THE NORTHERN FOREST FUTURES PROJECT: A FORWARD LOOK AT FOREST CONDITIONS IN THE NORTHERN UNITED STATES

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Abstract. Forests and forest ecosystems provide a critical array of benefits, from clean air and water to commercial products to open space. The forests and their ability to provide desired benefits constantly change in response to natural forces, human decisions, and human needs. The complexity and rate of change demand a rigorous evaluation of existing and emerging natural and anthropogenic forces, analysis of potential impacts of those forces, and consideration of how our response to them affects future forest sustainability. Nowhere is the apparent need for analysis of these challenges more critical than in the Upper Midwest and Northeast because this quadrant of the United States has both the greatest population density and the greatest percentage of forest cover.

The Northern Forest Futures Project is intended to be a window on tomorrow's forests, revealing how trends evident today and choices today and tomorrow can change the future landscape of the Northeast and Midwest. The project is a cooperative effort of the U.S. Forest Service, the Northeastern Area Association of State Foresters, and the academic community. This effort began with existing assessments and inventories and identification of trends and public issues. Current research is evaluating alternative future forest conditions based on scenarios from the Intergovernmental Panel on Climate Change, coupled with selected global circulation models and interpreted in the context of the latest ecological and social science. The results will provide a better understanding of the range of outcomes that may affect the North's 172 million acres of forest and the lives of the 124 million people who live near them. This information will be the basis for educational outreach that allows individuals, organizations, and resource managers to directly assess how differences that result from alternative social and economic choices about resource use, development, policy, and management affect the well-being of their communities and forests. Ultimately, the Northern Forest Futures Project provides the information needed for making wise decisions about the sustainable management of public and private forests in the northern United States.

INTRODUCTION

The 20-state region from Maine to Maryland to Missouri to Minnesota, referred to as the North, has a higher proportion of forest cover (42 percent) and a greater share of the U.S. population (41 percent) than the other three quadrants of the United States (Fig. 1).

Today, forest conditions in the North reflect the human activities of many decades or centuries ago. The large-scale harvesting of old-growth timber that was common in the 19th and early 20th centuries was followed by forest fires, forest species succession, and most destructively by agricultural and urban land clearing. Forest-based cultures were replaced by farming, land development, or open-range grazing as settlers followed the loggers across the landscape (Williams 1989). Over time, however, marginal farm and pasture lands were gradually abandoned in many areas, allowing millions of acres of former agricultural land to revert naturally to forest cover. As a consequence, forest land in the North increased from 134 to 172 million acres (28 percent) from 1907 to 2007, while total U.S. forest land area showed little change (Smith et al. 2009). This increase in forest area in the North is remarkable because over that same period population in the quadrant increased from 52 to 124 million people (138 percent) and total U.S. population increased from 87 to 300 million (245 percent) (Shifley et al. 2012, U.S. Census Bureau 2012).

Future forest conditions in the North will be influenced by contemporary land use decisions and forest management activity, as well as population change and many other factors. For example, the increase in forest area appears to have nearly peaked as expanding urban areas in the North now subsume 4 million acres per decade, of which 1.5 million acres was formerly forest land (Nowak and Walton 2005, Shifley et al. 2012, Smith et al. 2009). How will forest resources and ecosystem services change in proximity to expanding

