A FOREST RESOURCE MODEL OF THE STATES OF NEW YORK, VERMONT, NEW HAMPSHIRE, AND MAINE

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1. Executive Summary

In 1999, the North East State Foresters Association (NEFA) commissioned a modeling project for the forest land of its four member states; New York, Vermont, New Hampshire, and Maine. The purpose of this analysis was twofold. First, NEFA saw long-term value in developing a regional forest-modeling framework, a tool that would help them focus higher levels of technology on future policy questions. Secondly, the State Foresters saw immediate value in using this same computer simulation framework with the most recent forest inventory data as an aid to current and ongoing policy questions and debates. This report explains the model's purpose and intended use; the data and its limitations; model formulation and structure; and the assumptions and outcomes of a suite of different scenarios programmed into the model.

The forest land of the NEFA states covers an area of more than 45 million acres, stretching from the shores of Lake Erie in western New York to the Bay of Fundy in downeast Maine. This large region exhibits enormous variation and complexity in both natural and social systems. It would be extremely difficult to capture the precise elements of these relationships and systems, and this study does not claim to do that. However, the study does attempt to model the larger, better-documented natural and social dynamics of the forest resource, while posing relevant questions and offering clearly stated assumptions as a basis for the exploration of alternative future scenarios. For NEFA, this analysis represents a credible first step towards integrating state-level information into a regional composite by which ideas, data, and our current understanding of the forest can be tested, evaluated, and enhanced.

This analysis uses the USDA Forest Service Forest Inventory and Analysis (FIA) plot data, as well as information from state agencies and other sources, to establish initial conditions for projections over a 50-year time horizon. The plot data were mainly organized into ecological habitat types, a biophysical classification scheme that incorporates soils, understory vegetation, and other measures as a way of grouping forest land acres. Ecological measures, derived from FIA plot data, were used to add insight to the traditional projections of timber growth and harvest. Land-use change was incorporated into the analysis at the sub-state level, incorporating the loss or gain of forest land acres by ecological and geographical zones. Basic principles of resource supply and demand were used to characterize shifts in harvest demand. This report describes the results at a regional level, offering comments at the state level where appropriate. Technical appendices offer additional detail on a number of topics.

The results of all modeled scenarios depend on data and techniques that have varying degrees of uncertainty and error affecting the results. The selected scenarios are a collection of the best public data, organized in a purposeful fashion, with assumptions that pose "what if…?" questions about the future of our region's forests. In the process of building this model, however, substantial effort was made to consider many different information sources and consult with a variety of experts from both inside and outside the region.

There are 5 different projections described in this analysis. They include (1) keeping the current level of harvest constant, (2) sharply increasing the level of harvest demand, (3) proposing a substantial loss of timberland acres (4) evaluating the impacts of the elimination of clearcutting and (5) assessing the continued advancement of hemlock woolly adelgid. We also examine the sensitivity of harvest projections to input assumptions regarding timber yields and the amount of the initial inventory. For these tests, yield curves were increased and decreased by 20%, and the initial starting inventory was increased and decreased by 5%.

The results from the constant-demand projection indicate that the current harvest of approximately 12.9 million cords per year can be sustained for the 50-year time horizon, resulting in net increases in total inventory over the period. However, due to the aging and stocking levels of many hardwood stands, overall growth is projected to decline by 11% for the region (from 35.3 cubic feet per acre per year to 31.4 cubic feet per acre per year). Regional sustainability doesn't necessarily imply sustainability at the state, timbershed, or landscape level. For example, Maine's hardwood volume is projected to decrease slightly, which is compensated for by increasing softwood volumes.

Our land-use change assumptions for this run imply that the region will gain 480,000 acres of timberland over the 50 years. New York contributes the bulk of this gain from reverting agricultural land. New

Hampshire experiences a 4% decline in timberland acres and an accompanying 6% reduction in inventory.

The sensitivity runs did not change the ability of the timberland base to sustain the regional harvest, though declines in inventory did occur with the 20% yield reduction for some states. Consistent with an aging resource, indices for fine seed (aspen and others) and soft mast (miscellaneous berries, cherry) species declined while the indices for conifer and large-nut mast species increased.

The increased-demand run reflected the same base assumptions as the constant demand run, except that its harvest request was based on a 1% annual increase of the current harvest level of approximately 12.9 million cords per year. This results in a 56% harvest increase over the 5 decades and a 3% overall increase in inventory volumes over the 50-year period, though some relatively small, unmet harvest demands occurred. At the state level, inventory declined 29% in Maine and 19% in New Hampshire. Land-use change reflects assumptions from the previous run. The ecological results for this projection showed the forest responding to the increased harvest pressure with higher levels of fine seed and soft mast and a decline in vertical structure.

To address concerns about recent steep rates of timberland loss, the next scenario modified our initial assumptions about land use change to be more pessimistic. Under these new assumptions, the region loses 900,000 acres (about 2%) of current timberland area over the 50 years. Southern New Hampshire and southern Maine were projected to see the greatest declines and the oak-pine resource in those regions was negatively affected. Region-wide, timberland inventory volume still managed to build, though more slowly. We assumed that a portion of the timber currently on lands lost from the timberland base was recovered, which serves to partially satisfy the harvest demand and reduce the pressure on remaining acres. New Hampshire's inventory moved from modest gains in the early decades to roughly equivalent losses by 2050.

The fourth scenario explored the impacts of the elimination of clearcutting as a harvesting method. The acres currently expected to experience this form of harvesting were redirected to heavy partial cutting units. The model cut more acres for the same harvest request. This impact was small on the region but likely would affect specific locations more severely.

The last projection described in this report was chosen to illustrate how the model might be used to investigate the impacts of a pest infestation. The hemlock woolly adelgid (HWA) is an exotic insect pest that infests eastern hemlock trees, typically killing them over a 3 to 6 year period. The presence of HWA has been documented in the NEFA region and is a concern. This projection simulated the continued expansion of the HWA northward. It contained yield curves that reflect high levels of hemlock mortality and incorporates directed harvesting responses. Growth declined substantially in the hemlock-red spruce habitat and was noticeable at the regional level, particularly over the first two decades of simulation; but its impact on the larger resource base over the longer time frame was small.

NEFA now has a tool with which to examine issues of resource sustainability. The model was shown to be reasonably comprehensive, adaptable, and capable. Its results were reasonable and add to our insights about the resource.

The NEFA region supports a diverse and surprisingly resilient resource. The region is currently growing significantly more wood than it is harvesting, though each state has its own specific issues and concerns. As the increased demand run showed, however, harvests that increase by roughly 10% per decade become largely unsustainable towards the end of the modeling horizon, resulting in a downward trend in inventory. Different assumptions generate different results. Modeling forces managers, scientists, and policy makers to assemble information and articulate beliefs describing the forest. It creates a feedback mechanism for evaluating the quality and content of field data, helping to pinpoint weaknesses and needs regarding future data collection. This particular analysis has established a regional modeling framework that is but one step in an ongoing process that incrementally improves our insight and understanding of our regions forests, allowing us to improve assumptions and forge appropriate forest policy.

2. Preface

The North East State Foresters Association (NEFA) was formed in 1986 for the State Foresters of Maine, New Hampshire, Vermont, and New York to collaborate on issues of regional importance to the forests and people of these states. NEFA's purpose is to encourage sound decisions about the management and use of the region's forest resources by identifying significant regional trends; broadening awareness of forest health and sustainability issues; providing a regional context for state and local decisions about forest resources; and analyzing environmental, social, and economic impacts of forest land use.

This project had an ambitious goal: to build a model of this region's forest resource that could be used to explore issues of concern at both regional and state levels. Unlike many modeling projects, it was hoped that in addition to providing results of a series of proposed scenarios, the model would become a tool of long-term value for State Foresters as future needs arose.

The reader may find some of this material detailed and technical. From the start, the modeling team felt strongly that models are only as good as the assumptions behind them. In order to explain those assumptions and place the results in proper context, this report allocates considerable space to a description of the model's structure. It strives to convey the strengths and limitations of the data and methods used; then describes the results in a regional context, with state-level highlights. The authors hope this report encourages others to explore both the model and its results in more detail.[1] Our efforts here represent only a humble beginning, a black-and-white snapshot of an incredibly colorful and complex resource. There is much we may never be able to model; yet we believe this effort represents a credible step towards increased insight and understanding at both regional and state levels.

The authors would like to acknowledge the contributions of many individuals and organizations including the New York Office of Real Property Services, the regional offices of the Natural Resource Conservation Service, and the state forestry offices of the four states. Particular thanks go to the NEFA staff and to the other members of the modeling team for their rich insights, guidance, and their commitment to the forests of our region:

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Paul VanDeusen, National Council of the Paper Industry for Air and Stream Improvement (NCASI)

All the direct funding for this project came through a USDA Forest Service grant to NEFA. Additional resources were provided by the individual states through staff involvement in modeling team meetings and research.

[1]The results presented here are also a summary of the detail available in the model. Additional charts and tables are available in a technical appendix to this report.

3. Introduction

Purpose of the project

The NEFA states cover an area of more than 60 million acres, stretching from the Great Lakes in western New York to the Bay of Fundy in downeast Maine. As a region, it shares many things. Forty-five million acres is forested, including a substantial portion of each state. These forests formed in a similar climate with a similar set of soil-forming processes. With a few notable exceptions, the most common forest types are found distributed throughout the region. Nearly 85% of the region is privately owned. Management practices, while diverse and supporting a range of goals, can be generalized within a reasonably defined set of harvesting methods.

Of course, there is also enormous variation and complexity in this forest. The extensive spruce-fir region of northern Maine contrasts sharply with the Allegheny highlands of southwestern New York. A wide variety of forest types and species can exist in a compact area. Their variety reflects the impact of a staggering range of natural conditions, natural history, and human influence. Current management styles range from benign neglect, to ecologically informed, to cut-and-run liquidations. Vast expanses in the Adirondacks and Catskills of New York are unmanaged. Is it reasonable to attempt to model this complexity across a huge ecological region?

The answer, of course, depends on intended purposes of the model, as well as the resolution of the model and the data. The NEFA model is intended to be a regional model, built upon a state-level structure. The primary data source is the U.S.D.A. Forest Service Forest Inventory and Analysis (FIA) state-level database. Each plot in this database represents an average of 5000 to 6000 acres. The model's structure attempts to capture the important biological and management characteristics of this resource, relying heavily on available data to direct our choices.

The model is intended primarily to represent the flows and stocks of the resource base that occur in response to a range of modeling assumptions. These assumptions are collected into scenarios. As examples of the model's versatility, we include results of five scenarios in this report.

For many reasons, a *region-wide* forest resource model had never been attempted before this current effort. The modeling tools were awkward or insufficient, regional data were outdated and difficult to use, and the interest on the part of policy makers was low. Maine is the only state of the four that has pursued resource modeling. There, the critical role of forests in the state's economy has given rise to statewide studies starting in 1974 (Larson and Goforth), then again in 1985 (Seymour, et al. 1985), 1989 (Seymour and Lemin 1989), and recently in 1998 (Gadzik, et al. 1998). This most recent effort in Maine was intended to "aid the development of forest sustainability standards as directed by the 118th Maine Legislature" (Gadzik, et al 1998) and has been adapted to evaluate of the impacts of recent public policy referenda.

The NEFA model developed here is an extension of the Maine model. It uses a similar framework, components, and data, but also adds additional analyses and reporting. It incorporates the latest available inventory data for the states, includes structures that allow for state-level analysis and reporting, employs economic assumptions that affect the allocation of harvests across state lines, and attempts to frame the timber supply results in a broader ecological context. The result is a fairly large and complex assembly, but one that gives states considerable flexibility in how to analyze real or exploratory resource issues.

It is equally important to clarify what this model is *not*. First and foremost, this is not an attempt to predict the most likely state of the NEFA forests over the next 50 years. To attempt to do so would greatly expand the set of assumptions to include estimates of economic supply and demand, impacts of climate change, varying social attitudes, and countless other factors. Such a model would need to incorporate formal estimates of uncertainty and could only report results in terms of statistical likelihood. Our model is intended to be more pragmatic: given what good judgment allows us to reasonably assume (based on data, to the extent possible), how might these assumptions play out in the resource base over time? If the user wants to make assumptions about climate change or anticipated demand, the model can accommodate these assumptions, but the results will be only as good as the assumptions. In this way, this model is analogous to what a real estate investor might build to evaluate the feasibility of a commercial venture—cash flows and resource flows share many similar traits.

