234
	A1B-BIO	300	200	303	489	601	767
	A2-BIO	300	173	248	333	400	506
	B2-BIO	300	161	194	261	363	388
Ohio	A1B-C	189	251	204	218	227	252
	A2-C	189	213	223	244	244	253
	B2-C	189	212	229	198	243	204
	A2-EAB	189	219	186	212	230	219
	A1B-BIO	189	284	390	514	656	734
	A2-BIO	189	253	319	375	472	570
	B2-BIO	189	220	244	330	376	384
Pennsylvania	A1B-C	415	388	386	398	454	465
	A2-C	415	361	407	389	402	425
	B2-C	415	341	376	378	376	355
	A2-EAB	415	387	359	404	454	412
	A1B-BIO	415	395	577	798	1,132	1,308
	A2-BIO	415	397	421	587	741	993
	B2-BIO	415	374	363	503	696	748

Table A4.3 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Rhode Island	A1B-C	2	6	4	6	4	4
	A2-C	2	5	5	5	4	7
	B2-C	2	4	3	2	2	1
	A2-EAB	2	6	5	3	4	5
	A1B-BIO	2	7	9	5	7	6
	A2-BIO	2	6	6	4	6	6
	B2-BIO	2	6	2	1	2	1
Vermont	A1B-C	113	111	123	107	96	106
	A2-C	113	96	99	85	93	101
	B2-C	113	109	89	89	107	117
	A2-EAB	113	86	104	89	110	104
	A1B-BIO	113	109	164	220	311	367
	A2-BIO	113	102	144	162	195	249
	B2-BIO	113	89	96	128	147	190
West Virginia	A1B-C	322	330	277	350	345	321
	A2-C	322	296	280	330	311	328
	B2-C	322	319	312	344	334	304
	A2-EAB	322	355	338	330	325	325
	A1B-BIO	322	382	518	741	967	1,025
	A2-BIO	322	346	443	478	668	815
	B2-BIO	322	356	324	429	561	520
Wisconsin	A1B-C	327	394	421	449	439	486
	A2-C	327	392	417	463	446	471
	B2-C	327	408	396	447	469	492
	A2-EAB	327	383	380	413	425	448
	A1B-BIO	327	436	666	937	1,119	1,132
	A2-BIO	327	456	537	708	874	968
	B2-BIO	327	443	478	590	755	773

Table A4.3 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
All Northern States	A1B-C	3,509	3,466	3,445	3,776	3,747	3,858
	A2-C	3,509	3,332	3,475	3,485	3,612	3,851
	B2-C	3,509	3,393	3,370	3,543	3,692	3,590
	A2-EAB	3,509	3,372	3,389	3,454	3,497	3,781
	A1B-BIO	3,509	3,910	5,650	7,656	9,555	10,403
	A2-BIO	3,509	3,731	4,451	5,528	7,001	8,251
	B2-BIO	3,509	3,587	3,770	4,707	5,943	6,210

[a]*There are seven scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.*

Table A4.4—Projected volume of annual harvest removals in the North, 2010 to 2060, for seven future scenarios based on greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Connecticut	A1B-C	51	14	10	5	6	3
	A2-C	51	16	7	8	8	4
	B2-C	51	10	8	2	2	3
	A2-EAB	51	23	7	1	4	2
	A1B-BIO	51	13	20	14	14	12
	A2-BIO	51	12	10	15	6	9
	B2-BIO	51	13	18	9	7	11
Delaware	A1B-C	7	3	4	9	4	6
	A2-C	7	7	4	4	6	6
	B2-C	7	6	6	5	8	5
	A2-EAB	7	5	6	3	3	6
	A1B-BIO	7	7	5	12	18	16
	A2-BIO	7	4	6	7	9	14
	B2-BIO	7	5	7	8	8	11
Illinois	A1B-C	33	40	29	55	37	38
	A2-C	33	48	31	24	50	35
	B2-C	33	46	31	66	46	35
	A2-EAB	33	44	37	27	45	47
	A1B-BIO	33	50	50	88	122	150
	A2-BIO	33	55	41	65	89	133
	B2-BIO	33	48	54	49	77	71
Indiana	A1B-C	72	98	87	122	119	87
	A2-C	72	101	102	75	95	113
	B2-C	72	83	83	95	114	101
	A2-EAB	72	81	76	81	76	113
	A1B-BIO	72	105	149	261	347	395
	A2-BIO	72	98	142	181	243	311
	B2-BIO	72	111	89	155	204	210

Table A4.4 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Iowa	A1B-C	35	37	47	66	43	44
	A2-C	35	45	62	37	35	42
	B2-C	35	46	73	54	83	68
	A2-EAB	35	38	48	51	33	39
	A1B-BIO	35	47	102	131	140	164
	A2-BIO	35	50	61	76	98	116
	B2-BIO	35	47	55	96	84	96
Maine	A1B-C	542	539	547	544	546	559
	A2-C	542	515	540	557	491	567
	B2-C	542	578	569	560	559	494
	A2-EAB	542	532	532	509	503	550
	A1B-BIO	542	619	880	1,095	1,160	1,143
	A2-BIO	542	622	700	821	1,008	1,065
	B2-BIO	542	565	640	713	829	874
Maryland	A1B-C	54	62	25	28	24	38
	A2-C	54	47	34	40	45	31
	B2-C	54	44	35	43	55	42
	A2-EAB	54	49	25	29	46	42
	A1B-BIO	54	66	79	71	108	89
	A2-BIO	54	58	47	73	82	83
	B2-BIO	54	66	43	46	81	86
Massachusetts	A1B-C	13	19	14	12	< 1	3
	A2-C	13	21	14	4	0	0
	B2-C	13	26	12	11	6	8
	A2-EAB	13	18	18	6	3	4
	A1B-BIO	13	37	23	16	18	18
	A2-BIO	13	30	24	10	10	9
	B2-BIO	13	28	17	17	12	12

Table A4.4 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Michigan	A1B-C	318	327	310	370	357	359
	A2-C	318	339	330	341	354	392
	B2-C	318	328	358	353	360	398
	A2-EAB	318	294	299	340	316	360
	A1B-BIO	318	368	616	809	1,073	1,142
	A2-BIO	318	337	462	584	767	894
	B2-BIO	318	363	410	491	645	706
Minnesota	A1B-C	257	236	275	274	271	302
	A2-C	257	229	290	260	302	323
	B2-C	257	218	242	289	283	285
	A2-EAB	257	246	281	282	259	334
	A1B-BIO	257	291	422	590	663	605
	A2-BIO	257	237	283	405	496	527
	B2-BIO	257	256	314	363	445	461
Missouri	A1B-C	141	125	153	158	146	141
	A2-C	141	141	128	125	140	148
	B2-C	141	138	159	159	162	179
	A2-EAB	141	143	165	166	115	153
	A1B-BIO	141	160	232	329	442	595
	A2-BIO	141	180	181	243	314	394
	B2-BIO	141	132	164	214	257	301
New Hampshire	A1B-C	71	96	83	101	123	87
	A2-C	71	74	81	90	110	101
	B2-C	71	95	78	123	114	115
	A2-EAB	71	93	91	95	84	109
	A1B-BIO	71	100	189	263	344	404
	A2-BIO	71	100	152	155	239	285
	B2-BIO	71	101	107	149	207	215