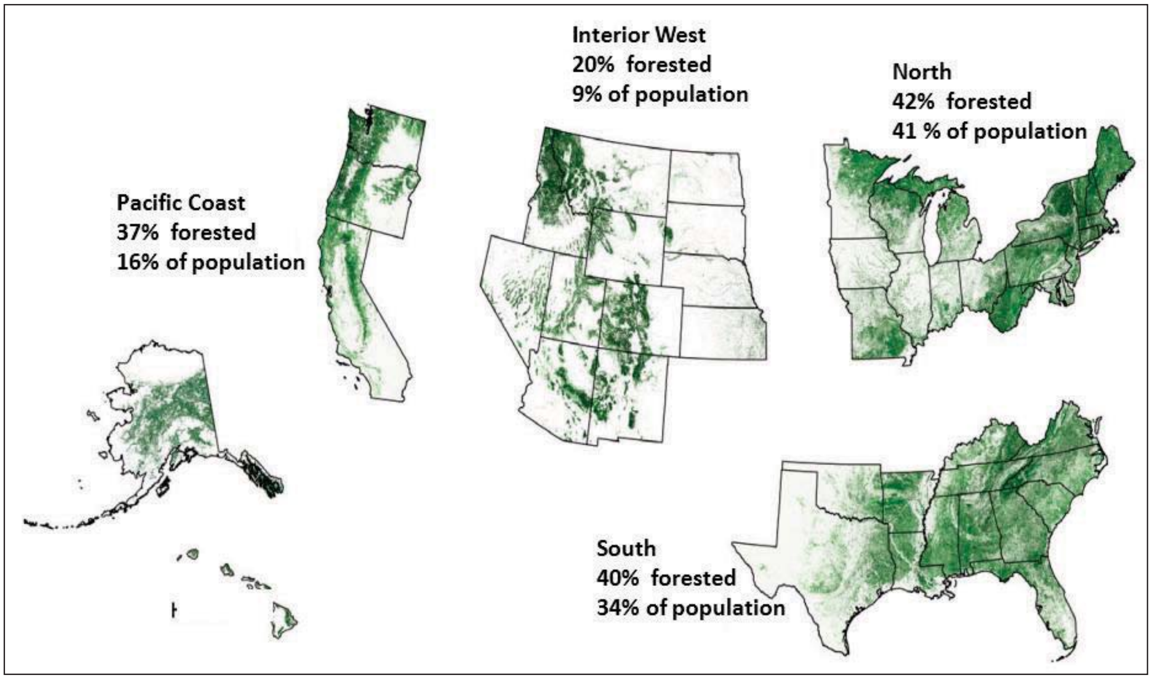

Figure 1.—Distribution of forests and people in the United States (Homer et al. 2004, Shifley et al. 2012, Smith et al. 2009, U.S. Census Bureau 2012). Shading shows forest land.

urban areas that house 80 percent of the North's population? The age distribution of the North's forest stands is concentrated in the 40- to 80-year-old age classes, rather than evenly balanced across a broader range of age classes. How is this age-class imbalance likely to affect forest biodiversity in coming decades, and how are management activities likely to affect future forest age-class distributions? The North's forests are being afflicted by new or expanding invasive insects and diseases. How are invasive species likely to affect the future condition of northern forests? How will the overarching effects of climate change over the next 50 years affect these patterns and trends? These and related questions have spurred research under the Northern Forest Futures Project.

Although the tradition of reporting forest statistics dates back to the 19th century, information on today's forests is more detailed and more complete than ever before. National assessments such as the Resources Planning Act (RPA) (USDA Forest Service 2012b), the 2010 National Report on Sustainable Forests (USDA Forest Service 2011a), and the billion-ton biomass report (Oak Ridge National Laboratory 2011, Perlack et al. 2005) highlight national trends and forecast national changes. Recently completed forest action plans for each state examine forest resource issues and proposed activities to address the most pressing of them (USDA Forest Service and Northeastern Area Association of State Foresters 2011). The Northern Forest Futures Project operates at a scale between states and the nation to examine issues, current conditions, trends, and projections of forest conditions, applying a consistent methodology to the 20 states within the North, individually and collectively. The methodology is linked to the Forest Inventory and Analysis (FIA) forest resource inventories and is intended to bring new forest resource projection capabilities to state and regional inventory data. Key projection methodologies and assumptions were developed from the methods applied for national RPA projections (USDA Forest Service 2012b) as well as the Southern Forest Futures Project (USDA Forest Service 2012c).

The Northern Forest Futures Project includes three components: (1) scoping contemporary issues and problems facing northern forests, (2) an assessment of current forest conditions and recent trends for a wide range of forest attributes, and (3) projections of future forest conditions for a range of alternative harvest, climate, and socioeconomic scenarios. The first and second components have been completed. Dietzman et al. (2011) analyzed hundreds of sources to produce a prioritized summary of issues and concerns recently expressed about the current condition of northern forests, which is supplemented by a summary of the issues raised in the forest action plans recently developed by each of the 20 states in the North (USDA Forest Service and Northeastern Area Association of State Foresters 2011). These products identify issues that can benefit from (or in some cases require) collaboration among states to address effectively. Examples include controlling invasive species, sustaining forest biodiversity, protecting water quality through watershed-scale management, and sustaining a viable wood products industry. The second component assessment is addressed by the recent publication of an assessment of 36 indicators of forest conditions in the North (Shifley et al. 2012). It provides a collective analysis of forest conditions and trends with comparative data at state and regional scales for many indicators of forest condition. In the remainder of this paper, we concentrate on the third component—development of forest projection capabilities.