Similarly, this model is not intended to be static. Rather it should be part of a dynamic process of researching, testing, and refining assumptions. With each run, some questions may be answered; many more will likely be raised. With state-level structures, state forestry staff can use the model to evaluate both state and regional impacts and assess the adequacy of collected data.

We have not attempted to integrate the social and economic implications of the scenarios we project. The NEFA model focuses primarily on the impacts to the forest resource. Others will (and, to some extent, already have begun to) explore implications that were beyond the scope of this project.

Overview of the modeling process

A good deal of the groundwork for this project was laid by recent efforts in Maine. Numerous decisions affecting the choice of a model framework, critical aspects of the resource to be modeled, and strengths and weakness of the data were addressed there. Building on the work in Maine, the NEFA model is really a composite of 4 "sub-models," each designed to facilitate a particular purpose, yet integrated into a cohesive system. The over-arching framework is based on the USDA Forest Service's Aggregate Timberland Assessment System (ATLAS) (Mills and Kincaid, 1992). ATLAS functions as the accounting system, keeping track of acres, volumes, harvesting, and growth for all elements over time. The model offers a very flexible framework that allows the user to control the performance and activity of the various model elements; however, in order to better specify *how* those elements are to perform, we used two additional models.

FlexFIBER (Solomon, et al. 1995) was used to specify the growth trajectory of most acres in ATLAS. It is a stand growth model, developed and calibrated in the Northeast, that predicts growth and mortality as a function of species, site index, stand density, tree diameter, proportion of hardwoods, and elevation, all within a framework of ecological habitat classes.

The Sub Regional Timber Supply model (SRTS, Abt et al. 2000) employs a series of economic assumptions, including supply and demand elasticities, to allocate harvest requests over time and across states in response to changes in inventory.

Finally, we developed our own database model to aid in the visualization of certain ecological trends implied by the output from the other model components.

Forests in the Northeast are amongst the most biologically complex ecosystems in temperate regions. This complexity supports an astounding resilience to natural and man-induced disturbance. The combination of diverse ownership objectives and varied silvicultural methods supports a variety of approaches to management.

Modelers face the challenge of building a model that is responsive to these complex resource dynamics. With notable exceptions, partitioning of acres in this forest into even-aged groups, with clearly articulated management is not an option for modelers in the Northeast. Even the general species composition of a site is fluid, responding to aspects of site and management over time. As a modeling team, we have attempted to evaluate the essential dynamics that we could both identify and represent within the confines of the data and the model framework. As the following section describes, this has required a number of simplifying assumptions, enriched by the creativity and tempered by the judgment of the modeling team.

Structure of this document

The rest of this document is organized as follows:

- Part 4 summarizes some of the characteristics of the NEFA forest region, highlighting issues that have been considered in constructing the model.
- Part 5 covers the conceptual and structural aspects of the model in detail, with emphasis on the data and required assumptions.
- Parts 6-11 describe the results of the model scenarios that were programmed as part of this project.
- Finally, Part 12 assesses the utility of the model and makes recommendations for its use and further development.

4. Timber Resources of the NEFA Region

A Regional Summary

For the last 50 years, the definitive source for information about the status of our forest resources has been the surveys performed by the FIA. On a cycle of 10 to 14 years, inventory plots are visited in each state, data are processed, and the results published. In the NEFA region, New York has the oldest data (1993), Maine was published in 1995, and Vermont and New Hampshire summaries for inventories completed in 1998 have only recently been released. Within the last 8 years, electronic copies of the plot- and tree-level data supporting the statistical reports have also been publicly available. It is primarily those data that form the basis of the charts and tables below.[2]

Forest Land and Timberland Area

Viewed as a region, the area of timberland has remained relatively stable over the 3 decades, increasing by roughly 3%. Gains from reverting farmland in the rural parts of most states are offset by losses to development in the more urban regions. Still, with nearly 75% of the area forested, slowing agricultural consolidation, and increasing development pressure from growing urban populations, significant increases to the future forest land base seem less likely.

Inventory Volume and Growth

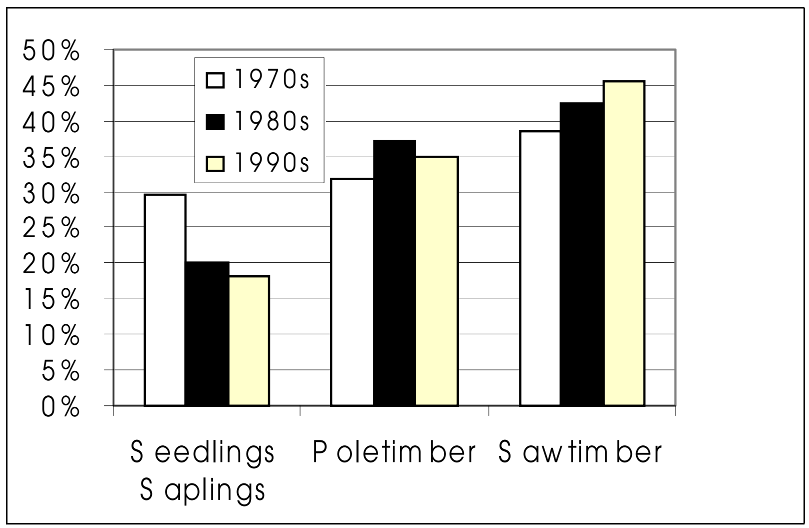
Generally speaking, our forests are maturing. Figure 4.1 shows the changes in composition of acres by stand size class for the three most recent inventories (roughly 30 to 35 years). The proportion of acres in the non-sawtimber classes has steadily declined while acres in sawtimber increased.

Figure 4.2 suggests regional inventories are building. New York inventory grew 32% over a 30-35 year period. Maine shows a decline in inventory, largely due to the spruce budworm outbreak and subsequent salvage harvesting of the 1980s.

Further evidence of the maturing of NEFA forests can be seen in Figure 4.3. Net growth increased only slightly, while the removals of mature timber increased in the more recent years. Region wide, mortality remained steady, though state data reveal increased mortality in Maine but decreased mortality in New York. Removals increased substantially between the two periods in Vermont, New Hampshire, and Maine; but remained steady in New York. Inventories are roughly 70 times the level of current annual harvest, or about 19 cords per acre.

Glossary:

FIA: USDA Forest Service Forest Inventory and Analysis Unit.
Forest land: Land that is at least 10% stocked with trees of any size or that formerly had such tree cover and is not currently developed as non-forest use.
NEFA: North East *State* Foresters Association.
Noncommercial forest land: Reserved productive forest land or land formerly forested but now in nonforest use. Sub-categories include reserved productive, urban forest land, other forest land, and Christmas tree plantations.
Timberland: Forestland producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and not withdrawn from timber utilization.



[2] FIA data and intervals are not completely coincident across the states. Data presented here are generalized.

Figure 4.1. Changes in stand size class over the last 3 inventories (percent of timberland acres)

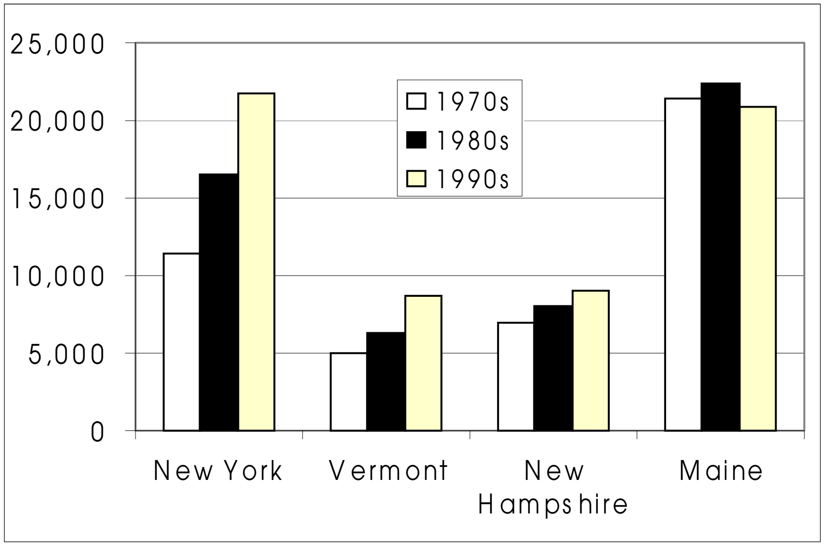


Figure 4.2. Changes in growing stock inventory (million cubic feet)

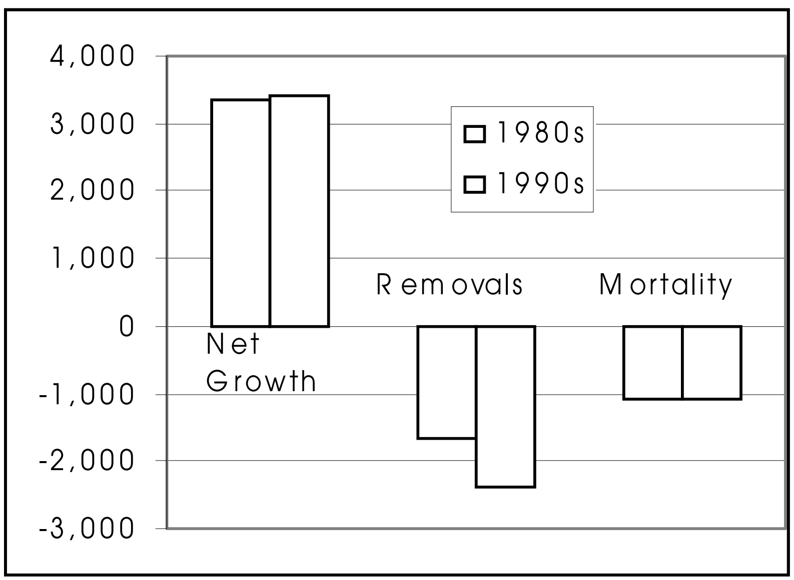


Figure 4.3. Selected Components of Inventory Change (average cubic feet per acre over 10-14 years)

Species Composition

Comparisons of the species with the greatest volume for the prior and most recent FIA inventory cycles are compared in Figure 4.4. Red maple and sugar maple, the most abundant species in our region, have both added substantial volume. Red maple gained enough to overtake sugar maple as the species leader in merchantable volume. Red spruce and balsam fir dropped down the list, while hemlock gained ranking.

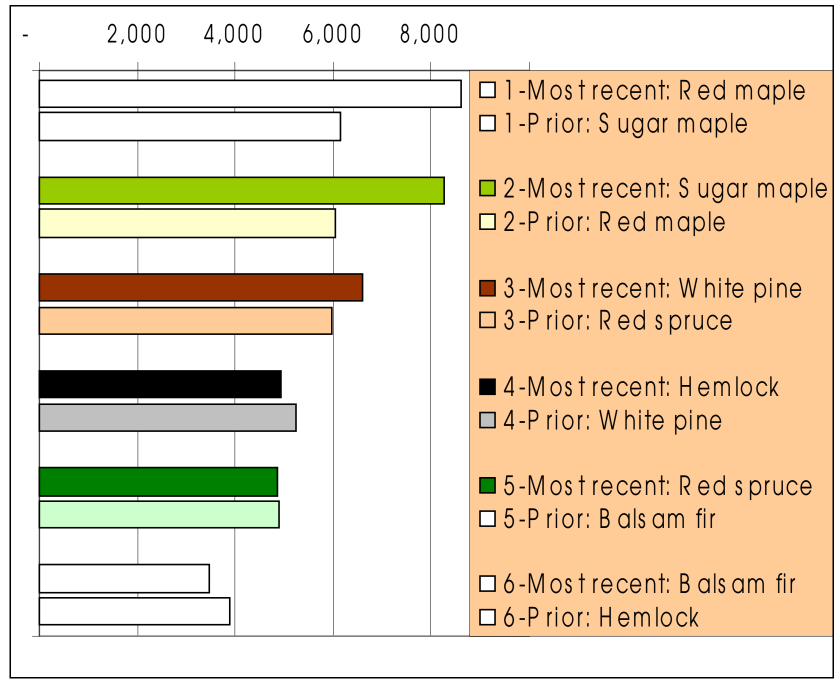


Figure 4.4. Species rank in the most recent and prior FIA inventories (million cubic feet)

Generally, we are still growing more wood than we are removing, though in the last 30 years the combination of slower net growth and increased harvesting has narrowed the margin. Seen in the long term, this is part of a predictable cycle. Much of our current forest has grown back from the heavy cutting early in this century and the abandonment of agricultural lands. Now mature, growth is less vigorous. Along with declining per-acre growth rates, we should expect increased harvests and slower increases (or even modest declines) in inventories.