Table A4.4 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
New Jersey	A1B-C	21	12	35	26	29	20
	A2-C	21	29	19	16	22	14
	B2-C	21	22	14	18	30	24
	A2-EAB	21	24	20	12	23	16
	A1B-BIO	21	26	27	41	69	71
	A2-BIO	21	30	19	38	58	48
	B2-BIO	21	21	22	36	47	38
New York	A1B-C	274	150	157	207	188	227
	A2-C	274	150	172	158	200	201
	B2-C	274	157	159	178	183	237
	A2-EAB	274	142	186	165	182	200
	A1B-BIO	274	177	280	463	570	732
	A2-BIO	274	154	227	311	373	473
	B2-BIO	274	142	184	251	349	377
Ohio	A1B-C	181	237	187	199	205	227
	A2-C	181	201	208	229	225	229
	B2-C	181	200	221	191	233	196
	A2-EAB	181	207	173	195	210	193
	A1B-BIO	181	270	375	496	635	710
	A2-BIO	181	241	306	360	453	546
	B2-BIO	181	209	237	323	366	376
Pennsylvania	A1B-C	362	332	327	333	379	380
	A2-C	362	315	358	336	338	349
	B2-C	362	295	349	351	338	324
	A2-EAB	362	340	309	350	389	334
	A1B-BIO	362	339	517	734	1,059	1,226
	A2-BIO	362	351	371	536	680	919
	B2-BIO	362	327	335	477	660	718

Table A4.4 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Rhode Island	A1B-C	1	3	< 1	2	< 1	< 1
	A2-C	1	2	1	1	< 1	2
	B2-C	1	1	1	< 1	< 1	< 1
	A2-EAB	1	3	1	< 1	< 1	< 1
	A1B-BIO	1	3	5	1	3	2
	A2-BIO	1	3	2	< 1	2	1
	B2-BIO	1	3	< 1	< 1	< 1	< 1
Vermont	A1B-C	105	100	113	95	82	91
	A2-C	105	88	91	76	84	90
	B2-C	105	100	84	83	99	110
	A2-EAB	105	78	96	82	101	94
	A1B-BIO	105	98	153	208	297	352
	A2-BIO	105	94	136	154	186	238
	B2-BIO	105	80	91	122	139	184
West Virginia	A1B-C	286	294	243	309	296	263
	A2-C	286	272	258	308	283	293
	B2-C	286	291	300	329	310	287
	A2-EAB	286	331	317	307	297	290
	A1B-BIO	286	346	484	703	922	970
	A2-BIO	286	322	421	456	641	781
	B2-BIO	286	328	312	413	537	503
Wisconsin	A1B-C	311	375	401	426	412	454
	A2-C	311	377	401	445	425	445
	B2-C	311	392	386	436	454	480
	A2-EAB	311	368	365	396	405	423
	A1B-BIO	311	418	646	915	1,094	1,102
	A2-BIO	311	442	521	690	853	943
	B2-BIO	311	427	469	580	741	761

Table A4.4 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
All Northern States	A1B-C	3,133	3,097	3,046	3,340	3,268	3,327
	A2-C	3,133	3,018	3,133	3,133	3,213	3,387
	B2-C	3,133	3,078	3,169	3,346	3,439	3,389
	A2-EAB	3,133	3,058	3,052	3,096	3,093	3,309
	A1B-BIO	3,133	3,541	5,255	7,240	9,099	9,899
	A2-BIO	3,133	3,418	4,113	5,179	6,607	7,790
	B2-BIO	3,133	3,272	3,566	4,513	5,694	6,012

[a]*There are seven scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.*

Table A4.5—Projected volume of total annual removals attributed to land-use change in North, 2010 to 2060, for seven future scenarios based on greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Connecticut	A1B-C	3	8	9	10	11	12
	A2-C	3	8	10	10	12	14
	B2-C	3	7	5	3	5	4
	A2-EAB	3	8	9	10	12	14
	A1B-BIO	3	8	9	10	10	11
	A2-BIO	3	8	9	10	12	14
	B2-BIO	3	7	5	3	4	4
Delaware	A1B-C	0	3	3	3	4	4
	A2-C	0	3	3	3	4	4
	B2-C	0	3	2	2	2	2
	A2-EAB	0	3	3	3	3	4
	A1B-BIO	0	3	3	3	3	4
	A2-BIO	0	3	3	3	4	4
	B2-BIO	0	3	2	2	2	2
Illinois	A1B-C	24	9	10	9	10	12
	A2-C	24	6	6	6	7	8
	B2-C	24	8	5	5	6	4
	A2-EAB	24	6	7	6	7	8
	A1B-BIO	24	9	10	9	11	12
	A2-BIO	24	6	7	7	8	9
	B2-BIO	24	8	5	6	7	4
Indiana	A1B-C	8	17	18	21	25	29
	A2-C	8	13	13	13	16	19
	B2-C	8	14	7	9	13	10
	A2-EAB	8	13	13	14	17	20
	A1B-BIO	8	17	19	21	24	29
	A2-BIO	8	13	13	13	16	19
	B2-BIO	8	14	8	9	13	10

Table A4.5 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Iowa	A1B-C	11	3	3	3	4	5
	A2-C	11	2	2	3	3	4
	B2-C	11	2	1	1	2	2
	A2-EAB	11	2	2	2	3	3
	A1B-BIO	11	3	3	3	4	4
	A2-BIO	11	2	2	3	3	4
	B2-BIO	11	2	1	2	2	2
Maine	A1B-C	21	10	11	12	13	15
	A2-C	21	9	9	10	12	14
	B2-C	21	9	5	5	7	6
	A2-EAB	21	9	9	10	11	14
	A1B-BIO	21	10	10	10	12	14
	A2-BIO	21	9	9	9	11	14
	B2-BIO	21	9	5	5	7	6
Maryland	A1B-C	13	40	49	48	43	41
	A2-C	13	38	46	40	36	36
	B2-C	13	37	30	27	26	18
	A2-EAB	13	38	45	44	38	38
	A1B-BIO	13	40	47	42	36	35
	A2-BIO	13	38	44	40	36	37
	B2-BIO	13	37	32	26	25	18
Massachusetts	A1B-C	22	15	18	18	18	17
	A2-C	22	16	18	19	20	22
	B2-C	22	14	10	7	8	7
	A2-EAB	22	16	18	18	19	21
	A1B-BIO	22	15	17	19	19	18
	A2-BIO	22	16	19	19	20	22
	B2-BIO	22	14	10	7	8	7