METHODS FOR FORECASTING CHANGE IN THE NORTHERN FOREST

Overview

The projection component of the Northern Forest Futures Project seeks to estimate forest area, size, structure, and species composition under alternative scenarios for 2010 to 2060 across the 20-state North. In most cases these projections will be made for individual states and aggregated for regionwide estimates of change over time. Influencing these projections will be large-scale estimates of land use change, forest harvesting, and climate change over the time period. Fortunately, the Northern Forest Futures Project is able to utilize regional land use change and forest harvesting estimates developed as part of the 2010 Resources Planning Act assessment that includes national projections of forest change (USDA Forest Service 2012b, 2012c; Wear 2011). Climate change scenarios examined under the Northern Forest Futures Project are tied to climate projection models from the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic et al. 2000). State-scale forest resource projection methods follow those developed for the Southern Forest Futures Project (Wear and Greis in press), except the projected harvest levels were adjusted to match as closely as possible the RPA timber market scenarios and the forecasts of forest conditions (pers. comm., David Wear, USFS, May 2012). To maximize compatibility among projections for the North and the South, projection models for the North were implemented by the Southern Forest Futures Project team (Huggett et al., in press) and converted by Pat Miles into a Microsoft Access database that can be readily summarized and analyzed using his FIA EVALIDATOR program (Miles 2012).

The Northern Forest Futures Project projections will focus on a core subset of future scenarios that reflect high, medium, and low levels of climate change. The projection system accesses inputs of other models, quantifies scenario assumptions, and applies them to current forest inventory data (i.e., FIA plots), transforms these inventory data using calculated relationships, outputs the projected forest inventory data, and summarizes the projected data into a cohesive assessment of conditions under each scenario (Wear et al., in press).

There are two major benefits of this design. First, it largely mirrors the structure of the information flows of the RPA and the Southern Forest Futures Project, so the Northern Forest Futures Project can take advantage of existing algorithms, software, and expertise. Because those methods have already undergone peer review (Polyakov and Wear 2010, Wear et al., in press), so we can concentrate on understanding the implications of expected changes in northern forests rather than on developing projection methodology. Second, the future (projected) forest inventory database possesses the same data elements and structure as the current FIA inventory database. Within the constraints of usable data in this future dataset, the same analyses applicable to current FIA data will work for the future data. This provides substantial efficiencies in summarizing projection results and making direct comparisons to past and current forest conditions.

Table 1.—Overview of IPCC storylines used in the 4th RPA asessment; Source: Nakicenovic et al. (2000) and Ince et al. (2011a)

Storyline Characteristics	Storyline A1B	Storyline A2	Storyline B2
General Description	Globalization, Economic Convergence	Heterogenic Regionalism, Less Trade	Localized Solutions, Slow Change
Global Real GDP Growth	Very High (6.2x)	Medium (3.2x)	Medium (3.5x)
U.S. GDP Growth	Medium (3.3x)	Low (2.6x)	Low (2.2x)
Global Energy Use	Very High	High	Medium
Oil & Gas Availability	High	Low	Medium
Technological Pace & Direction	Rapid; Gas, Biomass & Other Renewables	Slow; Coal & Gas	Medium; Gas, Oil & Biomass
Global Population Growth	Medium (1.3x)	High (1.7x)	Medium (1.4x)
U.S. Population Growth	Medium (1.5x)	High (1.7x)	Medium (1.3x)
General Development Themes	Economic growth; Introduction of New & More Efficient Technologies; Capacity Building	Self-reliance, Preservation of Local Identities	Sustainable Development, Diversified Technology
Global Expansion of Primary Biomass Energy Production (2010-2060)	High (Highest for USA)	Medium	Medium (lowest for USA)

Estimating Future Climate Change

The IPCC has evaluated alternative future climate scenarios based on selected atmospheric, economic, technological, and population variables (IPCC 2007). Future increases in greenhouse gas emissions are estimated based on four IPPC storylines. These storylines have differing assumptions about future economic, social, and technology changes that will influence future greenhouse gas emissions. The three IPCC storylines used in the Northern Forest Futures Project projections are summarized in Table 1. These storylines, which are also used in the RPA and Southern Forest Futures Project, can be summarized as follows:

- A1B—a future where the rest of the world approaches the United States in terms of per capita wealth, technology use, and population growth
- A2—a future where the world is not converging on the U.S. experience, but rather is much more regionally focused
- B2—a future of global sustainable development, with some regional economic convergence