5. Conceptual and Structural Framework of the Model

Overview

The NEFA model needs a structure that organizes and "classifies" the site quality and vegetative diversity of the forest. Once developed, the existing inventory would then be assigned to this structure. The model needs to represent change by incorporating growth and harvest. Lastly, it should reflect trends in land use and show the impacts of these trends on the resource base.

Since NEFA envisioned this process as an on-going effort rather than one that produces a "most likely" scenario and a report, the tools and structure needed to be simple enough that basic parameters could be understood and modified by state staff as new analyses presented themselves. Individual states wanted the flexibility to model state-level phenomena, and then to aggregate the results at the regional level. Finally, there was considerable interest in presenting the results not simply as timber flows, but also addressing associated ecological implications.

No one "model" exists that meets all these criteria. A variety of tools have been integrated into this project to meet the objectives. Beyond simple knowledge of available modeling tools, the realization of this framework demands creativity in their use.

Modeling Tools

ATLAS provides the framework for the NEFA model. ATLAS was developed by the USDA Forest Service for use in projecting the national timber supply under the 1989 Renewable Resources Planning Act (RPA) (Mills and Kincaid 1992). ATLAS belongs to a class of models called "accounting" models. Its design is highly flexible and is intended to accept a wide variety of ownership, forest type, or management "strata." Each prescribed stratum, or management unit, includes individual specifications for existing inventory, growth, and management regime. Using the prescribed parameters, the model action simulates growth, harvest, regeneration, and shifts in acres or management. Reports account for inventory, growth, acreage, and harvests for each period of the simulation. One attractive feature of ATLAS is that techniques have been developed that directly employ FIA data in the specifications of virtually all model parameters.

Glossary:

ATLAS: Aggregate Timberland Assessment System model
FIA: USDA Forest Service Forest Inventory and Analysis Unit**.**
FlexFIBER: A diameter-based stand growth model for the northeast.
Forest land: Land that is at least 10% stocked with trees of any size or that formerly had such tree cover and is not currently developed as non-forest use.
Habitat: This term refers to FlexFIBER's definition of habitat—"ecological land units defined by landform, soils, and typical climax tree species." (Solomon et al. 1995)
Management Unit (MU): A structural element of the ATLAS model. MUs are defined by the modeler to represent the dynamics of a group of acres having similar characteristics. Parameters controlling growth, area change, and harvesting methods are specified in the MU.
Management Intensity (MI): A subdivision of an MU. MIs are typically used to represent different management applied to acres within an MU.
Noncommercial forest land: Reserved productive forest land or land formerly forested but now in nonforest use. Sub-categories include reserved productive, urban forest land, other forest land, and Christmas tree plantations.
Sub-Regional Timber Supply Model (SRTS): An economic model that simulates the impacts of supply and demand on the forest resource.
Timberland: Forestland producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and not withdrawn from timber utilization.

While flexibility is one of ATLAS's strengths, there is a price paid in complexity. Each MU requires an extensive matrix of input parameters and coordinating these inputs can be tedious. Management units must be linked to "inventory units" and "harvest units." The completed set of input specifications filled 200 pages. Fortunately, much of the information for each unit duplicates others and many of the tasks have been automated with custom procedures.

The genesis of ATLAS is in even-aged forests and silviculture. Procedures have been added to simulate "partial cutting" as an alternative to a final harvest, however it remains organized around the principle that inventory be classified and managed along distinct age class groups. As described below, this required special treatment for the forests of the NEFA region. [3]

One of the critical inputs to the ATLAS model is an appropriate yield table for each MU. As each iteration of the simulation proceeds, acres are advanced one 10-year period in time. Inventory, growth, and available harvest volume are a function of the movement of acres along a specified growth trajectory or yield curve. Unlike growth models that use complex equations to model diameter, density, height, or mortality, ATLAS requires these dynamics to be implicit in this prescribed yield table. Fortunately, yield curves can be developed for inclusion in ATLAS by any appropriate method. In the national assessment, the Forest Service relies primarily on empirical yields developed from the FIA data. The NEFA team chose to model most yields with FlexFIBER.

Previous work in Maine explored alternative ways that ATLAS and FlexFIBER could work together. ATLAS offered the ability to aggregate the results of a large matrix of forest type, ownership and management and to rapidly evaluate alternative scenarios. FlexFIBER offered the opportunity to augment the empirical plot data with simulated growth and yield and to provide a level of detail unavailable in ATLAS alone. Bringing these two models together made sense but, as will be described further below, optimizing the value of each presented a challenge and held broad implications for the model framework.

Neither ATLAS nor FlexFIBER directly addresses issues of economic supply and demand. While the team accepted that an econometric model predicting forest resources demand was beyond the scope of this effort, there was an interest in recognizing the well documented tendency of harvest pressure to "follow the resource." There was sufficient evidence to suggest a tendency for industrial users to adapt their technology and thus shift demand to components of the resource that are most abundant and away from resources that are scarce.[4] We chose another model, the Sub-Regional Timber Supply Model (SRTS, Abt et al. 2000) to address this. SRTS has components that integrate regional estimates of demand elasticity and changes in inventory volume to gradually allocate harvests to areas of increasing inventory. Working with the developer of SRTS, we were able to interact with ATLAS.

[3] A discussion of some of the impacts of this structure and a proposal for modifying it to accommodate uneven-aged forests can be found in Turner and Sendak 1994.

[4] It has been argued that the recent shift of paper manufacturers away from a heavy reliance on softwood to hardwood over the last 20 years took place largely in response to a declining softwood supply and concomitant price increases.

Ecological Metrics

NEFA expressed an interest in developing measures that went beyond the reporting of modeled *timber supply* results and included reporting of *ecological characteristics*. Others have explored using FIA data to examine aspects of biological diversity (Allen and Plantinga 1999) and ecosystem management (Scharosch et al. 1997). With direction provided by these studies and the assistance of two ecologists on the modeling team, the following measures were developed: [5]

- <u>Large-nut mast</u>
  This measure summed the basal area per acre of tree species yielding large nuts (oaks, beech, hickory, etc.). It was constrained to include only trees in upper canopy positions (dominant and co-dominant) and equal to or greater than 8 inches in DBH.
- <u>Medium-seed mast</u>
  This calculated the basal area per acre of trees producing medium-seed mast (dominated by the maples and ash). Only trees equal to or larger than 5 inches DBH were counted.
- <u>soft mast</u>
  Soft-mast producing stems (berries, cherry, apple, mountain ash, dogwood, etc.) were included in this count (stems/acre). No diameter restrictions were applied.
- <u>Fine-seed mast</u>
  This calculated the stems per acre of trees and shrubs producing fine-seed mast (mostly the aspens and birches). No diameter restrictions were applied.
- <u>Conifer-seed mast</u>
  All conifers were included in this basal area per acre measure. Only trees equal to or larger than 5 inches DBH were counted.
- <u>large trees</u>
  All trees on a plot equal to or greater than 20 inches DBH were counted for this measure (stems/acre)

[5] Further discussion of the methods used to calculate the metrics is included in Appendix A.

- dead trees
  This measure counted all standing dead stems on a plot equal to or greater than 10 inches DBH.
- vertical structure
  All stems on the plot were assigned one of seven height classes (0-3'; 3-10'; 10-20'; 20-40'; 40-60'; 60-80'; 80'+) based on either the actual height (available when DBH=>5") or by an estimate of the height. The actual measure summed the number of height classes present (maximum=7) on the plot.

FIA plot-level data were used to develop "baseline" values for each measure, consistent with the finest level of resolution available in ATLAS. Using a custom spreadsheet, region-wide composite values for each measure were calculated by weighting these baseline values by the acres in each ATLAS "cell."

Data sources

The development of parameters for the model framework was greatly facilitated by the availability of the FIA data sets for each state. (Table 5.1). These data consisted of 7458 forest land plots (public and private land), with both plot-and tree-level data fields (See Appendix B). While FIA provided a rich data set, we needed to consider its limitations as well.

State	Year Completed	Forest land Plots	Timberland Plots
Maine	1995	2733	2630
New Hampshire	1997	853	802
Vermont	1997	773	750
New York	1993	3099	2956
TOTAL		7458	7138

Table 5.1. Summary of FIA plot count by state.

Inconsistencies resulted from the fact that the data were derived from 3 different surveys completed at different points in time. Certain variables collected at different times had slightly different definitions. Some data were available for some of the states but not others. Different dates of collection meant some results were more current than others. Substantial effort was invested in "normalizing" the data set to a single, aggregate of plots. In order to account for differences in collection dates, New York and Maine were eventually "grown ahead" using ATLAS to approximate a common year-2000 starting point.

New York presented additional data dilemmas. The FIA inventory at the time did not sample public lands within the Adirondack and Catskill state parks—an area accounting for over 2.5 million acres of forest land. We were able to use a collection of other data sources to piece together information on stand types, volumes, and average diameters, albeit without the statistical reliability of the FIA data.

While FIA data document harvesting within the plots, because this record covers a 10-14-year period, these data are insufficient to characterize current harvest demand. In 1999, NEFA commissioned a report that explored current harvesting and wood flows in the region (The Irland Group 1999). This study was the primary source for estimates of statewide harvest volumes.

Primary issues of concern

The modeling team quickly identified a number of shortcomings of previous modeling efforts, potential hurdles in using the chosen computer models, and critical aspects of the resource that had to be accommodated. The discussion of these issues below provides additional context for the choice of a model structure and the discussion of results.

Age class

Even though some stands have a single age-class structure, past harvesting, partial-mortality events, and the prevalence of shade tolerant tree species make the majority of the NEFA forest stands fall outside what could be considered even-aged. Even in Maine where industrial management is most intensive, the proportion of truly even-aged stands was small.

A typical ATLAS formulation organizes inventory by age class and advances these acreage groups forward in time; yet, few of the FIA plots had a reliable, field-determined age. A classification scheme was needed that served as a proxy for age. The chosen criterion also needed to change predictably with the passage of time.

Forest Type

FIA data describe the "forest type" of each plot based on "the plurality of all live stocking within the stand" (Hansen, et al 1992). This approach to measuring type is useful in comparing change in type between inventories, but it is less useful as an indicator of future stand species composition. For modeling purposes, we wanted a measure of the short- to medium-term composition of the site and the *tendency* of the site over the long term. Since much of the land in the region is capable of supporting a variety of both hardwoods and softwoods, the classification of acres into groups of similar vegetative tendency should embody physiography, site quality, elevation, and overstory and understory vegetation. It also needed to recognize the impacts of previous management and harvesting history on current and future composition.

Management

The diversity of ownership, forests, and products in the region combine to make the characterization of management difficult. Added to this are inherent limitations in the way ATLAS can represent management activities in the model specifications.

The FIA data are of limited value here. Data for each plot records removals since the previous inventory, but this could represent one or more harvest entries. While FIA field crews make determinations of treatment opportunities, the majority of plots have "no treatment" suggested. Maine and New Hampshire collect detailed information on types of harvesting, though only Maine's was available for analysis. Research on high-yield practices (particularly in Maine) produced some specifics, but only for the relatively small number of acres in that category.

We needed a scheme that would be simple and inclusive, yet descriptive enough to capture the broad trends in harvesting apparent in the data. Management categories needed to generalize the results of management reflected in the data rather than be prescriptive.

Specifying the Structure for the Model

The fundamental issues above had to be accommodated in ways that both reflected their influence on the forest and allowed us to work within the constraints of the modeling tools. After considering a variety of alternatives, the following choices were made.

Organizing Plots by FlexFIBER Habitat Types

Within ATLAS, we needed some logical scheme for grouping plots into types that would accommodate differences in composition and growth potential. We chose to pattern our groups after the scheme used by the FlexFIBER developers.

In order to "grow" plots in FlexFIBER, a vegetative type classification or "habitat" must be assigned to each plot. These habitats are "ecological land units defined by landform, soils, and typical climax tree species." This designation influences the default site index and the succession of species as growth is simulated. (Solomon, et al. 1995 and Appendix C). To generate yields, a user assigns plot data to one of the six available FlexFIBER habitats: sugar maple-ash, beech-red maple, oak-white pine, hemlock-red spruce, spruce-fir, and cedar-black spruce. FlexFIBER performs a validation check on the user's choice based on the basal area concentration of certain species groups in the plot data. Working with the developers of FlexFIBER, we built routines that used these species allocation limits as a decision matrix to assign all plots to an initial FlexFIBER habitat based on the concentration of key species. In order to represent the potential for a plot to be in a transitional vegetative stage, we performed this classification on both the overstory (merchantable sized trees >5.0" DBH, using basal area to measure species concentration) and on the understory (seedlings 6+" and saplings to a 4.9" DBH, using trees per acre).

