Projection Methods

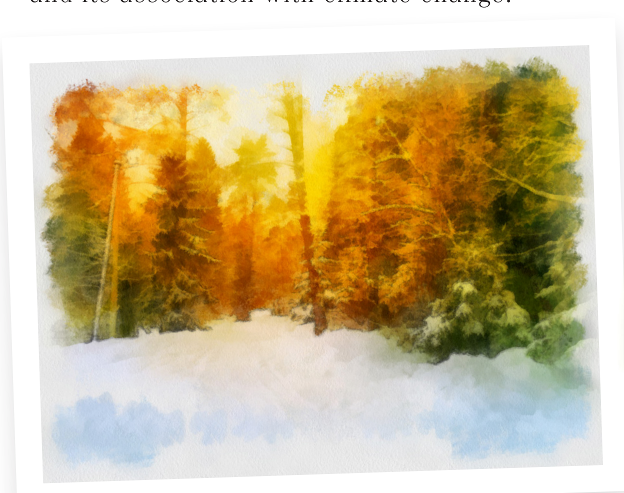
2

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.; 2013, 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).

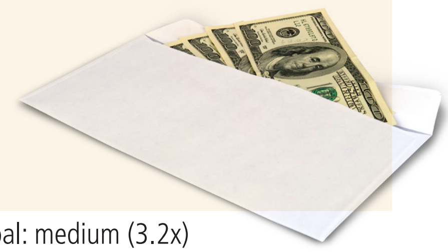
Climatologists have applied multiple models (competing hypotheses) to estimate and map future change in temperature and precipitation for a given future trend in greenhouse gas emissions. These general circulation models vary considerably in the rate of climate change that they predict. For example, 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 new and more efficient energy technologies; emphasis on capacity building. Storyline variation A1B assumes moderate greenhouse gas emission and a balanced use of fossil and renewable fuels.	High	Medium Global: 1.3x United States: 1.5x	Global: Very High (6.2x) United States: medium (3.3x)
A2	A more differentiated world with less trade compared to storyline A1B; uneven economic growth; slower technological change.	Moderate	High Global: 1.7x United States: 1.7x	Global: medium (3.2x) United States: low (2.6x)
B2	Sustainable development and diversified technologies; increased concern for environmental and social sustainability.	Low	Medium Global: 1.4x United States: 1.3x	Global: medium (3.5x) United States: low (2.2x)

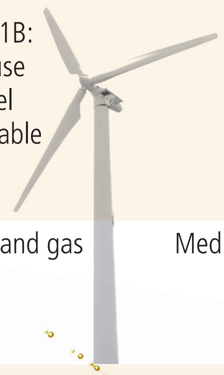


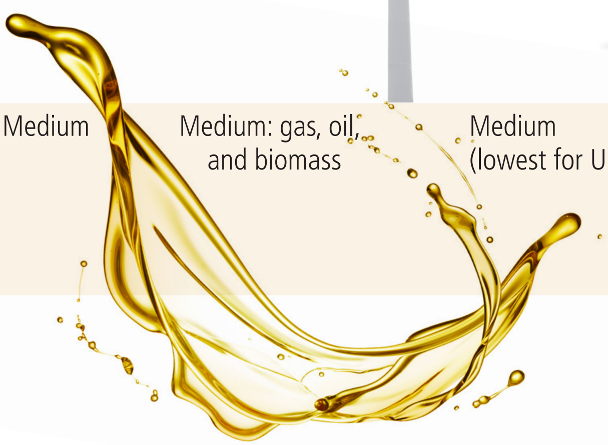
The key point for readers is that the labels identify relatively high (A2), medium (A1B), and low (B2) future emissions of greenhouse gases:

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.

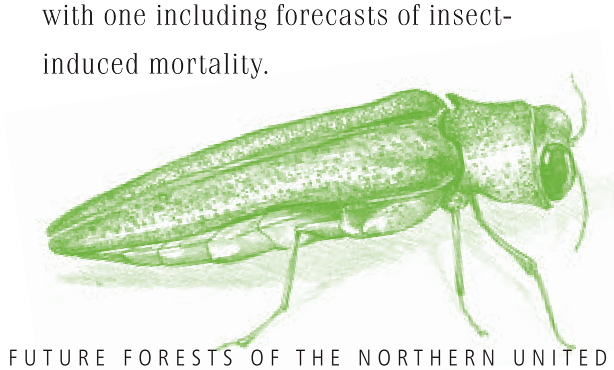


Table 2.2 summarizes the combinations for each scenario selected for the Northern Forest Futures Project. The scenarios differ from the IPCC/RPA efforts in two ways: assumptions about future harvesting and the scenario naming convention used. Scenarios labeled A1B-C, A2-C, and B2-C include the effects 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.