Table A4.5 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Michigan	A1B-C	21	31	33	38	43	49
	A2-C	21	26	28	31	37	45
	B2-C	21	26	17	17	23	20
	A2-EAB	21	26	28	31	37	46
	A1B-BIO	21	31	33	36	41	46
	A2-BIO	21	26	28	31	36	44
	B2-BIO	21	26	17	17	23	20
Minnesota	A1B-C	40	13	13	17	18	19
	A2-C	40	11	13	15	16	15
	B2-C	40	11	8	9	11	9
	A2-EAB	40	11	13	13	15	14
	A1B-BIO	40	13	14	15	16	17
	A2-BIO	40	11	12	15	16	15
	B2-BIO	40	11	8	9	11	9
Missouri	A1B-C	33	18	18	22	25	29
	A2-C	33	14	15	16	19	24
	B2-C	33	15	9	10	14	11
	A2-EAB	33	14	15	17	20	25
	A1B-BIO	33	18	18	20	24	27
	A2-BIO	33	14	14	16	19	24
	B2-BIO	33	15	9	10	14	11
New Hampshire	A1B-C	21	18	20	20	22	24
	A2-C	21	16	18	18	20	23
	B2-C	21	16	12	11	13	11
	A2-EAB	21	16	17	18	20	24
	A1B-BIO	21	18	19	20	22	24
	A2-BIO	21	16	17	17	19	22
	B2-BIO	21	16	12	11	13	11

Table A4.5 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
New Jersey	A1B-C	8	23	26	24	22	20
	A2-C	8	23	25	25	24	25
	B2-C	8	21	18	12	12	10
	A2-EAB	8	23	26	26	26	26
	A1B-BIO	8	23	25	24	22	20
	A2-BIO	8	23	28	25	25	26
	B2-BIO	8	21	16	12	11	9
New York	A1B-C	26	22	24	27	31	36
	A2-C	26	19	21	22	27	33
	B2-C	26	19	10	11	14	11
	A2-EAB	26	19	21	23	28	34
	A1B-BIO	26	22	23	26	30	35
	A2-BIO	26	19	21	22	27	33
	B2-BIO	26	19	10	10	14	11
Ohio	A1B-C	8	14	16	19	22	25
	A2-C	8	12	15	15	19	24
	B2-C	8	12	7	8	10	8
	A2-EAB	8	12	13	17	21	25
	A1B-BIO	8	14	16	18	21	23
	A2-BIO	8	12	13	16	19	24
	B2-BIO	8	12	7	7	10	8
Pennsylvania	A1B-C	54	56	59	66	75	85
	A2-C	54	47	49	53	63	77
	B2-C	54	47	27	27	38	31
	A2-EAB	54	47	50	54	65	78
	A1B-BIO	54	56	61	64	72	82
	A2-BIO	54	47	50	51	61	74
	B2-BIO	54	47	28	25	36	30

Table A4.5 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Rhode Island	A1B-C	2	3	4	4	4	4
	A2-C	2	4	4	4	4	5
	B2-C	2	3	2	1	2	1
	A2-EAB	2	4	4	4	4	5
	A1B-BIO	2	3	4	4	4	4
	A2-BIO	2	4	4	4	4	5
	B2-BIO	2	3	2	1	2	1
Vermont	A1B-C	8	11	11	12	13	15
	A2-C	8	8	8	8	10	11
	B2-C	8	9	5	6	8	6
	A2-EAB	8	8	8	8	9	11
	A1B-BIO	8	11	11	12	13	15
	A2-BIO	8	8	7	8	9	11
	B2-BIO	8	9	5	6	8	6
West Virginia	A1B-C	36	35	34	41	49	58
	A2-C	36	24	22	22	27	35
	B2-C	36	28	12	15	24	16
	A2-EAB	36	24	21	23	28	36
	A1B-BIO	36	35	34	38	45	54
	A2-BIO	36	24	22	22	27	34
	B2-BIO	36	28	12	16	24	17
Wisconsin	A1B-C	16	18	21	23	27	31
	A2-C	16	15	16	18	21	26
	B2-C	16	15	10	11	15	12
	A2-EAB	16	15	15	17	21	25
	A1B-BIO	16	18	20	22	26	30
	A2-BIO	16	15	16	17	21	26
	B2-BIO	16	15	10	11	15	12

Table A4.5 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
All Northern States	A1B-C	375	369	399	436	479	531
	A2-C	375	314	341	352	398	464
	B2-C	375	315	201	197	252	201
	A2-EAB	375	314	337	358	404	472
	A1B-BIO	375	369	395	416	455	505
	A2-BIO	375	314	338	349	395	461
	B2-BIO	375	315	203	194	249	198

[a]*There are seven scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.*

Table A4.6—Projected net annual growth of growing stock in the North, 2010 to 2060, for seven future scenarios based on greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Connecticut	A1B-C	79	15	55	-4	-4	-39
	A2-C	79	30	11	-2	-3	-32
	B2-C	79	4	2	-2	-2	11
	A2-EAB	79	31	8	-8	-7	-33
	A1B-BIO	79	15	35	5	4	-11
	A2-BIO	79	23	9	5	-5	-7
	B2-BIO	79	24	-6	6	3	-1
Delaware	A1B-C	31	1	8	5	< 1	-1
	A2-C	31	7	2	< 1	2	6
	B2-C	31	4	9	4	6	3
	A2-EAB	31	7	-4	1	< 1	11
	A1B-BIO	31	3	7	8	14	7
	A2-BIO	31	8	4	4	6	4
	B2-BIO	31	1	7	6	6	14
Illinois	A1B-C	226	110	-2	47	28	23
	A2-C	226	95	33	18	44	30
	B2-C	226	104	-21	61	41	104
	A2-EAB	226	81	38	22	39	81
	A1B-BIO	226	77	75	80	112	41
	A2-BIO	226	81	69	60	82	41
	B2-BIO	226	83	59	44	71	46
Indiana	A1B-C	318	165	104	102	96	91
	A2-C	318	154	103	63	80	171
	B2-C	318	131	120	87	102	94
	A2-EAB	318	127	142	68	60	104
	A1B-BIO	318	174	120	242	325	317
	A2-BIO	318	156	168	168	228	235
	B2-BIO	318	147	154	147	193	142