This initial classification yielded definite yet preliminary results. The plot-level, FlexFIBER-generated understory and overstory habitat variables became reference points for additional refinement using additional data and judgment. Further review considered the current and previous FIA forest type, soils, elevation, physical location in the region, plot volume, and other variables along with the vegetation-based habitat assignments made by FlexFIBER. Groupings of similar conditions became apparent and relatively few plots ended in the "undefined" category. While this process was time intensive, it produced valuable insights into the structural and vegetative characteristics of the forest, which in turn influenced the specification of management for these plots. The result was more useful than had we simply used the FIA forest type.

New York again required special consideration. The FlexFIBER model was not designed to specifically accommodate the central hardwoods species associations commonly found in this state's southern regions. After researching the characteristics of these types it was decided to separate plots that did not fit the FlexFIBER framework into two additional types: oak-hickory and Allegheny hardwoods. The growth curves for these types were based on an analysis of historical growth in the FIA database for NY. Maps showing the assignment of habitat to plots are presented in Appendix C.

Volume Classes

The previous ATLAS modeling project in Maine considered a number of analytical approaches designed to approximate stand age. In that study, all approaches were rejected as inadequate. Instead, the Maine project chose to classify and manipulate stands in ten-year *volume classes.* A similar approach was employed in this NEFA model.

Conceptually, we wanted to replace the volume-over-age relationship of the typical yield curve with a volume-over-time relationship. We recognized, on the one hand, that future growth is only partially dependent on current volume; yet we also felt that stand volume often drove management actions and harvest decisions, and thus made *operational* sense. This arrangement would be consistent with ATLAS yield table requirements as long as periodic volume class midpoints were roughly equivalent to the volume growth over the same period.

A separate FlexFIBER analysis developed appropriate volume-class intervals. (Already, all plots except high-yield acres (plantation, pre-commercial thinning, and herbicide release) and the special NY types had been assigned to one of the six FlexFIBER habitat classes.) A selection of plots representing a range of stand volumes were chosen from each habitat. Growth for these plots was simulated in FlexFIBER and the resulting mean annual and 10-year period increments were examined. These results provided the basis for approximate volume class midpoints and ranges. Further comparisons were made to published yield curves and to empirical curves developed from the FIA data. An iterative process ensued with further FlexFIBER projections, further comparisons, and refinements to the volume class intervals. Eventually, all plots were assigned a 10-year volume class.

Yield Curve Development

Typically, yield curves for ATLAS formulations are developed empirically from the FIA data. In addition to the obstacles presented by a lack of stand age, we knew that past attempts to develop empirical yield tables suffered from insufficient plot data and from the concentration of "high-graded" stands in older age classes (Seymour and Lemin 1991). Opting to use simulated growth, we submitted plots in habitat/volume class groups to FlexFIBER. Modifications to the FlexFIBER program allowed us to grow plots individually yet aggregate the results of a multi-plot run in a single output file. FlexFIBER also was reprogrammed to allow species present in the understory to be included in the ingrowth for the plot. This feature greatly improved the representation of understory species in the final stand and, depending on those species present, had a significant impact on the projected volume.

Certain groups of plots required special treatment. For management units that represented high-yield practices, we chose a growth model with specific relevance to the spruce-fir resource, GNY (GNY 1993). These simulated yields were supplemented and validated using both published reports and data supplied by contacts within forest industry.

Yield curves for Allegheny hardwood (stands with high percentages of black cherry and maples) and oak-hickory plots (mostly dry-site oak stands) were developed from empirical estimates of growth recorded in the FIA. With these acres, we adopted an approach similar to the "growth-yield" approach typically employed by Forest Service personnel using the ATLAS model (Mills 1990). Here we substituted volume classes for age classes that ATLAS normally employs.

Characterizing Silviculture: Removal Classes

After reviewing various summaries developed from FIA data, the modeling team recommended that most harvested acres could be put into 3 classes (relative to volume prior to harvest): 0% to 50% volume removed, 50% to 80% removed, and 80% to 100% removed. The lowest removal class represented light stand entries, symbolizing commercial thinnings, initial shelterwood harvests, or similar treatments that left more of the stand than was harvested. The middle class might encompass group selection, patch cuts and other nonspecific treatments. The heaviest removal class included clearcutting, final shelterwood harvests, and other forms of stand regeneration or release. By examining the FIA record of actual removals in each of these classes, estimates of volume harvested were developed for each class.

While the above analysis provided a conceptual framework for classifying management and harvesting, it was based on data from *harvested* plots only. Harvested plots represented less than one-quarter of the plots in the dataset. We assumed that virtually all plots would be harvested eventually, and we assumed the characteristics of plots harvested in the recent FIA data for future projections.[6] Remaining

[6] In one scenario, we modeled the effects of the elimination of clear-cut harvests.

unharvested plots were assigned to removal classes using the proportion of acres in each removal class to the total acres for that habitat. In cases where the management and harvesting methods were inherent in the definition of a management unit (e.g., plantation and high-yield groups), the best available historical information was used.

Non-commercial forests

A comprehensive resource model should include not only acres and inventory volume on timberland (forest land available and capable of producing industrial wood), but also should include those acres that are forested, but that, for various reasons, do not supply wood to the market. This category includes: urban forest land, unproductive forest land, *reserved* productive land, and unproductive reserved (Table 5.2). These were aggregated as non-commercial in the model and were not available for harvesting, but were otherwise treated as above.

The ATLAS Management Unit Structure

In ATLAS, groups of acres that share similar characteristics (vegetative, management, ownership, etc.) are aggregated into management units (MUs). This organization is central to the structure of the ATLAS model. Each MU has acres and inventory assigned to it, consistent with the definition of the MU. Parameters specified at the MU-level define growth, volume *available* for harvest, diameter class distributions, hardwood/softwood ratios, and other elements that define the MU and control the range of its activity.

	New York	***Vermont***	***New Hampshire***	***Maine***	***Total***
Reserved productive	2786.5	114	148.6	334.2	3383.3
Urban forest land	9.6	4	50.1	43.4	197.1
Unproductive forest land	122.8	18	108.1	367.6	616.5
Unproductive reserved	166.9	11	8.3	6.2	192.4
Total	3175.8	147	315.1	751.4	4389.3

Table 5.2. *Non-commercial* forest land acres by state (Source: FIA) (thousand acres).

After assigning habitat and removal class to plots, the structure of management units for the NEFA model becomes evident (Figure 5.1). Each state included 3 removal classes for each of 6 FlexFIBER ecological habitats, plus miscellaneous management units accounting for special types, non-commercial, plantations, and high-yield acres. Each plot (with its associated acres and inventory), now classified by state, habitat (or type), volume class, and removal level was assigned to an MU. The inventory volume available for harvest from each management unit was constrained to reflect the level of removal by volume class evident in the FIA data. All other parameters including growth-on-harvest multipliers, density/volume adjustment coefficients, minimum volume class harvest removal limits, average diameters, and softwood proportions were all developed directly from the FIA data.

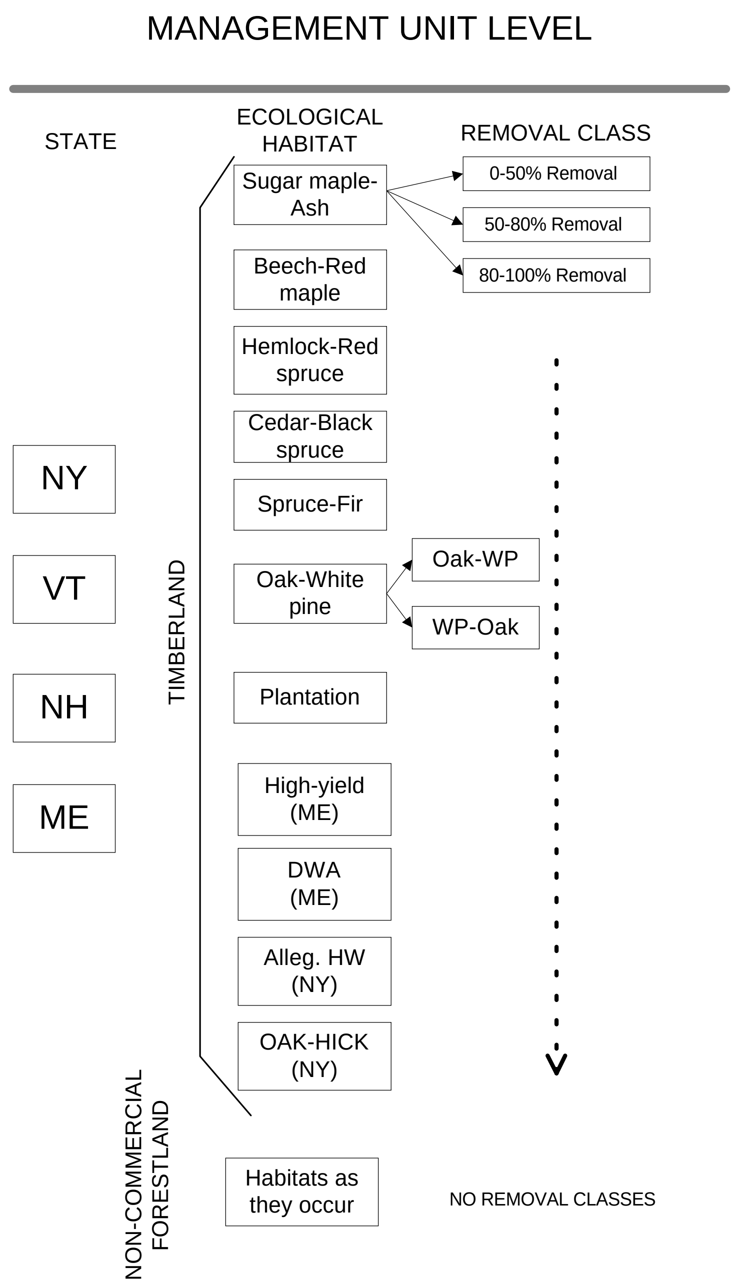


Figure 5.1. Schematic of the ATLAS management unit layout

Estimating Impacts of Land Use Change

Any model examining regional resource sustainability must consider changes in the area of productive forest over time. Estimates of resource availability and wood supply will be influenced by the area in productive timberland, which is influenced in turn by growing populations, increased development, and changing attitudes toward land use and harvesting. We recognized the need to project future timberland area. A survey of land economics literature shows decades of research on the theory and determinants of land use change. Yet while generalizations regarding the effects of geography, demographics, transportation infrastructure, and other factors can be made from this research, there are no recent studies predicting land use change for the entire NEFA region.

Using a variety of available resources, the modeling team chose to make its own projections of land use change over the next 50 years. Recent research was examined, available data were analyzed, and rates of change were estimated for each of 12 sub-regions across the 4 NEFA states. While the rigor of our approach may not meet the strict standards of science, it was consistent with the pragmatic needs of this project. As better estimates of land use change become available, they can be integrated into future modeling.

Overview

Encompassing over 60 million acres and 20 million people, the NEFA region includes some of the most densely populated areas of our country and some of the least densely populated. Many factors, within and external to the region, influence land use and rates of land use change. Certain geographical areas exhibit more forest land development pressure than others. Since forest types and our ecological "habitats" also have a spatial distribution, land use change will impact some habitats more than others. *Thus, the goals of this land use analysis were to develop estimates of timberland area change by logical state sub-regions and then to apply the implications of this change to appropriate acres within our ecological habitat scheme.*

The steps were as follows:

1. Research any recent studies of regional land use change that might provide specific predictions or information on important determinants of change.

2. Acquire available data on population, income, road density, housing, historical land use change, and other pertinent items that could be used to inform our predictions.
3. Generate estimates of change by sub-state region.
4. Apply the implications of these changes (acres of forest lost or gained over time) to the affected habitats in our model.

The result of this analysis allocated acres by habitat for each management unit over the 50-year time frame of our projections. The primary interest was in the projection of losses or gains to timberland. We did not directly try to project increases in non-commercial forest.[7]

Recent studies

A review of the literature uncovered three studies that examined state-level change in different states. The methods employed in these studies differed greatly. A brief summary follows.

Researchers Mauldin, Plantinga, and Alig (1998) used an econometric approach to estimate the relationships between acres in particular uses and proposed factors or "determinants" of those uses. Land quality, land "rents" (monetary returns associated with particular uses), and simple geographic terms were among the determinants included in the regressions. Once these relationships were estimated, they were used along with forecasts of changes in rents (implied from forecasted changes in stumpage prices, agricultural product prices, and population density) to predict state-wide estimates of acres in "private timberland," "agricultural land," and "urban land." They predicted Maine would lose between 447,000 and 1.5 million acres of forest land between 1995 and 2050, though they point out that the structure of their model may overestimate the urban land gains (and complimentary forest land losses).