A

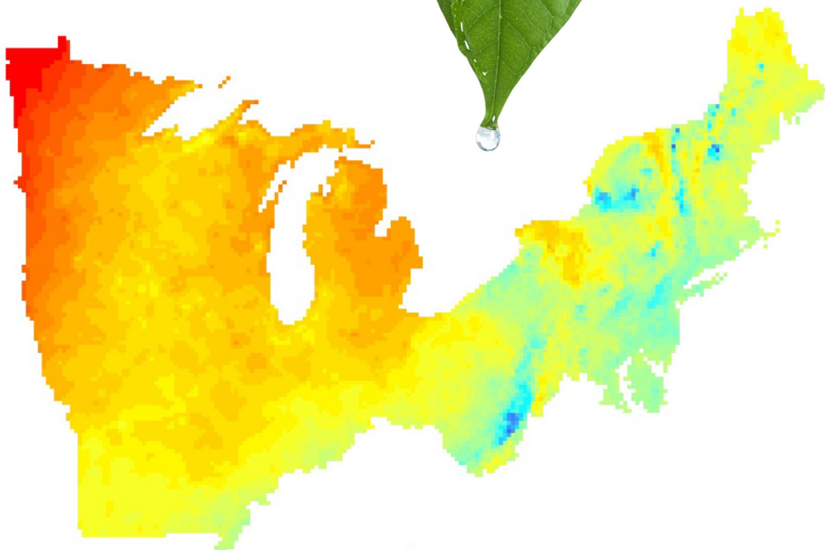
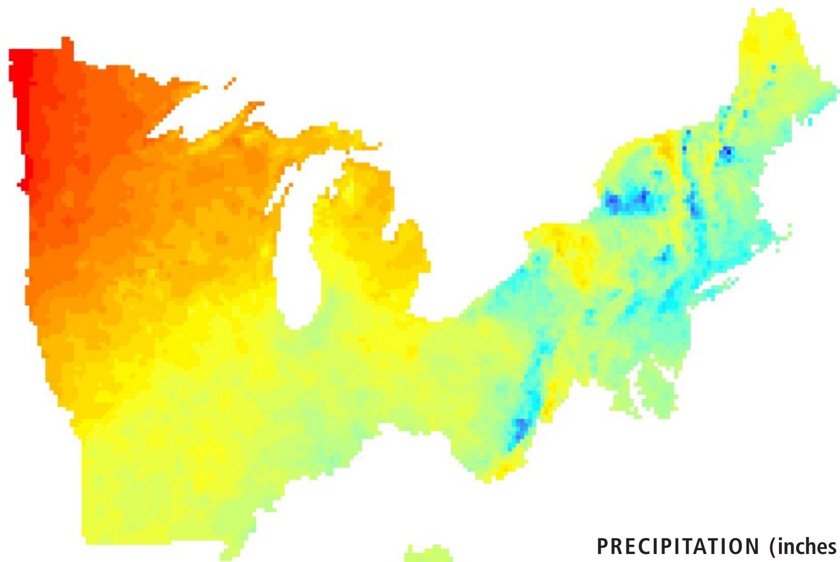


FIGURE 2.2

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).

B

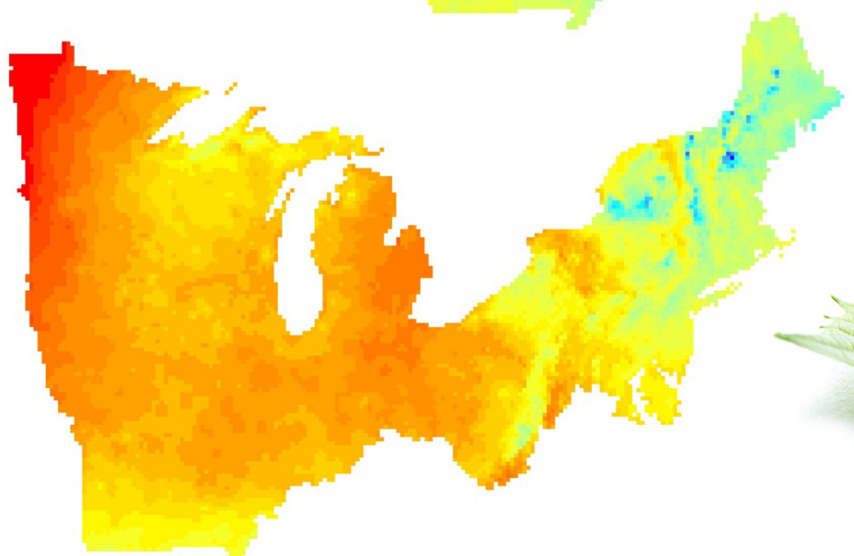


PRECIPITATION (inches per year)