Table A4.6 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Iowa	A1B-C	103	98	47	63	40	31
	A2-C	103	93	73	35	33	66
	B2-C	103	106	93	53	82	79
	A2-EAB	103	91	77	50	31	10
	A1B-BIO	103	89	102	128	137	100
	A2-BIO	103	87	72	74	95	68
	B2-BIO	103	89	82	95	82	65
Maine	A1B-C	573	634	598	533	534	476
	A2-C	573	596	645	549	481	523
	B2-C	573	672	606	556	553	521
	A2-EAB	573	613	560	500	492	519
	A1B-BIO	573	635	769	1,086	1,149	240
	A2-BIO	573	666	656	812	998	434
	B2-BIO	573	643	627	709	823	498
Maryland	A1B-C	176	40	-8	-18	-17	18
	A2-C	176	27	-5	1	11	-11
	B2-C	176	16	-6	17	30	16
	A2-EAB	176	47	7	-13	9	-25
	A1B-BIO	176	24	14	31	74	16
	A2-BIO	176	17	22	34	47	3
	B2-BIO	176	56	-14	22	57	30
Massachusetts	A1B-C	155	21	-27	-4	-16	-41
	A2-C	155	12	1	-14	-19	-36
	B2-C	155	6	4	4	-1	-21
	A2-EAB	155	4	11	-11	-15	-52
	A1B-BIO	155	32	3	-1	1	-26
	A2-BIO	155	22	-3	-8	-9	-51
	B2-BIO	155	39	1	11	4	-9

Table A4.6 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Michigan	A1B-C	697	445	348	336	318	494
	A2-C	697	446	383	313	320	542
	B2-C	697	444	469	337	338	572
	A2-EAB	697	397	372	311	282	493
	A1B-BIO	697	450	573	776	1,036	600
	A2-BIO	697	458	434	556	733	617
	B2-BIO	697	459	523	476	624	589
Minnesota	A1B-C	421	306	391	260	255	475
	A2-C	421	325	412	247	288	486
	B2-C	421	280	367	282	273	367
	A2-EAB	421	355	399	270	247	523
	A1B-BIO	421	352	409	577	650	119
	A2-BIO	421	306	418	392	482	390
	B2-BIO	421	333	405	355	436	282
Missouri	A1B-C	510	268	229	139	124	245
	A2-C	510	263	199	111	124	295
	B2-C	510	220	284	150	151	340
	A2-EAB	510	259	256	152	98	307
	A1B-BIO	510	248	279	312	422	482
	A2-BIO	510	304	234	229	298	402
	B2-BIO	510	227	269	205	245	365
New Hampshire	A1B-C	188	153	81	82	102	59
	A2-C	188	144	69	73	91	78
	B2-C	188	157	85	113	102	96
	A2-EAB	188	132	106	78	65	98
	A1B-BIO	188	133	181	244	324	220
	A2-BIO	188	160	122	139	221	174
	B2-BIO	188	123	144	139	195	118

Table A4.6 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
New Jersey	A1B-C	95	3	15	3	9	-15
	A2-C	95	-11	18	-7	-1	-5
	B2-C	95	20	1	6	19	4
	A2-EAB	95	-14	13	-13	-2	10
	A1B-BIO	95	4	3	18	49	39
	A2-BIO	95	11	11	15	34	-5
	B2-BIO	95	2	11	25	36	18
New York	A1B-C	627	335	324	182	159	278
	A2-C	627	352	283	137	176	263
	B2-C	627	320	357	168	170	316
	A2-EAB	627	389	323	143	157	315
	A1B-BIO	627	326	459	439	542	604
	A2-BIO	627	321	362	290	349	453
	B2-BIO	627	297	402	241	336	338
Ohio	A1B-C	410	377	233	181	185	373
	A2-C	410	361	210	216	207	312
	B2-C	410	314	317	184	224	273
	A2-EAB	410	304	282	180	191	239
	A1B-BIO	410	361	379	480	616	487
	A2-BIO	410	305	390	345	435	461
	B2-BIO	410	301	335	316	357	342
Pennsylvania	A1B-C	746	354	313	270	308	436
	A2-C	746	305	415	286	279	412
	B2-C	746	307	465	326	301	362
	A2-EAB	746	434	387	299	328	396
	A1B-BIO	746	402	421	673	991	700
	A2-BIO	746	428	356	488	622	609
	B2-BIO	746	352	374	454	626	581

Table A4.6 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
Rhode Island	A1B-C	19	-2	2	-2	-4	-9
	A2-C	19	4	-9	-3	-4	-3
	B2-C	19	-7	3	-1	-1	-2
	A2-EAB	19	< 1	1	-4	-4	-9
	A1B-BIO	19	2	12	-3	-2	-11
	A2-BIO	19	< 1	-3	-3	-2	2
	B2-BIO	19	< 1	-3	-2	-1	-5
Vermont	A1B-C	192	132	122	84	70	88
	A2-C	192	92	138	69	75	116
	B2-C	192	149	92	78	92	89
	A2-EAB	192	99	104	74	93	106
	A1B-BIO	192	132	145	197	285	170
	A2-BIO	192	98	198	146	178	98
	B2-BIO	192	121	99	117	131	174
West Virginia	A1B-C	609	226	303	271	250	223
	A2-C	609	233	238	287	257	352
	B2-C	609	187	333	315	287	333
	A2-EAB	609	325	413	285	270	346
	A1B-BIO	609	299	387	667	879	523
	A2-BIO	609	298	350	436	616	560
	B2-BIO	609	223	346	399	514	401
Wisconsin	A1B-C	586	618	544	405	387	603
	A2-C	586	613	539	429	406	629
	B2-C	586	619	534	427	441	672
	A2-EAB	586	581	485	380	386	625
	A1B-BIO	586	603	643	894	1,070	467
	A2-BIO	586	675	585	674	833	596
	B2-BIO	586	612	608	570	727	648

Table A4.6 continued

State	Scenario[a]	Year					
		2010	2020	2030	2040	2050	2060
		(million cubic feet)					
All Northern States	A1B-C	6,759	4,299	3,680	2,936	2,825	3,809
	A2-C	6,759	4,144	3,758	2,807	2,845	4,194
	B2-C	6,759	4,052	4,113	3,164	3,206	4,227
	A2-EAB	6,759	4,260	3,978	2,763	2,719	4,065
	A1B-BIO	6,759	4,358	5,017	6,855	8,679	5,083
	A2-BIO	6,759	4,424	4,455	4,856	6,241	5,085
	B2-BIO	6,759	4,133	4,424	4,334	5,465	4,638

[a]*There are seven scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO). Scenario A2-EAB is a variation of scenario A2-C that also assumes all ash species will gradually succumb to an expanding zone of infestation by the nonnative emerald ash borer.*

Please refer to the Literature Cited section at the end of Chapter 4 for the references.

Table A7.1—Projections of total aboveground biomass on timberland for enhanced biomass utilization scenarios in the North, 2010 to 2060, for three future scenarios based on greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007).