The Society for the Protection of New Hampshire Forests and the New Hampshire Chapter of The Nature Conservancy (SPNHF 1999) report examined forest fragmentation, particularly in response to population and housing growth. The methodology used data from the USDA Natural Resource Conservation Service Natural Resource Inventory (NRI) along with satellite-based land use/land cover maps and estimates of population to generate a variety of estimates for each municipality in the state. Among their estimates is "Predicted Decline in Forest Land Area 1993–2020." They predict a loss of nearly 144,000 acres of forest land area by 2020, with the bulk of this occurring in the southeastern corner of the state.

The Third study was commissioned by the Vermont-based Orton Family Foundation and conducted by the University of Vermont Spatial Analysis Lab. Entitled, "Vermont Land Conversion Analysis, 1962-1993" (SAL 2000) it also used satellite imagery along with other sources to document land use change at the municipal level. Numerous socio-demographic and biophysical factors were investigated as determinants of change. The focus of this analysis was conversion from forest and undeveloped non-forest to developed, with the goal of understanding the determinants of change. The total amount of statewide change and discussions of net change (with losses offset by reforestation) were ignored. Although several different regression models were estimated in this study to predict forest land change, none of the state-level models explained more than 24% of the variation in change (R^2). Many coefficients had unexpected signs and no clear set of reliable determinants was evident.

In summary, the available studies of land use in the NEFA region displayed little consensus in methodology or results. Each study offered background information about long-term land use trends, but none used a historical time-series of over 25 years in its model. None considered the "stock" of land available for conversion (either to or from forest), nor do these studies offer any suggestions about how rates of development might change as readily developable land gets used up. These aspects of land use change are inherent in the theoretical models, but not well accommodated by the empirical models we found. The modeling team chose to investigate available sources of data and generate its own estimates of forest area change.

Sources of Data

The primary sources of data included:

- Census of Agriculture extended time-series data on land use;
- USDA Natural Resource Conservation Service (NRCS) Natural Resources Inventory (NRI) data;
- Bureau of Census demographic data series;
- FIA data;
- County-level estimates of population change;
- County-level estimates of road miles;

[7] In the "reduced availability scenario", we did make some assumptions regarding increases in "urban" forest land.

Each of these data sets had strengths and weaknesses. In accounting for different categories of land use, the NRI data offers the most consistent (by county, across all states) and detailed information, though it is limited by its relatively short duration (1982-1997). These data were compared for consistency with the Census of Agriculture and FIA data.

Analysis

We examined both geographical and time-series trends for 10 multi-county groupings across the four states (Figure 5.2). Counties aggregated in these land use units shared reasonably similar levels of the measured attributes and seemed to be affected by similar sets of land use factors. Many of these factors are mapped and charted in Appendix D.

Future rates of change, as extensions of recent trends (tempered by the demographic and other data), were discussed within the modeling team. Using insights gained from the above-referenced reports, we considered the stocks of land in forest, agricultural, and urban uses over 100 years; components of land use change over the recent 2 decades; population densities along with projected rates of change; per-capita income levels and rates of change; road densities; and other factors.

Units that gain forest land are generally rural and have a current stock of crop and pasture land. Counties losing forest land have higher population densities, higher road densities, and proximity to urban concentrations. In general, our estimates reflect declining rates of change over time, both for gainers and losers. Once agricultural land stocks decline, less land will revert to forest. Likewise, not all land in the areas with greatest pressure can be developed before the marginal costs of development force conversion activities further into rural areas. Table 5.3 summarizes the results by land use unit and state.

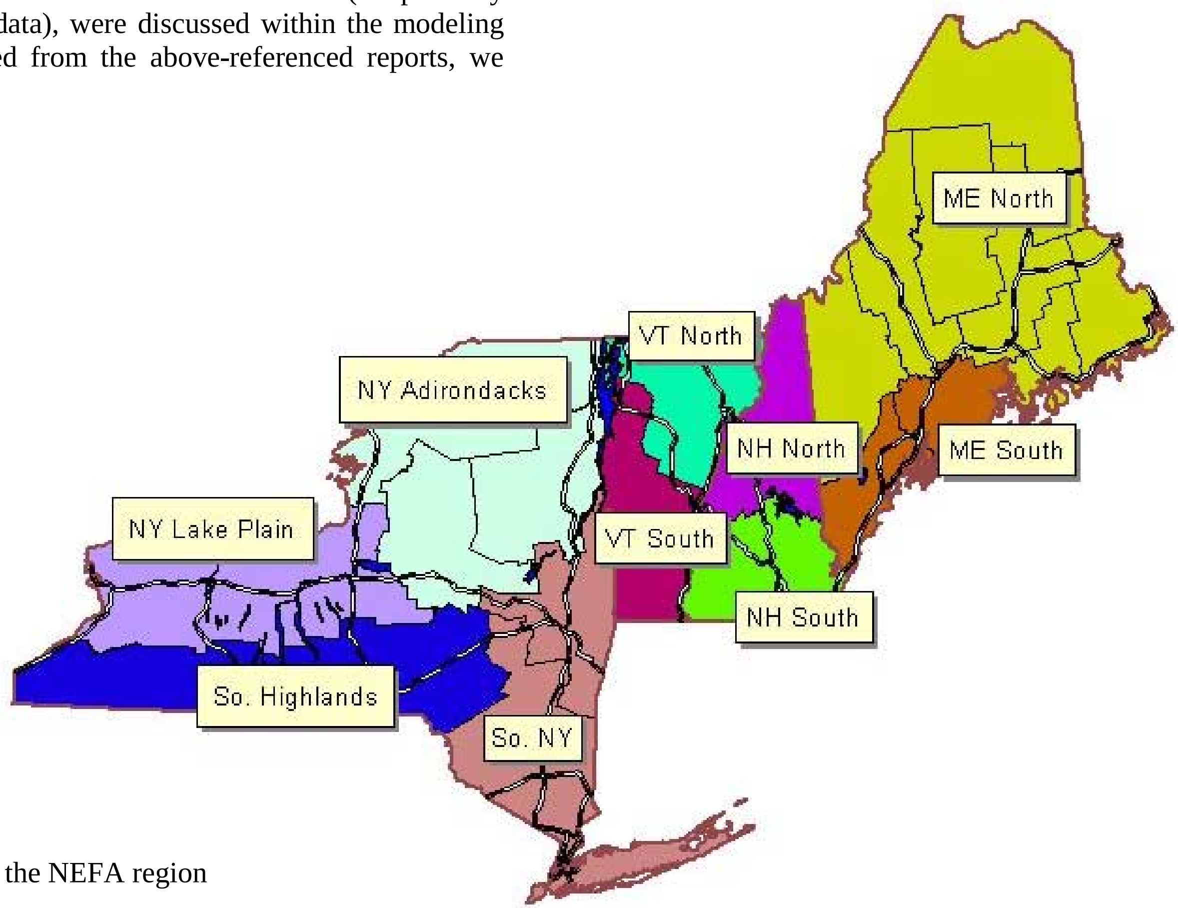


Figure 5.2. Land use units of the NEFA region

Land use unit	Change in Acres by Period					Net change
	2000- 2010	2010-2020	2020-2030	2030-2040	2040-2050	
ME North	25,000	15,000	10,000	6,000	5,000	61,000
ME South	(20,000)	(12,000)	(10,000)	(10,000)	(10,000)	(62,000)
NH North	(8,000)	(8,000)	(7,000)	(6,000)	(4,000)	(33,000)
NH South	(55,000)	(45,000)	(26,000)	(17,000)	(12,000)	(155,000)
VT North	16,000	12,000	10,000	8,000	7,000	53,000
VT South	(12,000)	(7,000)	(4,000)	(3,000)	(3,000)	(29,000)
NY Adirondacks	66,000	49,000	40,000	33,000	28,000	216,000
NY Lake Plain	60,000	30,000	25,000	15,000	10,000	140,000
NY Southern Highlands	69,000	52,000	41,000	35,000	29,000	226,000
NY Southern New York	19,000	14,000	12,000	10,000	8,000	63,000
Regional change/period	160,000	100,000	91,000	71,000	58,000	480,000

50-yr Summary by State	Change in acres
Maine	(1,000)
New Hampshire	(188,000)
Vermont	24,000
New York	645,000
Net change	480,000

Table 5.3. Summary of projected changes to timberland area.

The above results predict a net gain of 480,000 acres of timberland over the 50-year modeling period, with losses in New Hampshire and Maine more than offset by gains in New York. The southern units of Maine and New Hampshire see the largest percentage change and the largest drop in absolute acres. These areas are currently experiencing considerable development pressure from their proximity to metropolitan Boston. It is interesting to note however, that while long-term historical trends show increasing suburbanization, the rate of change and even the direction of change have taken wide swings as expansion pressure in the suburbs reflects economic cycles in adjacent urban areas. Population growth has been close to 50% in these units over the last 40 years, but is projected to slow. According to the NRI data, crop and pastureland still yield some acres to developed land, though forests provide the bulk of the acres.

Overall, Maine and Vermont see relatively small net changes over the projection period. In these states, there are still stocks of agricultural land reverting to forest, though agricultural consolidation is probably near its limit. In northern and western Maine (the ME North unit), population densities are low as are projected population increases. In Vermont, social attitudes and land-use policies are likely to continue to soften the impacts of population growth on land use change.

New York offers a contrast to the rest of the region. Its population is concentrated in urban areas, leaving vast areas in the north and west with fewer people per square mile than northern Vermont. Over the last 50 years, New York showed a 50% gain in forest land area (5.4 million acres) (USDA Agricultural Census data). Abandoned agriculture land supplied most of these acres. Projections of population change vary, but some areas of the state appear to have lost population in recent years and projected increases are being revised downward. The combination of low population pressure, relatively low road densities, and substantial stocks of pastureland along with a downward trend in cropland, leads us to anticipate some continued reforestation and an increase in timberland area over the projection. FIA summaries for New York (1993) show 43,000 acres of timberland *lost* between 1980 and 1993 while non-commercial forest land gained 178,000 acres. The bulk of the non-commercial gain came from additions to state-owned area in the "forever wild" Adirondacks and Catskills, with the majority of that coming from timberland.

The estimates developed here should be debated as the model is refined. We have tried to systematically evaluate the major forces and trends, stopping short of a major statistical study. The land use estimates presented in Table 5.3 show slightly more than a one percent gain in timberland area over the 50-year projection. Recent trends suggest the increase has been on the order of 1%-2% *per decade*, though this rate of increase has been steadily declining. Based on our review of the pertinent factors, we expect the region to continue to experience incremental net gains over the next 50 years.

Finally, the definition of "timberland" is based on the physical capacity of that land to grow crops of industrial wood. It excludes areas of poor soils or high elevation where that criterion is not met (these are accounted for as non-commercial, non-productive acres). However, it does not distinguish lands that may be economically sub-marginal (particularly related to the cost of extraction), lands where owners are disinclined towards harvesting, or lands where full access to the timber is restricted (riparian buffers, for example). At any point in time, some indeterminate amount of the volume associated with these acres will be unavailable. Seen across a 50-year horizon (and given the general abundance of the resource relative to the demand), we have ignored these possible limitations for all but one of the following modeled scenarios. The area changes presented in Table 5.3 are used for all model scenarios except the "pessimistic land use" scenario. Changes to our land use assumptions for that particular scenario will be discussed in the description of that run.

Assigning Land Use Change to Habitats.

Once acreage changes for each region and period were estimated, these changes had to be apportioned to the acres in each modeled management unit (MU). Doing this allows those regions experiencing the change to impact the volumes within habitats and removal classes in the same regions. Acres by MU and region were calculated for each state and the periodic change was assigned proportional to the acres in each category. Table 5.4 summarizes acres by habitat for the region. The distribution includes minor modifications to habitat apart from land use change. Based on the modeling team and conversations with other experts, we made exogenous adjustments to plantation acres, and high-yield acres.