The scenarios are categorized as very high, high, and medium global energy use for storylines A1B, A2, and B2, respectively (Table 1). Each storyline incorporates corresponding estimates of land use change and future greenhouse gas emissions. At least seven global circulation models (competing hypotheses) predict and map future temperature and precipitation based on estimates of future greenhouse gas emissions. To limit the total number of alternatives examined, we paired each of the three selected IPPC storylines (Table 1) with one of the midrange coupled global circulation models (CGCM) published by the Canadian Centre for Climate Modeling and Analysis (2012a, b). To define three Northern Forest Futures scenarios that represent high, medium, and low relative levels of future climate change, we modeled climate change using CGCM3.1 for IPCC storylines A1B and A2, and we used CGCM2 with IPCC storyline B2. The CGCM models chosen for the Northern Forest Futures Project analyses are intended to be consistent with the climate models used by the RPA and the Southern Forest Futures Project.

Modeling Forest Change Under a Changing Climate

A version of the forest dynamics model (Wear et al. in press) is used to estimate change in northern forest conditions in response to projected land use change and the projected change in climate conditions outlined above. The model starts with a set of current FIA inventory plots that represent initial forest conditions for a given state and then operates on that inventory list to estimate change in FIA plot characteristics over a 50-year scenario. By summarizing the estimated future conditions of plots for the entire state (or any subset), it is possible to estimate the cumulative change in forest conditions over time.

In practice, the modeling process is complex and incorporates data from numerous sources. However, the core modeling technique is based on an imputation process that in its simplest form is intuitive. For example, begin with a list of all FIA plots for a given state. Then, for the next 5-year interval, stochastically estimate which plots will be harvested and replace each of those with a duplicate copy of a recently harvested FIA plot drawn from a pool of plots with matching ecological conditions. Harvest probability estimates are based on empirical models of historical harvest choices for each forest-type group; these probabilities are adjusted by a common scalar to simulate the level of harvest used for the RPA Scenario's harvest projection alternatives (pers. comm., David Wear, May 2012). Then, estimate which plots will be largely undisturbed and stochastically replace each of those with a copy of a plot that is 5 years older but otherwise of the same forest type and found on similar site conditions.

The next step is to use results from an external model of land use change (Wear 2011) to estimate increases or decreases in forest area for the projection period; model the change in forest area by proportionally increasing or decreasing the area that each FIA plot represents on the forest landscape (i.e., adjust the plot area expansion factor). Forest changes resulting from climate change are modeled by modifying the general methodology to replace plots representing forest growing under one historical climate regime with corresponding plots representing forest growing under a different historical climate regime (e.g., slightly warmer and wetter) that reflects the mapped changes in climate for future decades from a specific Coupled Global Climate Model.

The forest dynamics model has three submodels: partitioning, transition, and imputation. These submodels facilitate estimation of transition probabilities used to classify FIA plots, summarize detailed inventory data, and estimate change over time. The partitioning submodel groups similar FIA plots by identifying attributes such as age, density, precipitation, temperature, and live timber volume to develop groups (buckets) of similar plots. The transition submodel estimates the probabilities that a given plot will transition from one status (bucket) to another based on historical transition rates observed from re-measured FIA plots. Two separate versions of the transition submodel have been developed for (1) unharvested and partially harvested plots and (2) harvested plots that will be replaced by a plot representing new forest regeneration. These transition probabilities are used by the imputation submodel to predict a future condition for each inventory plot for the next time interval by stochastically drawing a replacement plot from the most appropriate partition group (bucket) as developed in the partition process. For example, if the transition probabilities state that a 40-year-old oak-pine plot will become a 45-year-old oak-pine plot (instead of an oak-hickory plot or some other forest-type group), then the model imputes what this 40-year-old plot will look like in 5 years by randomly picking an oak-pine plot from the bucket of existing 45-year-old plots that have similar ecological characteristics. This plot then becomes the new base plot for the next 5-year time step.

The completed simulation summarizes the results of these transitions for future decades by summarizing plot conditions for a projected future date in the same way that one would summarize forest conditions for any current or past forest inventory (Miles 2012). The forest condition forecasts are modified to account for projected land use change from an external land use model. Removals of wood products from timberland are derived from a separate model and summarized by hardwoods and softwoods.