State	Initial for all scenarios	Scenario[a]				
	2010	A2-BIO 2020	A2-BIO 2030	A2-BIO 2040	A2-BIO 2050	A2-BIO 2060
	(million dry tons)					
New York	880	921	957	950	943	933
Missouri	606	643	641	637	631	625
Ohio	452	465	490	485	479	450
Iowa	111	122	126	125	124	109
Minnesota	428	442	464	460	456	416
Indiana	250	264	268	264	260	242
Illinois	229	233	239	237	235	211
Vermont	270	273	282	280	277	247
Wisconsin	595	636	645	640	635	544
Connecticut	119	119	121	118	115	108
Michigan	774	794	783	775	766	701
Pennsylvania	980	987	983	969	951	848
New Hampshire	270	276	273	269	264	232
Massachusetts	198	194	193	188	183	169
West Virginia	766	759	737	731	723	651
Delaware	23	24	23	22	21	19
Rhode Island	22	20	19	18	17	17
Maine	647	653	639	636	634	505
New Jersey	101	96	92	85	78	64
Maryland	168	156	146	135	126	106
All Northern States	7,890	8,079	8,119	8,024	7,917	7,196

Table A7.1 continued

State	Scenario[a]				
	A1B-BIO 2060	B2-BIO 2060	A2-BIO	A1B-BIO	B2-BIO
	----------(million dry tons)----------		----------(percent change, 2010 to 2060)----------		
New York	903	948	6.1	2.6	7.7
Missouri	573	653	3.2	-5.4	7.8
Ohio	388	481	-0.6	-14.2	6.3
Iowa	99	119	-1.9	-10.4	7.3
Minnesota	303	410	-2.8	-29.3	-4.3
Indiana	226	254	-3.0	-9.7	1.5
Illinois	207	223	-8.0	-9.8	-2.5
Vermont	219	277	-8.6	-18.9	2.6
Wisconsin	447	605	-8.6	-24.9	1.7
Connecticut	111	109	-9.4	-6.8	-8.4
Michigan	625	772	-9.4	-19.3	-0.3
Pennsylvania	748	911	-13.5	-23.7	-7.1
New Hampshire	207	248	-14.1	-23.5	-8.0
Massachusetts	173	191	-14.5	-12.6	-3.3
West Virginia	553	701	-15.0	-27.9	-8.4
Delaware	18	21	-18.9	-21.8	-8.8
Rhode Island	17	18	-21.3	-23.5	-18.4
Maine	430	577	-22.0	-33.6	-10.8
New Jersey	65	80	-36.7	-36.0	-21.2
Maryland	95	119	-36.9	-43.4	-29.3
All Northern States	6,405	7,717	-8.8	-18.8	-2.2

[a]There are three scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections (labeled –BIO) assume harvest will increase to reflect increased harvest for bioenergy production.

Table A7.2—Estimates of annual net forest biomass change based on enhanced biomass utilization scenarios in the North, 2010 to 2060, for three future scenarios based on greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007). Note that estimates for 2060 are based on both a 10-year increment (2050 to 2060) and a 50-year increment (2010 to 2060), and the initial 2010 estimate was calculated using volume growth and removals from the current FIA inventory panel.

State	Estimated for 2010	Scenario[a]				
		A2-BIO 2010 to 2020	A2-BIO 2020 to 2030	A2-BIO 2030 to 2040	A2-BIO 2040 to 2050	A1B-BIO 2050 to 2060
	(thousand dry tons)					
Maine	-930	569	-1,433	-239	-287	-12,892
Pennsylvania	10,095	701	-364	-1,465	-1,753	-10,310
West Virginia	9,013	-680	-2,228	-637	-784	-7,200
Michigan	9,713	2,063	-1,179	-770	-917	-6,459
Maryland	3,406	-1,116	-1,057	-1,054	-952	-1,979
Wisconsin	6,784	4,111	847	-430	-517	-9,141
New Hampshire	2,708	599	-283	-440	-493	-3,165
New Jersey	2,155	-551	-433	-691	-684	-1,391
Massachusetts	3,465	-387	-106	-507	-535	-1,333
Vermont	1,184	245	912	-210	-241	-3,049
Illinois	5,612	392	630	-189	-214	-2,426
Minnesota	4,166	1,343	2,195	-356	-386	-4,051
Connecticut	459	47	192	-292	-345	-712
Indiana	6,930	1,391	365	-354	-429	-1,724
Rhode Island	565	-128	-143	-107	-117	63
Delaware	772	70	-49	-90	-101	-258
Ohio	7,555	1,312	2,403	-454	-560	-2,987
Iowa	2,274	1,119	317	-68	-81	-1,527
Missouri	11,209	3,627	-151	-466	-564	-567
New York	10,362	4,166	3,523	-619	-742	-974
All Northern States	97,497	18,893	3,959	-9,439	-10,701	-72,083

Table A7.2 continued

State	Scenario[a]				
	A2-BIO 2050 to 2060	B2-BIO 2050 to 2060	A1B-BIO 2010 to 2060	A2-BIO 2010 to 2060	B2-BIO 2010 to 2060
	(thousand dry tons)				
Maine	-18,649	-7,587	-2,856	-4,350	-1,401
Pennsylvania	-16,377	-5,266	-2,638	-4,636	-1,381
West Virginia	-14,292	-3,505	-2,306	-4,274	-1,297
Michigan	-12,563	-2,743	-1,452	-2,986	-38
Maryland	-1971	-1,505	-1,232	-1,449	-976
Wisconsin	-15,832	-4,328	-1,026	-2,965	198
New Hampshire	-5,327	-2,433	-756	-1,265	-428
New Jersey	-1,106	-713	-750	-736	-437
Massachusetts	-928	-259	-573	-499	-129
Vermont	-5,177	-107	-469	-1,029	133
Illinois	-2,537	-1,382	-361	-444	-112
Minnesota	-11,761	-4,310	-251	-2,512	-376
Connecticut	-514	-256	-222	-160	-200
Indiana	-2,260	-1,653	-150	-484	77
Rhode Island	-295	-112	-86	-96	-74
Delaware	-248	5	-86	-99	-40
Ohio	-7,743	-1,771	-57	-1,290	566
Iowa	-2,228	-1,107	-48	-235	157
Missouri	-5,001	369	376	-663	935
New York	-4,073	-2,077	1,071	471	1,357
All Northern States	-128,882	-40,740	-13,874	-29,702	-3,465

[a]*There are three scenarios, each representing a global greenhouse storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections (labeled –BIO) assume harvest will increase to reflect increased harvest for bioenergy production.*

Table A7.3—Values for annually available woody biomass for bioenergy by net annual woody biomass increase (NAWI), logging residues, standing dead material, and unused mill byproducts by State, 2010. Note that logging residues and standing dead material were assessed for both 100 percent availability and 65 percent availability to account for an assumed 35 percent retention rate for residues and dead material for ecological stability and physical inaccessibility.