Habitat	***Decade Beginning***						***Net change***
	2000	***2010***	***2020***	***2030***	***2040***	***2050***	
Sugar maple-Ash	12.72	12.82	12.90	12.96	13.02	13.06	0.300
Beech-Red maple	10.02	10.08	10.13	10.17	10.20	10.23	0.180
Hemlock-Red Spruce	3.77	3.77	3.77	3.78	3.78	3.78	0.010
Cedar-Black Spruce	2.31	2.32	2.32	2.33	2.33	2.34	0.030
Spruce-Fir	9.22	9.18	9.19	9.20	9.20	9.21	-0.020
Oak-White Pine	5.06	5.05	5.05	5.04	5.05	5.05	-0.010
Plantation	0.90	0.90	0.85	0.81	0.76	0.72	-0.140
Deer wintering areas (ME only)	0.25	0.25	0.25	0.25	0.25	0.25	0.000
Allegheny Hardwoods	1.02	1.05	1.06	1.08	1.09	1.10	0.070
Oak-Hickory	0.40	0.40	0.40	0.41	0.41	0.41	0.010
Total Acres (millions)	45.67	45.83	45.93	46.03	46.10	46.15	0.480

Table 5.4. Acres by habitat over the model period (million acres)

Harvesting in ATLAS

Basic Harvesting Structure

In ATLAS, harvesting occurs as part of a specific sequence of events. This flow of events is portrayed in Figure 5.3. Harvest volume is generated by the 3 activities boxed on the left side of the figure:

1. Volume recovered from area loss (land use change or shifts across MUs for other reasons)
2. Any commercial thinning specified in the MU.
3. Cutting in response to a specified harvest request.

The first two are distinguished from the third by the fact that they are triggered by the passage of model time, regardless of any specified harvest request. If acres in an MU decline (areas loss), the user can specify what proportion of the volume in those acres will be recovered. *In our formulation, one-half of the inventory volume from acres lost to land use change was recovered; the balance was considered to be unavailable.* No commercial thinning was explicitly specified in our model, though some is recognized to occur. We felt the 3-tiered removal class structure of our MU formulation accommodated this relatively limited commercial thinning activity. Thus, most of the volume harvested is a result of an externally specified harvest request; external in the sense that it is "outside" or exogenous to the management unit section of the model.

The external harvest request and the MU specifications are certainly linked. ATLAS looks to the specifications within each MU for the inventory *available* for harvest in that unit. This is specified in the yield table and minimum harvestable volume class settings for each MU.[8] When the periodic sequence of model events reaches the harvest point, available volume in all MUs is apportioned to meet the harvest requested. Our formulation allows all MUs across all states to be eligible for meeting the total harvest request; however, the amount of harvest shifting across states and habitats is determined and constrained in the SRTS model. This will be explored further below.

Determining the Initial Harvest Request

Each state in the NEFA region collects harvest information differently. Maine has the most extensive reporting, followed by

[8]Each ATLAS MU actually requires many more modeling decisions. Throughout this report we have attempted to convey key concepts, with a minimum of detail.

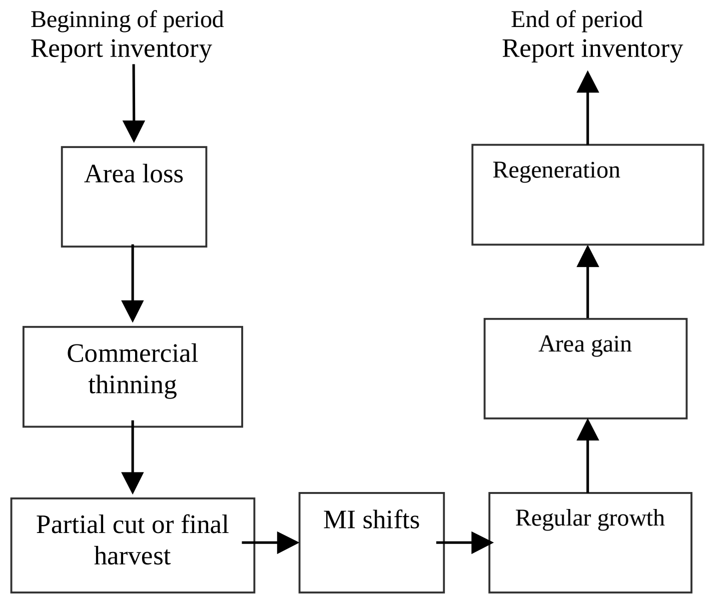


Figure 5.3. The order of occurrence of model activities (Mills and Kinkaid 1992).

Vermont. New Hampshire and New York collect minimal information. The USDA Forest Service performs periodic surveys and some information is available in the FIA data set. NEFA commissioned it's own review of these data sources and compiled a summary of the best available information across the NEFA region for 1997. With the exception of Maine, this wood flow report (NEFA TPO, 1999) is the basis for our estimates of the initial (2000) harvest requests in our model (Table 5.5).

Certain aspects of these data deserve further consideration.

- Volume estimates published in the NEFA report were used for New York, Vermont, and New Hampshire. Harvests in Maine are based on 1999 Maine Forest Service (MFS) wood processor reports.
- Wood flow is known to cross international boundaries. The total volumes estimated here capture these flows in the current harvest. No attempt was made to predict how these export proportions might change.

- NEFA volumes include biomass. Discussions among the modeling team suggested a portion of this component is composed of non-bole material as a by-product of harvesting and milling operations. It would be inappropriate to categorize all biomass volume as part of demand. We removed all the estimated biomass volume from New York and Vermont totals, and all but 10% from New Hampshire. More of the New Hampshire biomass is a result of land clearing and whole-tree harvesting. Maine's data did not include biomass.
- The total harvest volume for each state was allocated to management units using a formula that considered the softwood/hardwood ratio of the harvest and the initial volume in each MU. Generally speaking, this allocation resulted in the MU receiving a harvest request that was proportional to its inventory volume.
- NY plantation harvests were increased to better reflect the maturing of theses acres and their disproportional contribution to the wood supply over the next 5 decades.

SRTS Adjustments to Harvest Requests

As mentioned above, our model initiates with MU-level harvest requests proportional to MU volume. During the first model period, if the volume available in that MU does not meet this request, ATLAS will not attempt to satisfy it with volume from another MU. No cross-MU or cross-state sharing is allowed. Experience suggests this is unrealistic.[9] We know market demand is more flexible.

The Sub-Regional Timber Supply model (SRTS) provides a mechanism for adjusting the allocation of the MU-level harvest requests. It examines the rate of change in inventory volume for each MU at the end of each 10-year model period. Assuming the harvest demand will gradually equilibrate to "follow" MUs with more available inventory volume, it reallocates the harvest requested for the subsequent period to those units better able to supply it. Underlying SRTS's allocation is the principle that many of the products yielded from NEFA forests are roughly substitutable, given sufficient time. Prices will respond to supply (inventory) and the market will, through technological change or attitudinal change, shift its demand preferences. These changes are not instantaneous; rather "elasticities" define

[9] In the 1980s, facing higher prices and constrictions in softwood supply, many regional pulp mills extended procurement areas across states and adopted hardwood pulping technology.

	Total*	***Biomass***	***Net***
NEW YORK			
hardwood	217.69	-11.90	205.79
softwood	51.17		51.17
Total (mcf)	268.86		256.96
Note: all estimated biomass removed			
VERMONT			
Hardwood	73.59	-4.66	68.93
Softwood	46.60		46.60
Total (mcf)	120.19		115.53
Note: all estimated biomass removed			
NEW HAMPSHIRE			
Hardwood	104.11	-28.21	75.90
Softwood	76.60		76.60
Total (mcf)	180.71		152.50
Note: 10% of biomass included			
MAINE			
Hardwood			273.90
Softwood			284.60
Total (mcf)			558.50
Note: 1999 MFS estimates used instead of NEFA TPO numbers. Biomass excluded			
Adjustments:			
Increase harvest to NY plantations:			14.20
Total, all states (mcf)			**1097.69**
Hardwood			624.52
Softwood			473.17

*Note: the hardwood/softwood breakout is based on NEFA TPO estimates. Actual hardwood/softwood allocation in the ATLAS harvest will depend on these proportions in the *inventory*. A comparison of the two ratios shows minor differences.

Table 5.5. Estimated harvest requests for the initial 10-year model period (million cubic feet).

how quickly a change in demand will respond to a shortage of supply and an increase in price.

The SRTS adjustment process incorporates these principles. Values for the elasticities are based on regional historical evidence. In this iterative fashion, inventories (after growth, harvest, and land area change) are investigated and harvest demand is adjusted after each period.

In the model runs that follow, SRTS affects a very gradual shifting across MUs and states. Under the most severe harvesting scenario we ran, the maximum decadal shift across states is 2.5% (5% over 50 years). Again, critics may debate the methods and assumptions here. Markets forces affecting primary wood products in the region are extremely complex. Research continues to be done and may soon yield further insights (Sendak, pers. comm.).

Summary of pertinent assumptions

We have described in some detail the structure and key specifications required in the construction of this model. Our intent has been two-fold. First, by explaining the model structure we wanted to mitigate the "black-box" notion of the model as something unintelligible and instead convey its workings as a series of logical steps. Second, we wanted to emphasize that any model incorporates a great many assumptions and an appreciation for the nature and reliability of those assumptions directly affects our interpretation of and confidence in the results. Having laid sufficient groundwork, this section of the report highlights some of the general assumptions the reader (and model user) should keep in mind before we begin to discuss model results. Additional assumptions will be discussed as they pertain to each of the modeled scenarios that follow.

The following list is by no means exhaustive. Some items repeat aspects of the discussion in previous pages; others are more broad.

General Assumptions

We assume that:

- The goal of this model is to develop a pragmatic, versatile tool that can be used to explore the impacts of various policy assumptions on the wood supply, ecology, and economics of the forests in the NEFA region. The primary intent is not to make predictions of the future, but rather to explore the relative consequences of a range of assumptions. Given the constraints of data, models, scientific knowledge, and time, some questions may be answered with better precision and confidence than others. Uncertainty or disagreement about assumptions may be addressed with alternative sets of assumptions and alternative model runs.
- The available data are sufficient to support the assumptions drawn from it. This assumption applies to all of the categories below. We accept that the data are incomplete, but if our assumptions are reasonable and well understood, the purposes of the model can be met. One valid conclusion may be the identification of the need for better data.
- The detail of the model structure is appropriate for the resolution of the data and intended interpretation.
- Catastrophic events such as hurricanes, global warming, or widespread infestations are not explicitly modeled. A scenario designed specifically to examine the threat from hemlock woolly adelgid was included as an alternative run.

Ecological Habitat

- The ecological habitat approach taken is a practical and appropriate way to characterize the present and future regional landscape. Habitat assignments are intended to describe the expected ecological trajectory of plots—to suggest the "climax" vegetation. This characterization is preferable to "forest type" because it accommodates the potential for different forest types to occupy the same habitat.
- FlexFIBER's definitions of habitats, including the implicit criteria used to assign them are reasonable and defensible. Non-FIBER types used in the model are also defensible. Combined, these sufficiently describe the range of types we need concern ourselves with, given the intended resolution of the model.
- Sufficient plot data exist to discriminate plots into distinct habitat types.
- Since the habitat assignment is ecologically based, assigned acres will not shift habitat. The relative dominance of species across the region may change as the mix of acres in various MUs change through management and harvesting.
- Habitat assignment will affect the growth and species composition of the assigned acres.

Land Use

- Land use estimates reasonably capture the effects of the major determinants of land-use change.
- Anticipated changes in acres in particular sub-state regions affect the ecological habitats in those regions in proportion to the habitat area.
- Current physical and statutory limitations of the land are accommodated to the extent these are reflected in the FIA data.

Removal Classes

- Three removal classes sufficiently describe harvest activity and, along with habitat and management distinctions, reasonably describe existing management.
- With minor exceptions for predictable management trends (e.g. increases in acres under plantation or intensive management), the *total* acres in each removal class are assumed to remain constant over the time span of the model. (This does not mean these are always *the same* acres. On the ground, an acre harvested under one removal class may be subsequently harvested under a different class; however, our model assumes any acres that leave a removal class will be replaced be newly recruited acres in that same class. That is, the proportion of the study area currently represented in each removal class is assumed constant.)

Volume Classes and Yield Tables

- Volume classes approximately define the amount of net growth on growing stock over a 10-year period. Yield tables will reflect a combination of documented growth (empirical growth-yields) and simulated growth (FIBER-based). Factors influencing the "weighting" of these two approaches include (a) the suitability of FlexFIBER's original data set to adequately model this type; (b) the sufficiency of non-harvested, re-measured plots in a habitat/removal group to allow for representative empirical growth-yields; (b) the extent to which the historical performance of plots in a group can be expected to continue.
- All yield tables are based on FlexFIBER growth simulations except for high-yield MUs (where the GNY model was used), and Allegheny hardwood and oak-hickory types (where empirical growth-yields were developed from FIA data).