DISCUSSION

Limitations of the Modeling Framework

Model resolution

The partition submodel used to define groups of similar plots for the imputation process operates at the forest-type group level of aggregation, which is necessary to ensure sufficient sample sizes for imputation. For example, the oak-hickory forest-type group is an aggregation that includes 17 distinct forest types (e.g., white oak, red oak, bur oak, yellow-poplar/white oak/red oak, sweetgum/yellow-poplar, red maple/oak, southern scrub oak) and dozens of oak species. During the projection, the partition submodel aggregates more than 100 forest types into 10 or fewer forest-type groups that are carried forward in the projection. Projections of future forest species composition can be reported only by forest-type group, not by forest type or individual species. Thus, even though the projection system carries complete individual FIA plots forward in time, there are limits on the suite of variables that can be realistically summarized for future decades. The primary variables available for characterizing future forest inventories include forest-type group, area, age, site quality, size class, number of trees, volume, and biomass. Likewise, the methodology limits the spatial scale of results reporting to inventory units, entire states, or groups of states.

Verification and validation

The forest dynamics model has been verified for U.S. forests by determining that the model is working as expected: the computer algorithms are correctly implementing the statistical models and the external assumptions about land use change and harvest are correctly applied to the projected forest conditions. The model projections have been validated in two ways. First, before the model was applied for the 2010 RPA projections, past FIA inventories for selected states were projected forward in time with the calibrated model and compared to observed present-day FIA inventories. Results were judged satisfactory by the model developers (pers. comm., David Wear, USFS, May 2012), and the subsequent RPA regional and national projections of forest change for 2010 to 2060 based on the model have undergone internal and external review. Second, the initial round of state-scale projections of forest change from 2020 to 2060 for the Northern Forest Futures Project were reviewed by the Forest Service FIA analysts working in the North and by state foresters and planners from northern states. Those evaluations, based on expert knowledge of forest conditions and past trends at the state scale, resulted in some modifications to model calibration for individual states, particularly with respect to estimated changes in forest area. More rigorous statistical validation of model projection accuracy and bias for individual northern states will occur over time with ongoing FIA state inventories. Present-day model projections from 2010 to 2060 serve as provisional hypotheses of forest change, and FIA statewide forest inventories completed in the coming decades will determine the accuracy of those projections in a de facto validation process.

In general, we anticipate that the longer the projection periods are, the lower the accuracy of the projection will be. For this application the imputation model uses the trends observed in the 2003 to 2008 forest inventories and other inputs, such as climate models, to build transition matrices. Consequently, trends occurring in that time span determine the future rates and patterns of forest change for the entire projection period. This may downplay the influence of some longer term trends, especially if those trends vary greatly from year to year. For example, mortality rates inherent in the model structure are based on those observed from 2003 through 2008 and may not reflect longer term or episodic cycles of forest pest attacks.

Complexity

The imputation model is a custom product developed by the U.S. Forest Service, Southern Research Station's Forest Economics and Policy project (Wear et al., in press). Calibration and application require specialized knowledge and programming skills, which limits model implementation to a group of specialists. However, after a scenario is modeled the results will be readily accessible using a simple Web-based interface (Miles 2012).

Table 2.—Northern Forest Futures Project research topics aligned under natural resource, human, or interaction categories (USDA, Forest Service 2011b).

Natural Resources	Human Systems	Natural Resource—Human Interactions
Wildlife habitat and biodiversity	Wood products	Insects and diseases
Forest area, species composition, and size structure	Environmental literacy	Stewardship and forest management
Water	Urban forest dynamics and management	Invasive plant species
Recreation		Forest fragmentation and parcelization
Biomass and bioenergy		

Strengths of the Modeling Framework

Linkage to FIA data

There are many practical advantages to this modeling framework. Foremost, it can be calibrated and applied using existing FIA data that systematically sample all forest conditions in the United States. Consequently, it can be applied to all states in the North. Moreover, the same methodology has been applied to forecast nationwide changes in forest conditions as part of the RPA Assessment (USDA 2012b). Projections for the 20-state North use the same methods to provide state forecasts. Because the projection model input and output are databases of standard FIA plots, data summaries over time can be created using standard Web-based tools used to summarize current and historical FIA field inventory data (Miles 2012). This provides an efficient mechanism for summarizing projected changes over time in forest area, number of trees, age, size class, volume, and biomass in the same manner that present and past FIA data can be summarized.

Linkages to other forest characteristics

Use of the FIA forest inventory plots as the basis for projecting forest conditions in future decades provides opportunities to link projected changes in forest conditions to estimates of other ecosystem services. Many forest attributes that can be estimated using a contemporary FIA inventory also can be estimated using projected inventory conditions (Table 2). Four principal investigative themes are outlined below.