High: 70

Low: 16

C



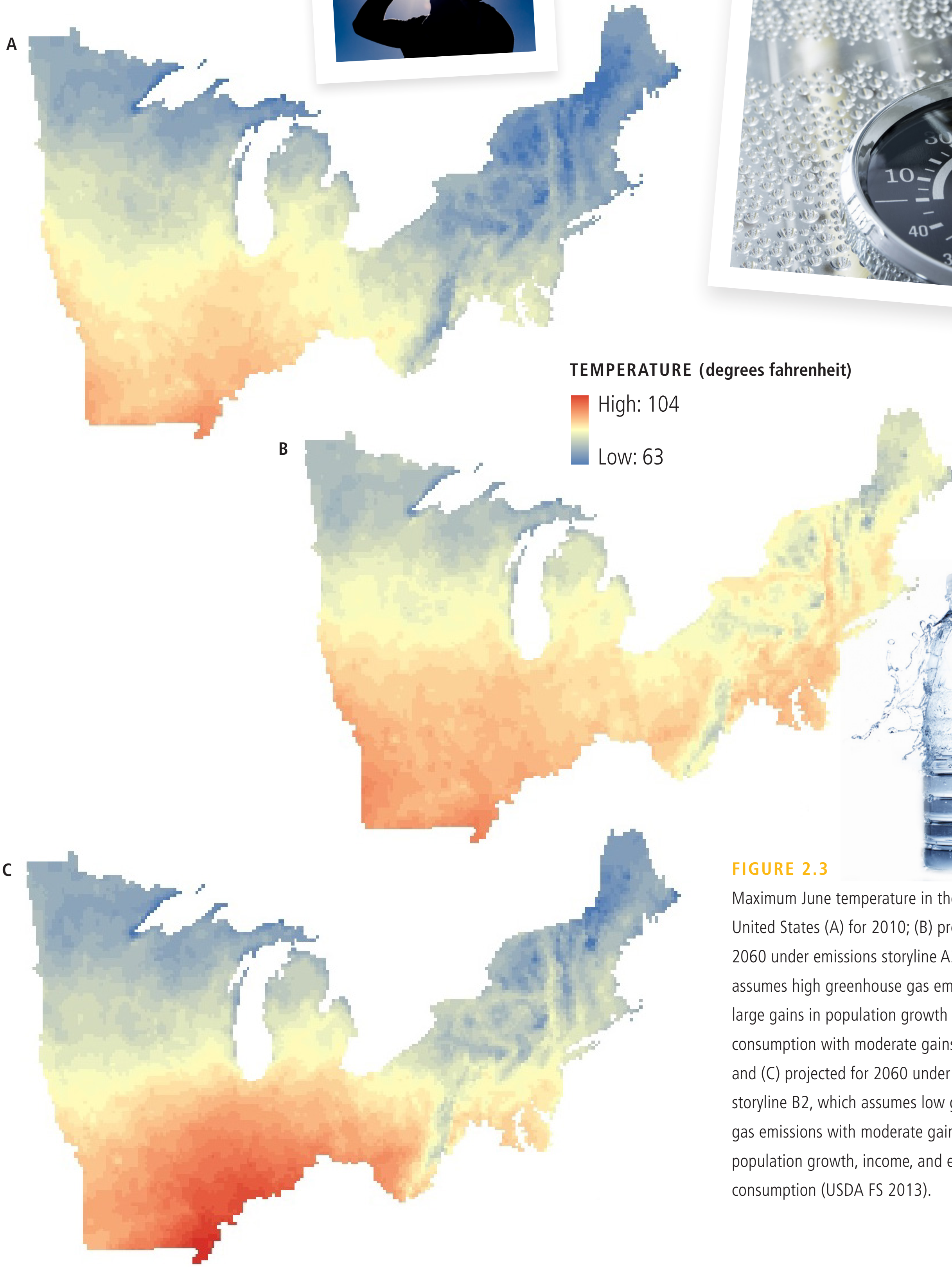


FIGURE 2.3

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 (126 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.

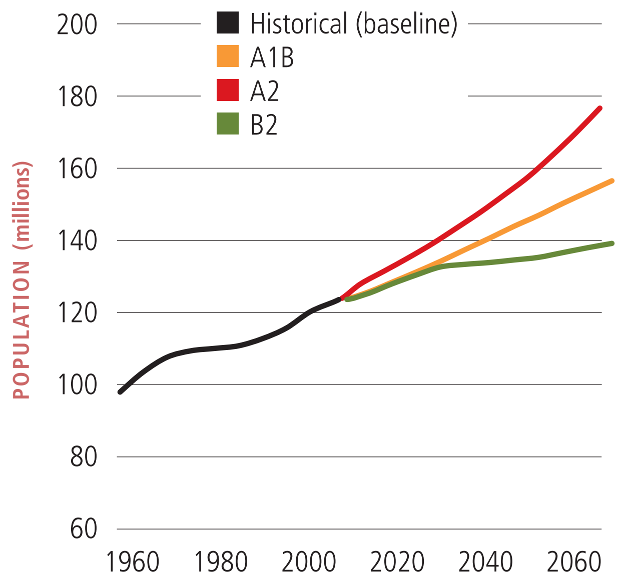


FIGURE 2.4
Historical and projected population growth in the Northern United States under three greenhouse gas storylines (U.S. Census Bureau 2004, USDA FS 2012b): A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a 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).