Ecological indicators

- The broad ecological measures calculated are intended to aid understanding the ecological implications of modeled scenarios. They offer minimal spatial detail and are therefore only likely to be appropriate in a regional context.
- The measures are based on relationships calculated from FIA data at the habitat/volume class-level. These relationships are assumed to apply to projected acres in these same classes. The number of acres in each class will change but the class-level relationships are held constant over the 50-year projection.
- Tree groupings (based on fruit types), structural indices, and dead wood measures are reasonable surrogates for more direct measures of ecological patterns, including wildlife habitat, soil processes, biological diversity, and spatial variability within the forest canopy. They are not intended to be predictive or statistically robust, rather they indicate potential trends for further investigation while giving a sense of what the forest may look like across the larger landscape.

Harvesting

- Harvest volumes by state are from reasonable sources. These have been apportioned to habitats within states according to the proportion of volume in each habitat. Using this scheme, hardwood/softwood proportions of the harvest data closely parallel the same proportions in the inventory.
- The SRTS model reasonably shifts harvest requests across habitats and states to account for changes in inventory levels. Friction affecting these shifts reflects assumptions about elasticities that are reasonable for this region.

6. Modeling Results

Modeled Scenarios

The balance of this report presents the results of a set of modeled scenarios or "runs" that use the model structure we have described. These scenarios were suggested by NEFA as ways to explore specific issues of regional concern. They demonstrate the versatility of the model and are intended to promote further discussion about its use.

Each scenario incorporates extensions or modifications to the assumptions presented previously, and as an introduction to each run, these modifications are reviewed. While our model structure allows detailed reporting, the results presented here take a regional perspective, with charts and tables that generally do not disaggregate results by state. We do not ignore finer-level implications however, and in many cases, make specific reference to state-level, or habitat-level results in the discussion. Detailed reports by habitat and state are included in Appendix E.

In order to facilitate the comparison of results between different runs, we have chosen a standardized set of charts and tables. Not all charts accompany each run, but those used are consistent in form and content. The reader should note that charts detailing information specific to the timber supply (e.g., inventory, growth, and harvest charts) account for ***timberland*** acres only. The volume class charts and ecological measures include ***all forest land*** (timberland *and* non-commercial forest land). We have added appropriate descriptions to the chart titles to clarify this.

Results for the following scenarios appear in this section:

- *Constant-demand run*. Most of the assumptions for this run have been described in the body of this report. We project the results on the NEFA forest resource if harvest demand remains constant at current levels. We also report on variations to the assumptions in this run designed to test the sensitivity of the resource to uncertainties in inventory and growth rates. This run forms a reference case for comparison with different sets of assumptions in subsequent runs.
- *Increased-demand run.* In this run we assume harvest demand increases at a rate of 1% per year, continuously, over the 50-year projection. The purpose of this run was to examine the long-term sustainability of a substantial increase over current harvest levels.
- *Pessimistic land-use change run.* Losses to timberland are accelerated in this run.
- *No-clearcutting run.* Clearcutting as a method of harvesting is eliminated in the first period. This run examines the impact of this exclusion on remaining acres under a constant harvest demand.
- *Hemlock woolly adelgid run.* We make a range of assumptions about the advance of this pest into the NEFA region to show how the model can be used to investigate catastrophic phenomena.

After discussions with State Foresters and the modeling team, we have made efforts to choose scenarios that are pertinent to the policy makers of the NEFA region. We have used the best available data to describe the forest and its management. We have tempered our assumptions with prudent analysis and collective judgment. The projections reflect the interaction of the numerous small decisions that we made in building the model, *yet no data perfectly represent reality and no decision is made with complete certainty*. There is huge natural variation in our forests. Management and harvesting practices do change over time. Natural catastrophic events occur with regularity.

Every assumption carries with it varying amounts of uncertainty, and this uncertainty must be considered when interpreting the results. Some models treat uncertainty formally, using Monte Carlo or other simulation techniques to assign probabilities to future events. This model does not make predictions about the likely state of the future; rather it compels the analyst to articulate a particular set of assumptions, and then accumulates the results of these assumptions acting on the resource. As we modify or improve our assumptions, we expand our understanding of the impacts of those assumptions on the resource.

7. Constant Demand Run

Background and Assumptions

We designed the constant-demand run to mimic the long-term, forest response to the continuation of the current harvest level. This is estimated at 1097.69 million cubic feet per year (12.9 million cords) of merchantable volume. While the assumption of no increase in future harvest demand may appear simplistic, the run serves many purposes. First, it provides a test of the reasonableness of the set of general assumptions used in constructing the model. That is, under reasonable assumptions, do the results conform to our expectations? Having a reference case is particularly useful as we consider the results of other runs with more severe assumptions. Compared to runs that follow, this scenario allows a study of the model dynamics. Which habitats gain or lose volume? How do current distributions of volume classes change over time? What impacts do current levels of harvest have on our ecological measures? Like many regions of the country, our region's forests are not "balanced" with respect to the distribution of acres in age, volume, or size classes (see discussion in section 4). These imbalances, along with stochastic and unavoidable natural events, would cause fluctuations in net growth over time, even if there were no harvest at all. Keeping the assumptions basic for this run allows these trends to be examined. The constant-demand run also addresses a basic policy question: Can *current* harvest levels be sustained by the resource? After the basic scenario is discussed, we explore the sensitivity of the results to a range of growth and inventory assumptions.

Most of the assumptions of this run have been articulated in earlier sections. Here we reiterate the major details of the formulation. First, we used the most recent FIA data to develop a beginning inventory for the year 2000. Because New York and Maine's most recently completed inventories were done in 1993 and 1995 respectively, we "grew" these states ahead (using the model) to year 2000. Secondly, estimates for the Adirondacks and Catskill regions of New York were not provided by the FIA data; we developed our own estimates using data from several other sources. Third, based on our experience and Maine Forest Service data, we allowed Maine's high-yield management units (herbicide release of conifers, precommercial thinning, and plantation establishment) to recruit acres in the first period of model time and then held these acres constant in subsequent periods. Lastly, because we modeled land use change at the sub-state level and then applied changes proportionally to habitat types within these sub-state units, land use change effects vary for each state (see Table 5.3 and Figure 5.2). Non-commercial forest land units, described earlier in Table 5.2, do not gain or lose area in this scenario.

Results

- Inventory (all forest land)

Initial merchantable inventory volume totals 74.4 billion cubic feet or 19.2 cords per acre. The hemlock-red spruce habitat type has the highest average volume at 26.2 cords per acre, with the sugar maple-ash habitat type having the second highest average volume at 21.4 cords per acre. Over the course of the 50-year projection, inventory volume increases by approximately 29% to 96.1 billion cubic feet, or 24.5 cords per acre. These gains are evenly split between softwoods and hardwoods.

All habitat types except cedar-black spruce gain volume by 2050. The Allegheny hardwoods forest type has the highest average natural stand volume at 30.7 cords per acre (but occupy only 2% of the area). The sugar maple-ash acres gain the most overall volume (8 billion cubic feet). This result is expected: this habitat contains 1) more area than any other habitat type in the model (12.7 million acres), 2) higher than average site quality, and 3) lower than average harvest levels (70% of these acres are in New York and Vermont).

- Growth (timberland only)

Net growth per acre in the decade from 2000 to 2010 averages 35.3 cubic feet per acre per year (0.4 cords), with 62% of this being hardwood and 38% softwood. By 2050, the senescence of mature and over-mature hardwood forests causes average regional net growth to decline to 32.8 cubic feet per acre per year. As this occurs (2030 to 2040), the softwood proportion of regional net growth increases slightly to 40%, benefiting from the rebound of the spruce-fir habitat in Maine. Overall, slower growth at a constant harvest reduces the gap between harvest and growth over the 50-year period. Growth declines from 1.33 to 1.25 times removals.

- Harvest (timberland only)

The initial distribution of 12.9 million cords per year harvest assigns 6.5 million cords to Maine, 1.8 million cords to New Hampshire, 3.2 million cords to New York, and 1.4 million cords to Vermont. By the end of the model run, adjustments by SRTS assigned the same 12.9 million cords per year as follows: Maine had 6.2 million cords, New Hampshire had 1.5 million cords, New York had 3.9 million cords, and Vermont had 1.3 million cords. Essentially, New York was assigned gradually higher harvest levels, while Vermont, New Hampshire, and Maine were assigned gradually less. The slow rate of adjustment recognizes barriers to "frictionless" flow of this resource across states, but also reflects basic laws of supply and demand.

- Land use change

Timberland gains 480,000 acres across the region over the projection period. All ecological habitat types gain acres except the oak-white pine and spruce-fir types, which show slight declines. Plantation acres decrease by 178,000 acres during the 50-year simulation. New York does not expect most harvested plantations to be replanted, thus these acres revert to natural stands. Slight plantation gains occur in Maine. New Hampshire experiences an 188,000-acre net loss in timberland (4.2%) as shown in Table 5.3.

- Non-commercial component

Region-wide, the model tracks 4.4 million acres of non-commercial forest land, 3.1 million acres of which is in New York. These acres remain constant through the projection, and are not available for harvest in the model. Average net growth on these acres starts out at 33.2 cubic feet per acre and slows to 23.2 cubic feet per acre by 2050, a 30% decline. This decline can be attributed to the aging and sen-escence of stands on these acres.

The chart in Figure 7.1 details inventory, growth, and harvest on timberland for the 4-state NEFA region in the constant-demand scenario. The solid lines represent hardwood and softwood harvest levels (11 billion cubic feet per decade when combined). The dashed lines represent hardwood and softwood decadal net growth volumes. The upper dashed line, representing hardwood growth, can be seen to trend slowly downward over the 50-year modeling horizon, while softwood inventory trends upwards through 2030, then declines slightly. Lastly, the columns track hardwood and softwood inventory, both of which increase as growth outpaces harvest.

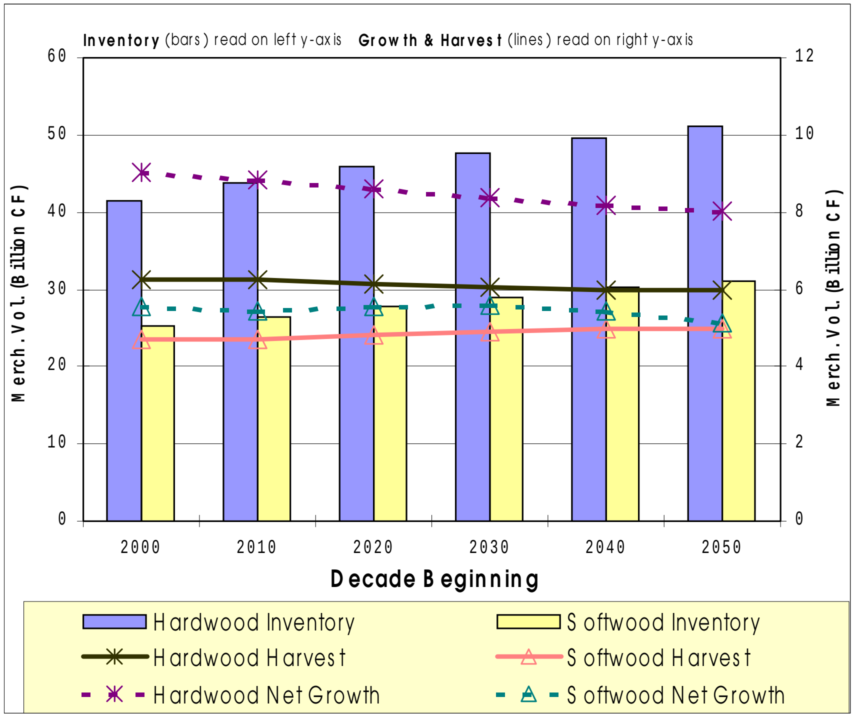


Figure 7.1 Constant-demand run: hardwood/softwood inventory, growth and harvest (timberland only).

The distribution of forest land within the habitat types or type groups is profiled in Figures 7.2 and 7.3 below. Figure 7.2 shows volume classes 4 through 7 in the sugar maple-ash habitat to have the most acres at the start of the simulation. By 2050 (Figure 7.3), volume class 4 in the spruce-fir habitat ties volume class 7 in the sugar maple-ash habitat for most acres in the model. The general trend of the acres-by-volume-class distribution is towards flattening and spreading of volume classes. At the habitat level, more growth than harvest leads to more volume classes having more acres. The volume in the initial distribution is significantly more concentrated in fewer classes.