1. Invasive species

The Northern Forest Futures baseline assessment (Shifley et al. 2012) summarizes invasive insects and diseases that are likely to negatively impact northern forests in coming decades. These include (but are not limited to) emerald ash borer (*Agrilus planipennis*), gypsy moth (*Lymantria dispar*), Asian long-horned beetle (*Anoplophora glabripennis*), sirex wood wasp (*Sirex noctilio*), hemlock wooly adelgid (*Adelges tsugae*), and thousand cankers disease of black walnut.

Potential impacts of the emerald ash borer are well suited to examination with the Northern Forest Futures modeling framework. As it spreads, the emerald ash borer exclusively attacks ash trees (*Fraxinus* spp.) and kills virtually all of them. Consequently, it is relatively easy to model emerald ash borer impact on forest structure and composition by systematically removing ash trees from the imputed plots as the borer moves across the region. Other invasive species present greater modeling challenges within this projection system. The impact of the gypsy moth, which infests multiple species and kills only a portion of all infested trees, is much more difficult to model within the projection system and must be analyzed externally (e.g., USDA Forest Service 2012d).

2. Forest biodiversity

Projections of forest age class through time can be used to examine broad change in forest age-class diversity. Age class is one of the simplest indicators of forest structural diversity (e.g., seedling, sapling, poletimber, saw log, and old-growth forest conditions) and associated wildlife habitat diversity (Tirpak et al. 2009). The current age-class distribution in the North is clustered in the 40- to 80-year-old range (Shifley et al. 2012). This has strong implications for current habitat diversity (Greenberg et al. 2011). The projection system allows exploration of anticipated changes in forest age class and structural diversity both spatially and temporally.

Gross changes in forest species composition can also be explored through the scenario projections of the Northern Forest Futures Project. As noted above, the assumptions underlying the projection process limit analyses of species composition to the aggregated forest-type group. Nevertheless, change in the relative proportion of oak-hickory vs. maple-beech-birch forest-type groups is sufficient to examine issues such as the rate of mesification of northern hardwood forests (Nowacki and Abrams 2008) and the associated loss of oak forest cover.

3. Wood volume and biomass

Because the modeling system operates on FIA plots as the basic unit indicating forest conditions, it is possible to summarize estimates of future wood volume and biomass over time for individual states or groups of states in exactly the same way as for current volume and biomass. Volume and biomass typically increase with increasing stand age. Consequently, the imbalanced age-class distribution of existing northern forests will be reflected in changes in wood volume and biomass under alternative future scenarios. Under most IPCC storylines, woody biomass is projected to supply an increasing proportion of the nation's energy needs (Ince et al. 2011b). This will affect energy portfolios, forest management opportunities, income opportunities for landowners, future forest age-class distribution, and associated forest biodiversity.

4. Ownership and urban-rural forest distribution

The FIA definition of forest is based on composition, structure, and function. Yet forest land is owned and managed for a variety of reasons. Five acres of suburban forest in New Canaan, Connecticut, may well be owned for different reasons than 5 acres of forest in Aroostook County, Maine. One consideration influencing different attitudes and management practices on forest land can be the proximity to the cultural and economic influences of major metropolitan areas. In the North, 80 percent of the population lives in urban areas that cover 6 percent of the land area. Consequently, forests near urban areas have the potential to provide ecosystem services such as aesthetics, recreation, water quality, air quality, and wildlife benefits to a large number of people. Anticipated demographic changes over the next 50 years are expected to exert a strong influence on forest conditions in proximity to urban areas. Specific research on the expected human influences on forest management and valuation in urban as well as rural environments helps us understand the special values of forests near urban areas (Butler et al. 2010, Nowak et al. 2010).

SUMMARY

The Northern Forest Futures Project is intended to provide a view of what the region's forests are today and what they might become over the next 50 years. Comprising three components—scoping, assessment, and projection—the project uses projections of future economic, demographic, technological, and climate scenarios to produce future scenarios of forest land cover, composition, and structure. These future scenarios provide a quantitative basis from which to examine future forest threats, biodiversity characteristics, biomass production and utilization, ecosystem services, and landowner attitudes and influences. The project has already completed the issue identification or scoping phase (Dietzman et al. 2011) and the initial assessment (Shifley et al. 2012). Collaborating scientists are now completing the projection phase and expect to produce an assessment of alternative future northern forest conditions within the next year. The Northern Forest Futures Project can help refine expectations about future forest conditions and assist policy makers and forest managers in defining future priorities.

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