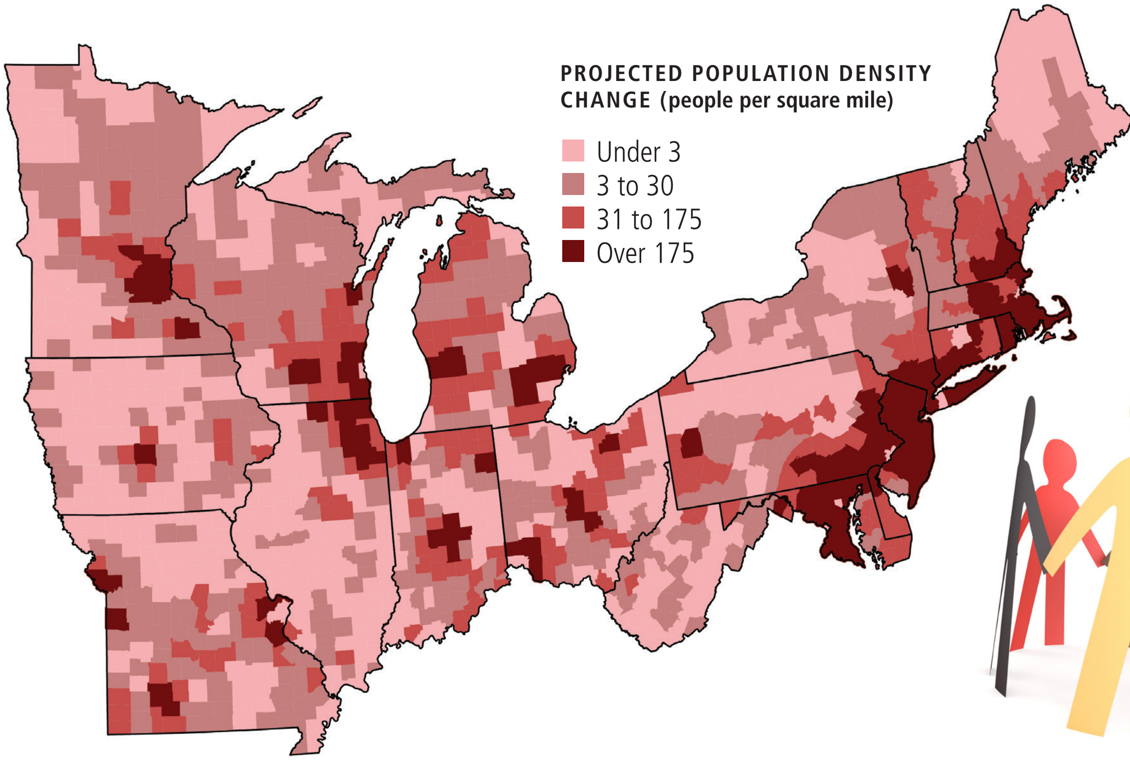


FIGURE 2.5

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).

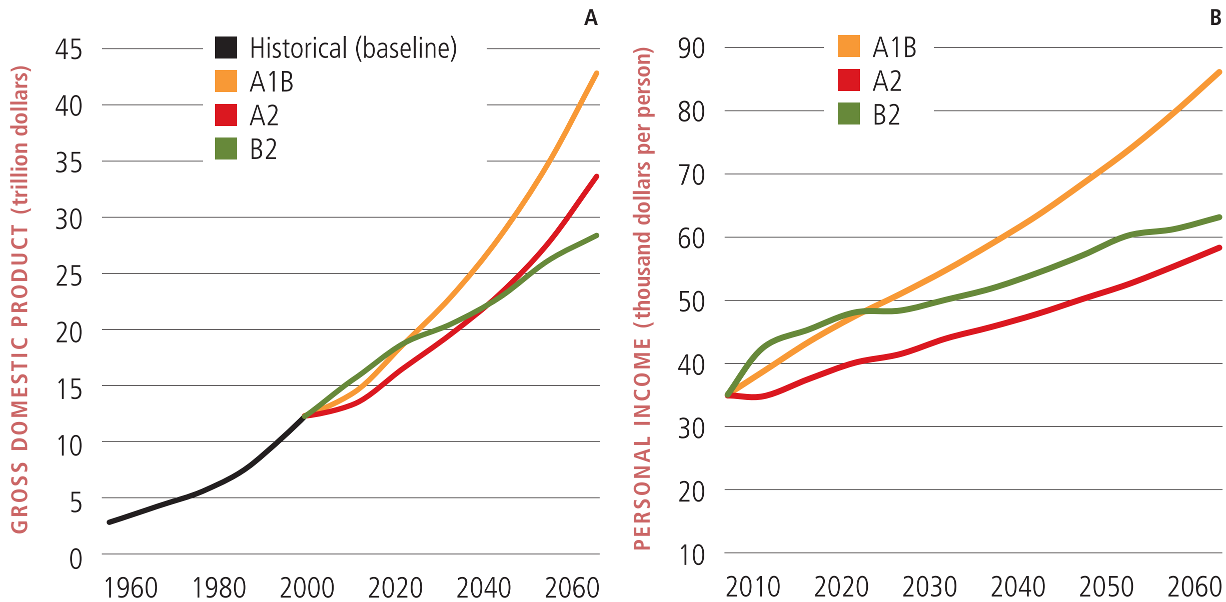
Counties with the highest growth, which are expected to add >175 persons per square mile, would be concentrated mainly in the Washington-to-Boston urban corridor and in other suburban areas throughout the region. Second-tier growth counties would either be found adjacent to counties with the fastest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



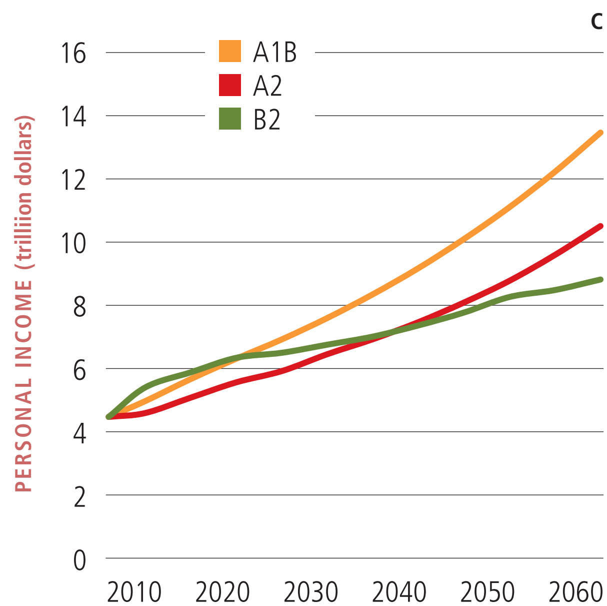


FIGURE 2.6

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, projected per capita 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).