State	NAWI	Logging Residues		Standing Dead		Unused mill byproducts
		100 percent	65 percent	100 percent	65 percent	
	(1,000 dry tons)					
Connecticut	459	921	599	935	608	13
Delaware	772	113	74	124	81	0
Illinois	5,612	539	350	2,415	1,570	58
Indiana	6,930	1,227	798	1,970	1,281	34
Iowa	2,274	522	339	981	638	1
Maine	0	9,178	5,966	7,030	4,570	141
Maryland	3,406	931	605	1,191	774	57
Massachusetts	3,465	200	130	1,603	1,042	0
Michigan	9,713	5,368	3,489	6,888	4,477	46
Minnesota	4,166	4,166	2,708	6,179	4,016	89
Missouri	11,209	2,520	1,638	3,959	2,573	259
New Hampshire	2,708	1,261	820	2,517	1,636	23
New Jersey	2,155	355	231	650	422	5
New York	10,362	4,733	3,076	7,337	4,769	91
Ohio	7,555	3,241	2,107	3,631	2,360	75
Pennsylvania	10,095	6,416	4,170	6,810	4,427	570
Rhode Island	565	10	7	137	89	1
Vermont	1,184	1,799	1,170	1,584	1,030	0
West Virginia	9,013	5,048	3,281	4,892	3,180	394
Wisconsin	6,784	5,284	3,435	5,307	3,449	212
All Northern States	98,427	53,831	34,990	66,141	42,992	2,068

Please refer to the Literature Cited section at the end of Chapter 7 for the references.

Table A8.1—Estimated value of shipment of forest products, 2001 to 2011, in the North (U.S. Census Bureau 2012).

State	Year								
	1997	2002	2005	2006	2007	2008	2009	2010	2011
	(million dollars)								
Connecticut	191	215	242	251	244	--	--	--	156
Delaware	90	89	--	--	--	--	--	--	--
Illinois	1,138	1,301	1,500	1,515	1,729	1,695	1,294	1,423	1,322
Indiana	3,167	3,121	3,558	3,434	3,243	2,823	2,173	2,328	2,502
Iowa	1,063	1,464	1,884	1,979	1,802	1,654	1,322	1,434	1,411
Maine	925	1,079	1,290	1,150	1,149	1,100	702	776	797
Maryland	567	905	1,118	1,166	802	589	457	464	441
Massachusetts	398	506	732	768	617	538	385	442	451
Michigan	2,034	2,022	2,501	2,535	2,410	2,027	1,645	1,930	1,903
Minnesota	2,499	3,002	3,697	3,643	3,585	2,977	2,228	2,415	2,398
Missouri	1,030	1,169	1,264	1,240	1,289	1,150	893	908	998
New Hampshire	476	629	606	599	544	437	383	387	401
New Jersey	406	484	715	810	806	683	558	498	455
New York	1,334	1,439	1,607	1,713	1,622	1,482	1,032	1,163	1,114
Ohio	2,386	2,505	2,749	2,784	2,559	2,352	1,818	1,909	2,019
Pennsylvania	3,293	4,090	5,539	5,401	5,027	4,359	3,475	3,386	3,261
Rhode Island	101	137	--	--	--	--	--		--
Vermont	420	429	424	416	383	344	277	239	239
West Virginia	1,074	1,620	1,999	1,887	1,808	1,522	1,034	1,191	1,185
Wisconsin	3,748	4,302	5,281	5,169	4,756	4,184	3,159	3,297	3,324
All Northern States	26,341	30,507	36,704	36,460	34,376	29,917	22,837	24,190	24,378
U.S. total	88,470	89,436	112,095	112,403	102,029	87,765	65,440	--	--

--- *Value is zero or not available.*

Table A8.2—Estimated value of shipment of paper and paperboard in the North, 2001 to 2011 (U.S. Census Bureau 2012).

State	Year								
	1997	2002	2005	2006	2007	2008	2009	2010	2011
	(million dollars)								
Connecticut	1,839	1,736	1,675	1,700	1,791	1,678	1,554	1,501	1,560
Delaware	804	647	549	--	--	--	--	--	--
Illinois	5,873	5,290	5,801	5,782	5,768	5,829	5,239	5,615	5,281
Indiana	2,765	3,158	3,305	3,416	3,834	3,777	3,517	3,872	3,901
Iowa	1,531	1,345	1,407	1,522	1,759	1,714	1,467	1,611	1,638
Maine	4,460	4,131	3,840	3,476	3,914	4,491	4,080	3,512	4,028
Maryland	1,166	1,216	1,371	1,314	1,210	1,063	1,005	1,091	1,056
Massachusetts	4,042	3,412	3,340	3,267	3,546	3,257	2,829	2,988	2,896
Michigan	4,878	4,632	4,802	4,965	4,944	5,189	4,482	4,848	4,968
Minnesota	4,050	4,050	5,067	4,384	5,204	5,420	4,791	5,504	5,853
Missouri	2,986	3,660	4,256	4,579	4,647	4,574	4,374	4,513	4,886
New Hampshire	882	511	496	415	--	--	--	--	--
New Jersey	3,211	3,255	3,476	3,241	3,216	3,198	2,760	2,427	2,582
New York	5,140	4,512	4,947	5,059	4,996	5,190	5,022	5,397	5,659
Ohio	6,844	6,858	6,904	7,422	8,119	7,785	6,653	7,188	7,415
Pennsylvania	8,901	9,236	9,793	10,935	10,285	11,057	10,503	11,336	11,554
Rhode Island	303	259	264	257	247	254	158	--	--
Vermont	382	390	302	--	--	--	--	--	--
West Virginia	130	200		--	--	--	--	--	--
Wisconsin	12,652	13,603	13,261	13,806	14,193	14,258	13,042	14,221	14,465
All Northern States	72,840	72,103	74,855	75,540	77,675	78,734	71,476	75,624	77,742
U.S. total	150,296	153,223	161,929	169,033	176,108	179,249	161,816	--	--

-- Value is zero or not available.

Please refer to the Literature Cited section at the end of Chapter 8 for the references.

Table A10.1—Percentage and area of additional urban development, 1990 to 2000, in various land-cover classes in the conterminous United States (Nowak et al. 2005).