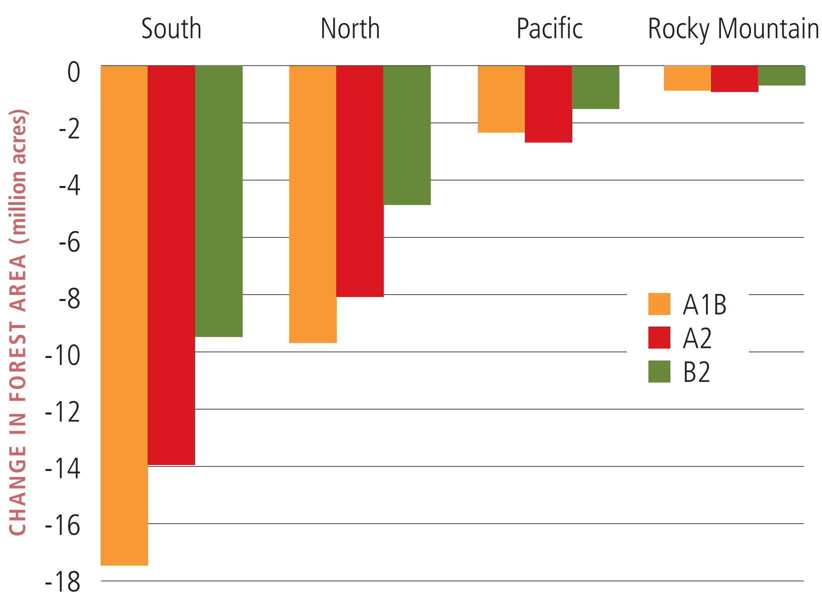


FIGURE 2.7

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.

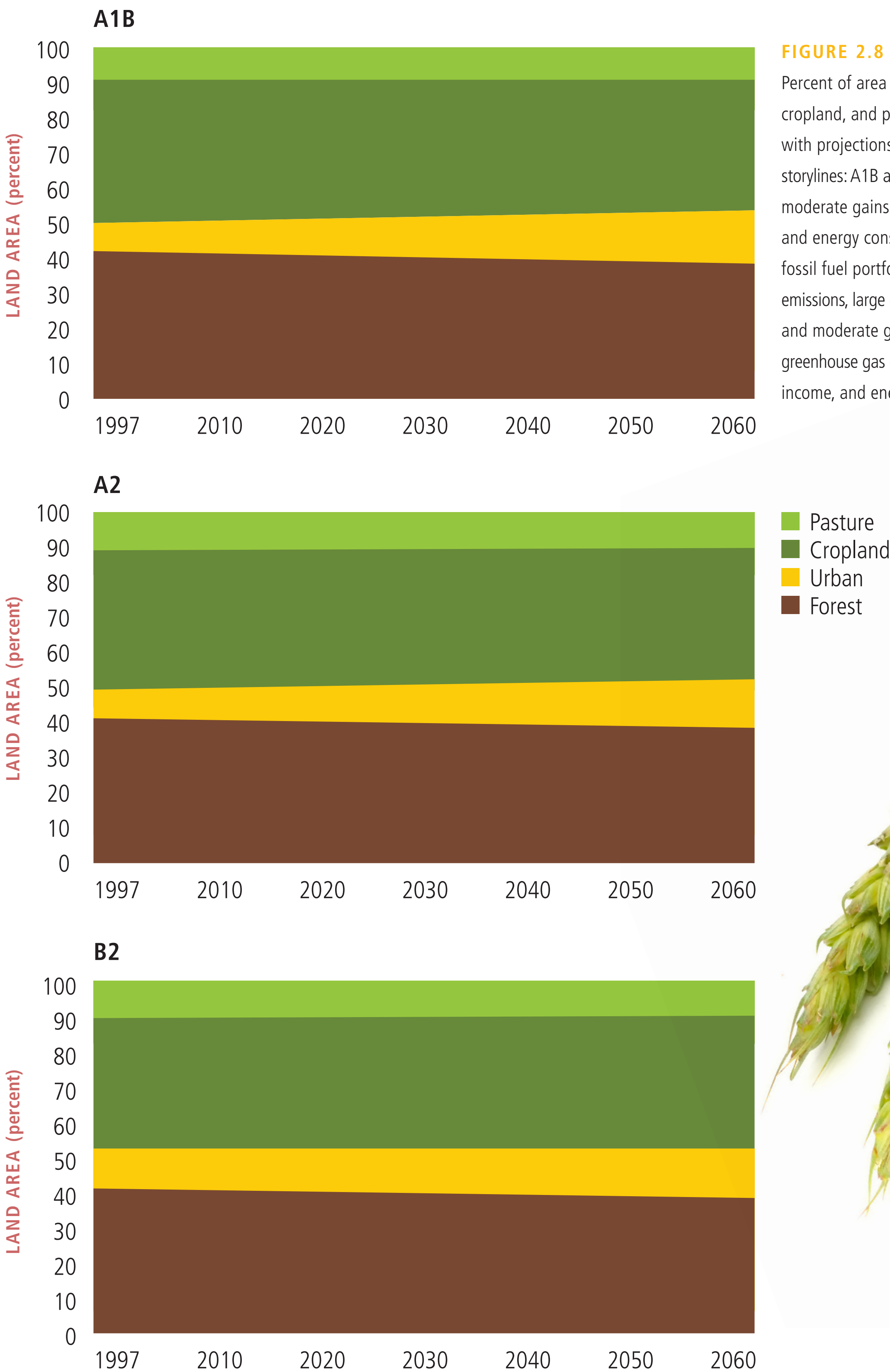


FIGURE 2.8

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).

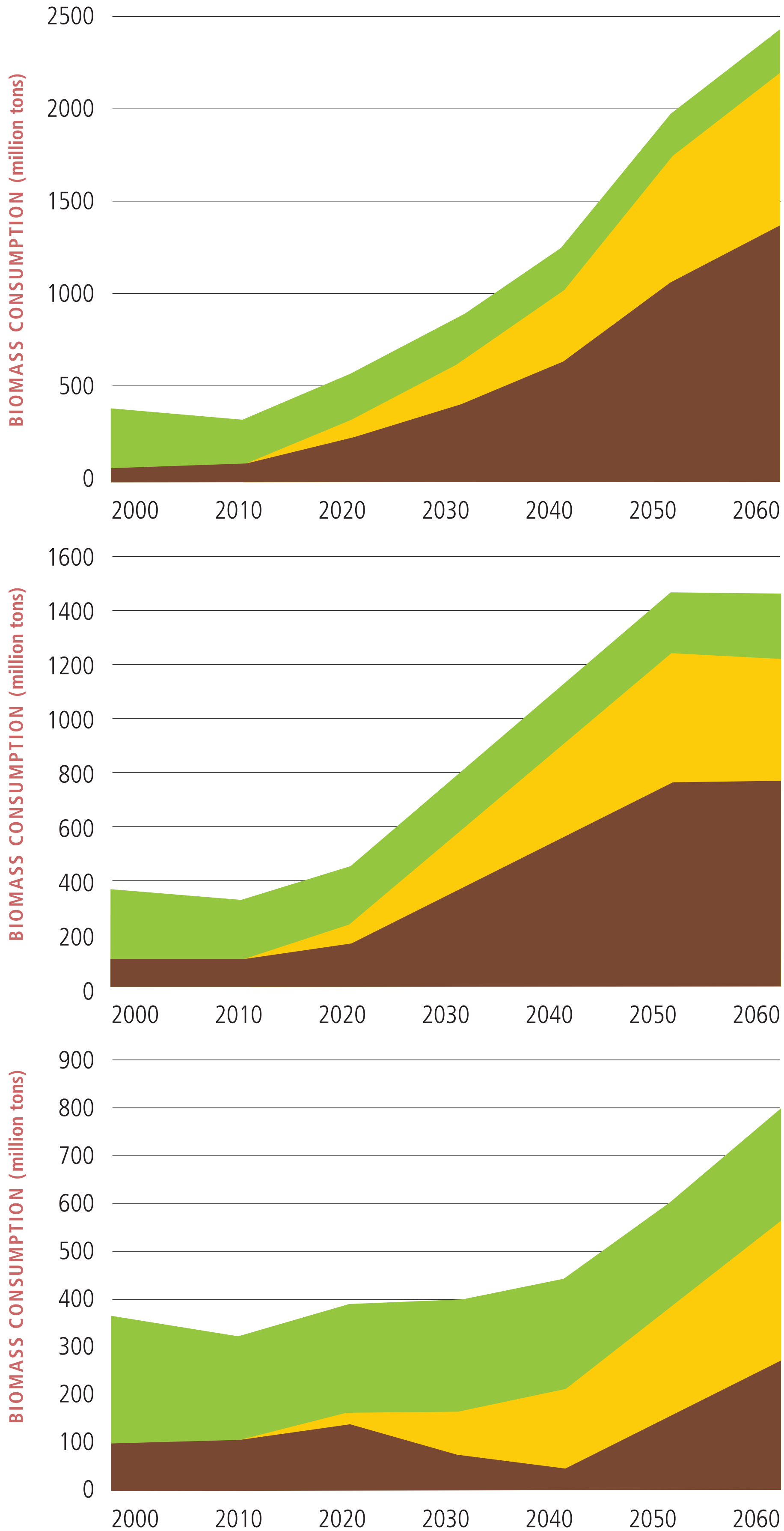


FIGURE 2.9

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.

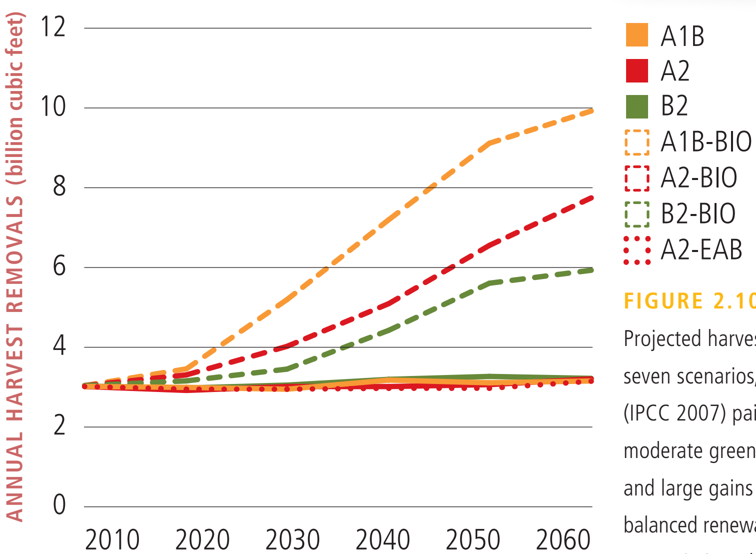


FIGURE 2.10

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.

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).