State and region	Forest[a]	Agriculture[b]	Other[c]	Developed[d]	Woody wetland[e]	Herbaceous wetland[f]
	(percent)					
Connecticut	64.1	11.5	0.9	16.2	5.8	1.7
Delaware	28.4	45.6	1.4	15.3	5.2	4.0
Maine	54.8	7.7	1.3	26.1	3.7	6.3
Maryland	43.5	40.7	2.6	9.5	2.7	0.9
Massachusetts	62.9	7.6	1.4	17.7	6.1	4.2
New Hampshire	61.3	10.2	1.3	20.7	4.2	2.4
New Jersey	48.4	28.0	1.0	12.7	8.6	1.3
New York	51.2	28.1	0.5	17.5	1.9	0.7
Ohio	31.6	50.8	0.4	14.3	2.3	0.6
Pennsylvania	42.7	45.5	1.4	9.7	0.4	0.2
Rhode Island	64.8	5.7	0.8	19.0	7.9	1.9
Vermont	39.7	28.1	1.7	22.4	5.5	2.6
West Virginia	62.2	25.4	1.8	10.4	0.2	0.1
Northeast total	47.9	32.0	1.2	14.1	3.4	1.4
Illinois	15.2	64.8	1.8	15.2	2.4	0.7
Indiana	15.2	66.8	0.8	14.9	1.9	0.5
Iowa	12.1	52.3	8.0	25.4	1.7	0.6
Michigan	31.2	47.5	2.1	12.2	6.1	1.0
Minnesota	17.7	52.4	1.1	17.6	3.7	7.4
Missouri	28.6	44.7	6.5	19.0	0.8	0.3
Wisconsin	18.3	62.0	2.2	14.5	2.2	0.6
North Central total	20.9	56.7	2.5	15.5	3.0	1.3
All Northern States	37.0	42.0	1.7	14.7	3.3	1.4
Florida	18.8	17.9	13.8	28.9	14.4	6.1
Georgia	64.0	18.8	3.1	8.9	4.0	1.3
North Carolina	55.9	22.8	1.1	14.5	5.0	0.6
South Carolina	52.9	21.4	2.3	15.4	6.0	1.9
Virginia	48.4	28.1	3.4	13.9	4.5	1.7
Southeast total	44.9	20.6	6.1	17.8	7.8	2.8

Table A10.1 continued

State and region	Forest[a]	Agriculture[b]	Other[c]	Developed[d]	Woody wetland[e]	Herbaceous wetland[f]
	(percent)					
Alabama	55.5	30.2	1.1	8.8	4.2	0.2
Arkansas	36.8	44.8	0.6	16.3	1.1	0.4
Kentucky	38.1	46.1	0.4	13.3	1.9	0.2
Louisiana	36.3	38.7	1.1	16.5	4.4	3.1
Mississippi	41.9	39.5	1.0	11.6	5.4	0.6
Oklahoma	16.9	38.5	24.4	19.8	0.3	0.1
Tennessee	48.0	37.6	0.6	12.4	1.4	0.1
Texas	21.2	40.9	22.1	14.3	0.5	0.9
South Central total	33.8	39.3	10.6	13.7	1.8	0.7
All Southern States	39.9	29.0	8.1	16.0	5.1	1.9
Kansas	8.3	46.8	23.7	19.6	0.1	1.4
Nebraska	3.2	68.9	12.4	14.4	0.2	0.8
North Dakota	3.3	32.7	19.5	42.9	0.1	1.5
South Dakota	5.5	50.6	19.9	22.2	0.4	1.4
All Great Plains States	6.3	51.3	20.1	20.8	0.2	1.3
Arizona	8.4	19.2	60.7	11.6	0.0	0.0
Colorado	10.3	26.1	48.6	15.0	0.0	0.0
Idaho	3.1	54.6	26.0	15.5	0.5	0.2
Montana	5.5	37.4	23.9	30.9	1.9	0.3
Nevada	0.8	7.7	77.8	13.5	0.1	0.1
New Mexico	3.2	11.4	73.8	11.0	0.4	0.1
Utah	6.8	40.5	41.1	11.1	0.5	0.1
Wyoming	1.8	11.1	60.2	24.5	0.9	1.5
Intermountain total	6.2	22.5	57.6	13.4	0.2	0.1
All Rocky Mountain States	6.3	27.0	51.7	14.5	0.2	0.3
Oregon	26.3	41.3	14.2	17.3	0.3	0.5
Washington	46.5	20.4	13.9	18.4	0.7	0.1
Pacific Northwest total	40.3	26.9	14.0	18.0	0.6	0.2
California	9.3	20.1	58.9	11.3	0.1	0.4
Pacific Southwest total	9.3	20.1	58.9	11.3	0.1	0.4
All Pacific Coast States	19.1	22.2	44.7	13.4	0.2	0.3
Conterminous U.S. total	33.4	32.7	14.0	15.1	3.5	1.4

Table A10.1 continued

State and region	Forest[a]	Agriculture[b]	Other[c]	Developed[d]	Woody wetland[e]	Herbaceous wetland[f]
	(acres)					
Connecticut	108,600	19,400	1,500	27,500	9,800	2,800
Delaware	15,800	25,500	800	8,500	2,900	2,200
Maine	22,800	3,200	600	10,800	1,600	2,600
Maryland	98,800	92,500	6,000	21,600	6,100	2,100
Massachusetts	198,600	24,000	4,400	55,900	19,400	13,300
New Hampshire	66,100	11,000	1,400	22,300	4,500	2,500
New Jersey	130,200	75,300	2,600	34,200	23,300	3,400
New York	152,500	83,700	1,500	52,200	5,700	2,000
Ohio	131,600	211,500	1,800	59,400	9,700	2,600
Pennsylvania	251,800	268,600	8,500	57,500	2,600	1,500
Rhode Island	26,400	2,300	300	7,700	3,200	700
Vermont	7,000	5,000	300	4,000	1,000	500
West Virginia	47,600	19,500	1,400	8,000	100	100
Northeast total	1,257,900	841,400	30,800	369,600	89,800	36,400
Illinois	59,900	254,800	7,000	59,600	9,300	2,900
Indiana	45,900	201,100	2,300	44,800	5,600	1,400
Iowa	9,500	41,200	6,300	20,100	1,300	500
Michigan	124,800	190,100	8,400	48,700	24,500	4,100
Minnesota	30,000	88,700	1,800	29,900	6,300	12,600
Missouri	61,800	96,500	14,100	40,900	1,800	700
Wisconsin	39,000	131,700	4,700	30,900	4,800	1,400
North Central total	370,800	1,004,200	44,600	274,800	53,600	23,400
All Northern States	1,628,700	1,845,600	75,500	644,400	143,400	59,800
Florida	182,300	173,200	133,500	279,700	139,400	59,300
Georgia	472,100	138,400	22,700	65,700	29,300	9,800
North Carolina	381,900	155,900	7,700	99,400	34,100	4,000
South Carolina	161,800	65,500	6,900	47,200	18,300	6,000
Virginia	141,800	82,400	9,900	40,700	13,000	5,100
Southeast total	1,340,000	615,500	180,700	532,700	234,100	84,100