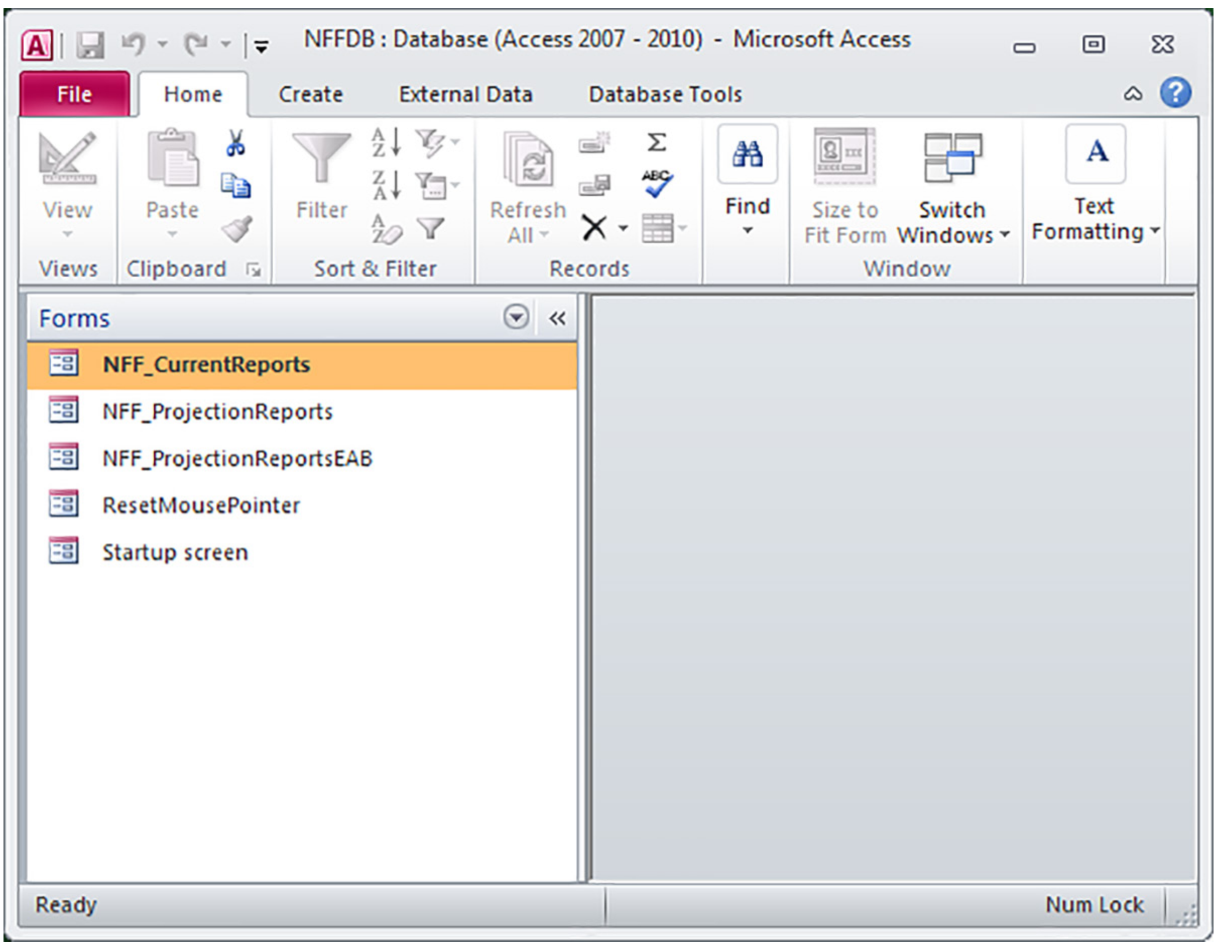


FIGURE 2.11
Screenshot of the three reporting forms available in the Northern Forest Futures database (Miles and Wear 2015).

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

Literature Cited

Bowker, J.M.; Askew, A.E. 2013. Outlook for outdoor recreation in the Northern United States. A technical document supporting the northern forest futures project with projections through 2060. Gen. Tech. Rep. NRS-120. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 62 p.

Canadian Centre for Climate Modelling and Analysis. 2012a. CGCM2-coupled global climate model, medium resolution (T47). Ottawa, ON, Canada: Environment Canada. http://www.cccma.bc.ec.gc.ca/models/cgcm2.shtml (accessed August 20, 2014).

Canadian Centre for Climate Modelling and Analysis. 2012b. CGCM3.1-coupled global climate model (CGCM3), medium resolution (T47). Ottawa, ON, Canada: Environment Canada. http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml (accessed August 20, 2014).

Canadian Food Inspection Agency. 2011. *Agrilus planipennis* – emerald ash borer. Ottawa, ON, Canada: Canadian Food Inspection Agency. http://www.inspection.gc.ca/english/plaveg/pestrava/agrpla/agrplae.shtml (accessed December 16, 2010).

Cordell, H.K.; Betz, C.J.; Mou, S.H.; Gormanson, D.D. 2012. Outdoor recreation in the northern United States. Gen. Tech. Rep. NRS-100. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 74 p.

DeSantis, R.D.; Moser, W.K.; Huggett, R.J., Jr.; Li, R.; Wear, D.N.; Miles, P.D. 2013. Modeling the effects of emerald ash borer on forest composition in the Midwest and Northeast United States. Gen. Tech. Rep. NRS-112. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 23 p.

Gandhi, K.J.K.; Herms, D.A. 2010. Direct and indirect effects of alien insect herbivores on ecological processes and interactions in forests of eastern North America. Biological Invasions. 12: 389-405.

Herms, D.A.; Klooster, W.; Knight, K.S. [et al.]. 2010. Ash regeneration in the wake of emerald ash borer: Will it restore ash or sustain the outbreak? In: Lance, D.; Buck, J.; Binion, D.; Reardon, R.; Mastro, V., eds. Emerald ash borer research and technology development meeting. FHTET–2010–01. [Morgantown, WV]: U.S. Department of Agriculture, Forest Service; Animal and Plant Health Inspection Service: 17-18.

Ince, P.J.; Kramp, A.D.; Skog, K.E.; Spelter, H.N.; Wear, D.N. 2011. U.S. Forest Products module: a technical document supporting the Forest Service 2010 RPA assessment. Res. Pap. FPL–RP–662. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 61 p.

Intergovernmental Panel on Climate Change [IPCC]. 2007. Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change. 104 p. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm (accessed August 19, 2014).

Intergovernmental Panel on Climate Change [IPCC]. 2012. Fifth assessment report. Geneva, Switzerland: Intergovernmental Panel on Climate Change. http://www.ipcc.ch/ (accessed August 19, 2014).

Meehl, G.A.; Covey, C.; Delworth, T. [et al.]. 2007. The WCRP CMIP3 multimodel data set. Bulletin of the American Meteorological Society. September: 1383–1394.

Miles, P.D. 2012. Forest inventory EVALIDator Web application. Version 1.5.00. St. Paul, MN: U.S. Department of Agriculture Forest Service, Northern Research Station. http://apps.fs.fed.us/Evalidator/evalidator.jsp (accessed August 19, 2014).

Miles, P.D.; Huggett, R.J., Jr.; Moser, W.K. 2015. Northern forest futures reporting tools and database guide. Gen. Tech. Rep. NRS-150. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 48 p.

Miles, P.D.; Wear D.N. 2015. Northern Forest Futures database. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. http://dx.doi.org/10.2737/RDS-2015-0009.

Montréal Process Working Group. N.d. The Montréal Process. http://www.montrealprocess.org/ (accessed May 20, 2013).

Nakićenović, N.; Alcamo, J.; Davis, G. [et al.]. 2000. Special report on emissions scenarios: special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge, UK; New York: Cambridge University Press. 599 p.

Prasad, A.M.; Iverson, L.R.; Peters, M.P. [et al.]. 2010. Modeling the invasive emerald ash borer risk of spread using a spatially explicit cellular model. Landscape Ecology. 25: 353–369.

Randall, D.A.; Wood, R.A.; Bony, S. [et al.]. 2007. Climate models and their evaluation. In: Solomon, S.; Qin, D.; Manning, M. [et al.], eds. Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK; New York: Cambridge University Press: 590–662. Chapter 8.

Solomon, S.; Qin, D.; Manning, M. [et al.], eds. 2007. Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK; New York: Cambridge University Press. 996 p.

U.S. Census Bureau. 2004. U.S. interim projections by age, sex, race and Hispanic origin. Washington, DC: U.S. Department of Commerce, Census Bureau. http://www.census.gov/population/www/projections/usinterimproj/natprojtab01a.pdf (accessed August 19, 2014).

U.S. Department of Agriculture, Animal and Plant Health Inspection Service [USDA APHIS]. N.d. Plant health (PPQ). Washington, DC: U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine. https://www.aphis.usda.gov/wps/portal/aphis/ourfocus/planthealth (accessed December 3, 2015).

U.S. Department of Agriculture, Forest Service. 2011. National report on sustainable forests – 2010. FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 212 p. http://www.fs.fed.us/research/sustain/2010SustainabilityReport/ (accessed June 11, 2012).

U.S. Department of Agriculture, Forest Service. 2012a. Future of America's forest and rangelands: Forest Service 2010 Resources Planning Act assessment. Gen. Tech. Rep. WO-87. Washington, DC: U.S. Department of Agriculture, Forest Service. 198 p.

U.S. Department of Agriculture, Forest Service. 2012b. Future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. RMRS–GTR-272. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 34 p.

U.S. Department of Agriculture, Forest Service. 2012c. Resources Planning Act (RPA) assessment online. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/research/rpa/ (accessed July 27, 2012).

U.S. Department of Agriculture, Forest Service. 2013. 2010 RPA assessment historical climate data and climate projections. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/research/rpa/assessment/climate–data.php (accessed March 28, 2013).

Wear, D.N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 41 p.

Wear, D.N.; Greis, J.G., eds. 2013. The southern forest futures project: technical report. Gen. Tech. Rep. SRS–GTR-178. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 542 p.

Wear, D. N.; Huggett, R.; Li, R.; Perryman, B.; Liu, S. 2013. Forecasts of forest conditions in regions of the United States under future scenarios: a technical document supporting the Forest Service 2012 RPA assessment. Gen. Tech. Rep. SRS-170. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 101 p.

Woudenberg, S.W.; Conkling, B.L.; O'Connell, B.M.; LaPoint, E.B.; Turner, J.A.; Waddell, K.L. 2010. The Forest Inventory and Analysis database: database description and users manual version 4.0 for Phase 2. Gen. Tech. Rep. RMRS-GTR-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 336 p.

Zarnoch, S.J.; Cordell, H.K.; Betz, C.J.; Langner, L. 2010. Projecting county-level populations under three future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. e–Gen. Tech. Rep. SRS-128. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 8 p.