Table A10.1 continued

State and region	Forest[a]	Agriculture[b]	Other[c]	Developed[d]	Woody wetland[e]	Herbaceous wetland[f]
	(acres)					
Alabama	163,800	89,200	3,400	25,900	12,300	700
Arkansas	51,200	62,400	800	22,700	1,500	600
Kentucky	63,000	76,100	700	21,900	3,200	200
Louisiana	73,600	78,400	2,200	33,400	8,900	6,200
Mississippi	57,900	54,500	1,300	16,100	7,500	800
Oklahoma	22,200	50,400	31,900	25,900	400	100
Tennessee	190,000	148,600	2,200	48,900	5,400	300
Texas	209,600	405,300	218,800	141,800	5,300	9,000
South Central total	831,300	964,900	261,300	336,600	44,400	18,000
All Southern States	2,171,200	1,580,400	442,000	869,300	278,500	102,100
Kansas	8,700	48,900	24,700	20,500	100	1,500
Nebraska	1,500	31,600	5,700	6,600	100	400
North Dakota	600	5,700	3,400	7,500	0	200
South Dakota	1,100	10,200	4,000	4,500	100	300
All Great Plains States	11,800	96,300	37,800	39,100	300	2,300
Arizona	28,400	65,500	206,600	39,600	0	0
Colorado	18,000	45,700	85,200	26,200	0	0
Idaho	2,000	34,200	16,300	9,700	300	100
Montana	1,700	11,300	7,200	9,300	600	100
Nevada	1,200	10,800	109,100	18,900	100	100
New Mexico	4,600	16,300	105,800	15,700	600	100
Utah	7,100	42,000	42,700	11,600	500	100
Wyoming	300	2,000	10,700	4,300	200	300
Intermountain total	63,300	227,800	583,600	135,400	2,400	900
All Rocky Mountain States	75,100	324,200	621,400	174,400	2,700	3,300

Table A10.1 continued

State and region	Forest[a]	Agriculture[b]	Other[c]	Developed[d]	Woody wetland[e]	Herbaceous wetland[f]
	(acres)					
Oregon	33,700	52,900	18,200	22,200	400	700
Washington	133,400	58,600	40,000	52,600	1,900	200
Pacific Northwest total	167,100	111,400	58,100	74,800	2,300	800
California	83,600	181,200	530,400	101,500	600	3,500
Pacific Southwest total	83,600	181,200	530,400	101,500	600	3,500
All Pacific Coast States	250,700	292,600	588,600	176,200	2,900	4,300
Conterminous U.S. total	4,125,700	4,042,800	1,727,600	1,864,400	427,500	169,500

[a]*Deciduous, evergreen, or mixed forests, with 25 to 100 percent tree cover.*

[b]*Pasture, hay, row crops, small grains, or fallow (75 to 100 percent of the cover); or orchard, vineyards, or other planted woody vegetation (25 to 100 percent of the cover).*

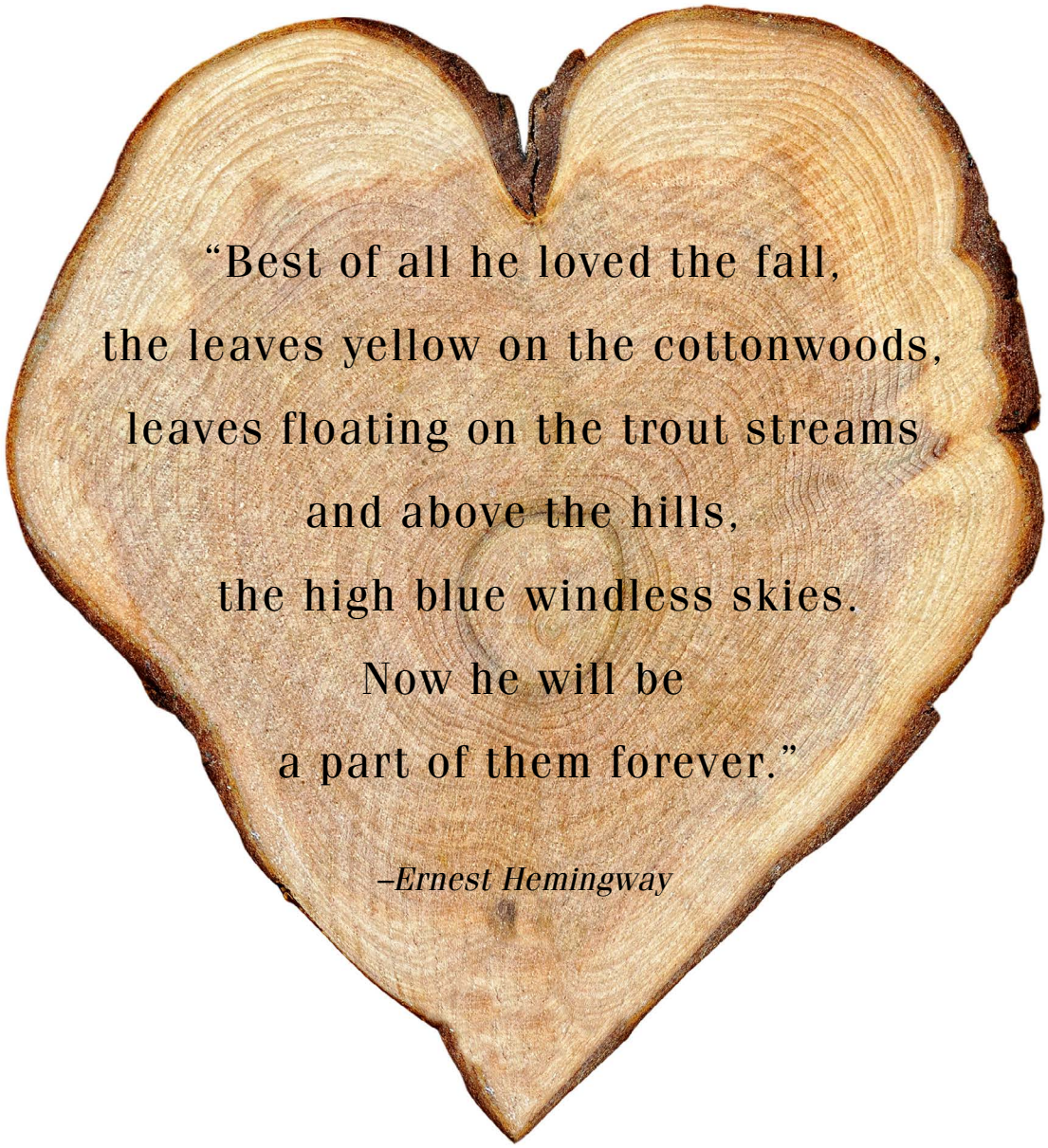
[c]*Bare, rock, sand, clay, quarries, strip mines, gravel pits, transitional areas, or shrubland (25 to 100 percent of the cover); or natural, seminatural grasslands and herbaceous plants (75 to 100 percent of the cover).*

[d]*Areas characterized by a high percentage (30 percent or more) of constructed materials or vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes (75 to 100 percent of the cover).*

[e]*Areas where forest or shrubland vegetation accounts for 25 to 100 percent of the cover and the soil or substrate is periodically saturated with or covered by water.*

[f]*Areas where perennial herbaceous vegetation accounts for 75 to 100 percent of the cover and the soil or substrate is periodically saturated with or covered by water.*

Please refer to the Literature Cited section at the end of Chapter 10 for the references.


"Best of all he loved the fall,
the leaves yellow on the cottonwoods,
leaves floating on the trout streams
and above the hills,
the high blue windless skies.
Now he will be
a part of them forever."
–Ernest Hemingway

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