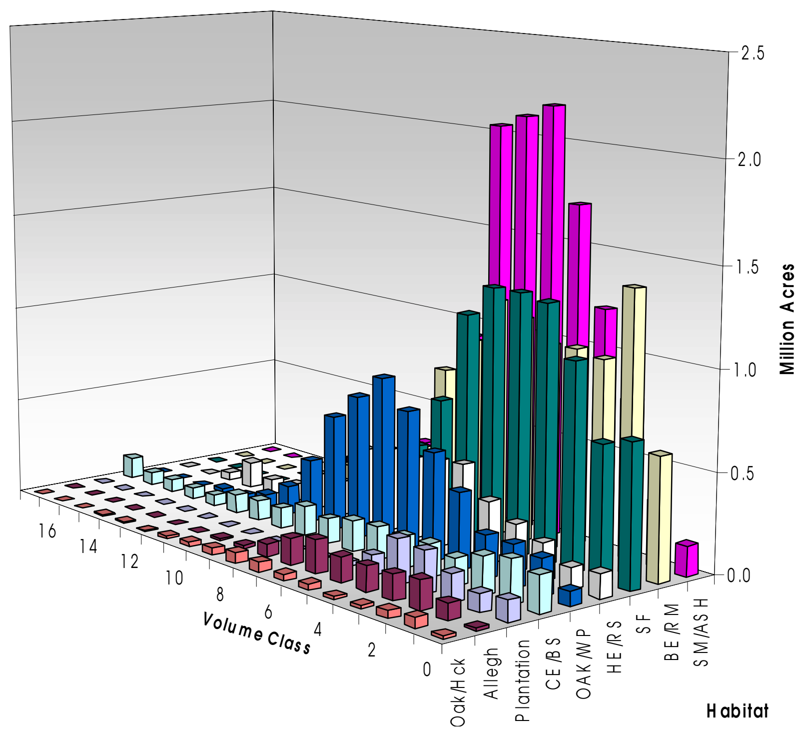


Figure 7.2 Year 2000 acres by habitat and volume class (all forest land).

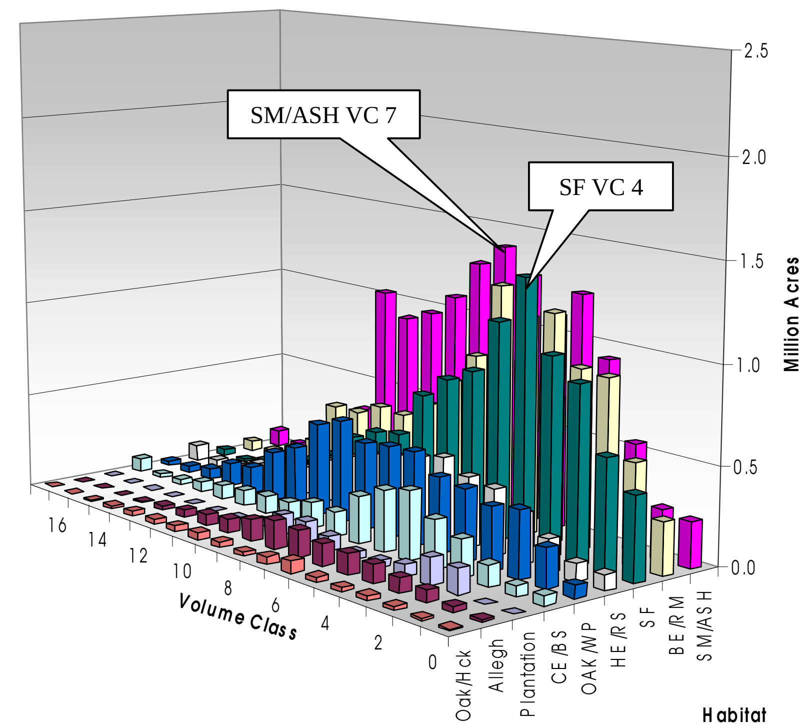


Figure 7.3 Year 2050 acres by habitat and volume class (all forest land).

Ecological Measures[10]

The ecological measures presented below reinforce the view that the forest resource described in this run is aging. Fine-seed mast (aspen and other spercies and soft mast (cherry, miscellaneous berries, and other early successional species) decline, while the number of dead trees, and large trees increase. The results suggest more basal area in large-nut and medium-seed species (mostly the maples), along with an increase in the dead stems per acre. These measures tend to increase in older stands. The increase in conifer basal area is partly a response to increased volume in spruce-fir habitats, but also reflects the general increase in softwood volume across many habitats (Cedar-black spruce is an exception). Minimal movement in the vertical structure measure and the complex interactions of habitats and volume classes affecting it makes interpretation difficult. The slight decrease in vertical structure after 2030 could be seen as a combined response to increasing harvest pressure and the fairly large "pulse" of spruce-fir acres building over the model timeframe.

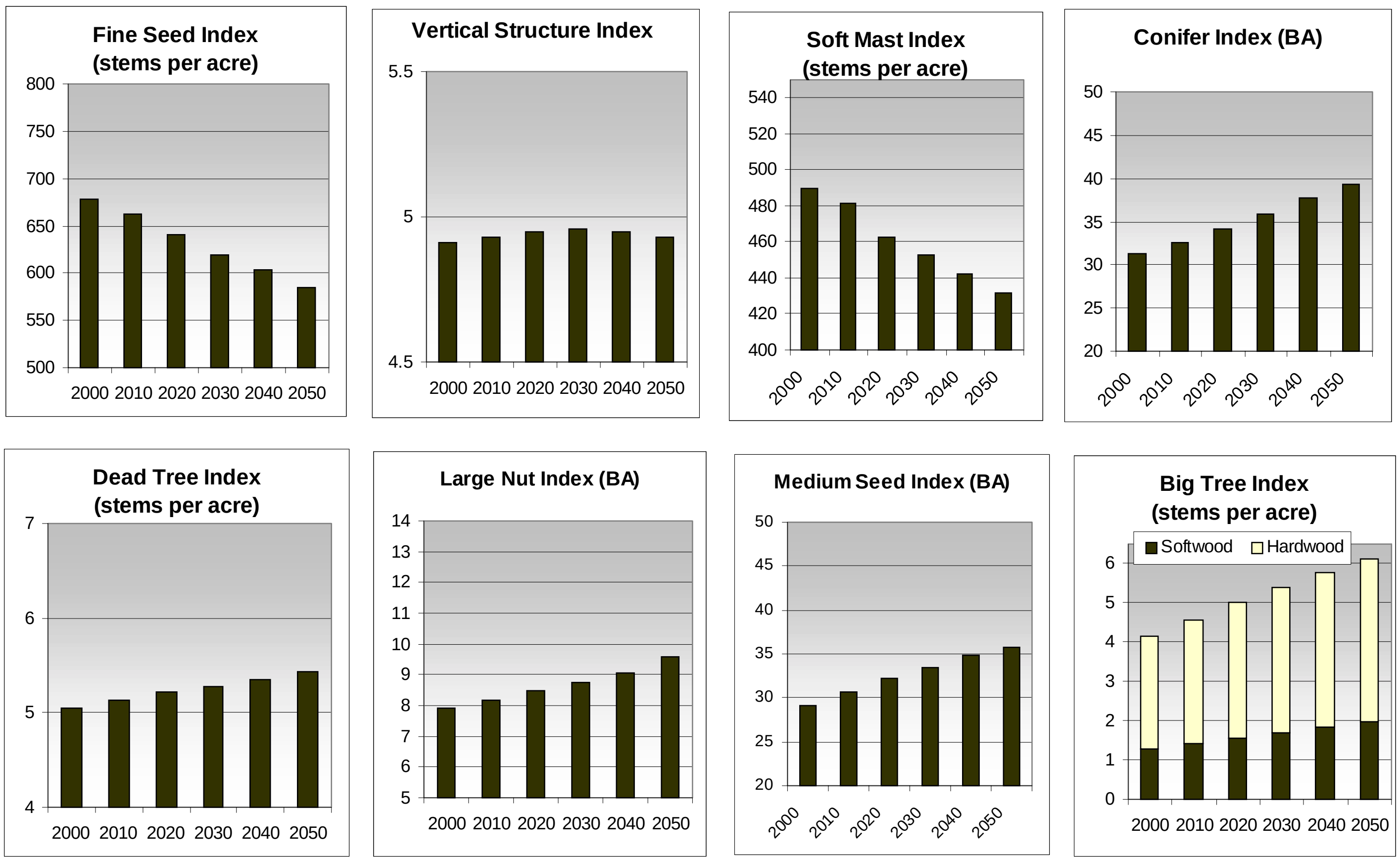


Figure 7.4 Ecological metrics for the constant-demand run (forest land)

[10] Appendix A contains a description of the building and interpretation of these charts.

Inventory and Yield Sensitivity

We performed six runs that tested the sensitivity of the constant-demand scenario to a range of inventory and growth assumptions. We chose these parameters because they play a large role in our model results, are not known with certainty, and historically have been very dynamic attributes of our region's forests.

- *Alternative growth scenarios* increased and decreased all yield curves by 10% and 20% respectively (4 runs total), while holding harvest demand and land use change the same as in the constant-demand scenario.
- *Alternative inventory and growth scenarios:* 1*) increased* the initial inventory level by 5% and the yield curves by 10%, 2) *decreased* the initial inventory level by 5% and the yield curves by 10%. All other parameters including harvest demand and land use change were the same as the constant-demand scenario.

Because the constant-demand scenario showed building inventories (growth exceeding harvest), any of the scenarios having increased growth rates or increased inventory logically led to further gains in inventories through time. Results for the region show even the pessimistic scenarios lead to building inventories, as regional net growth exceeds harvest removals. In the most pessimistic scenario, the –20% growth rate run, New Hampshire and Maine did suffer inventory declines of 8% and 6% respectively. Under these assumptions, more is being cut than is replaced by growth over the period for these states. New York and Vermont timberlands experience less harvest pressure than New Hampshire and Maine and could continue to build timber inventory even if growth rates declined substantially. Conversely, New Hampshire and Maine are more dependent on healthy average growth rates (32-35 cubic feet per acre) to maintain their inventory volumes over the next 50 years. Much of the spruce-fir habitat acres in these states are currently in the seedling and sapling stand-size classes. As they grow into poles and sawtimber during the second half of the modeling horizon, per-acre and total growth in this component improves.

The growth-to-removal rates by habitat reinforce outlook for healthy growth, but also reflect by SRTS's (minor) reallocations of harvest in response to harvest pressure.

Figure 7.5 Constant-demand run sensitivity: inventory, growth and harvest at 20% *decreased* growth rates (timberland only).

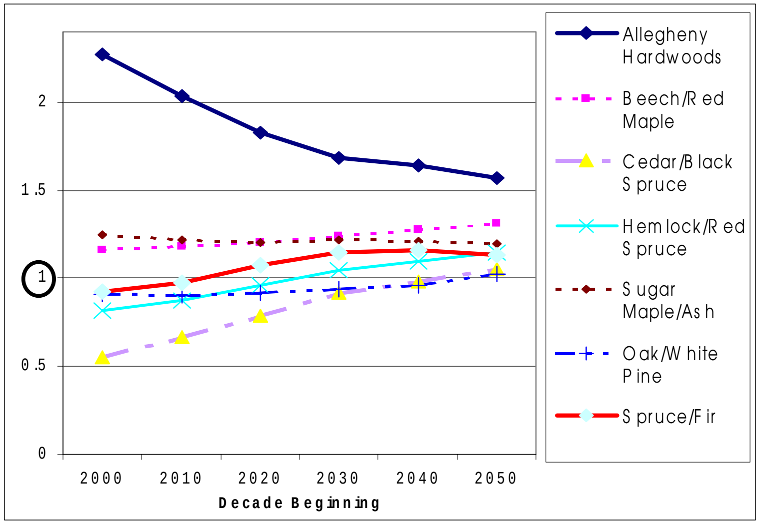


Figure 7.6 Constant-demand run sensitivity: growth-to-removal rates by habitat at 20% *decreased* growth rates (timberland only).

8. Increased-Demand Run

Background and Assumptions

This run increases the harvest demand by a rate that approximates recent market trends—and assumes these trends continue for the 5 decades simulated by the model. This is in contrast to the assumptions of the previous run where demand is held constant at year-2000 levels.

Historically speaking, the felling and removal of trees from the forest has molded the economies, communities, and landscapes of the NEFA region. A brief review of history indicates a very dynamic past.

In 1869, New York led the nation in lumber production (NY DEC 1981), producing more than twice as much lumber as the state of Maine. Forty years later, the roles would be reversed with Maine producing more than twice as much lumber as New York (Irland 1998), which by then had developed a considerable paper-making economy and was feeding over 100 pulp mills. Today, Maine produces more paper than New York.

Changes in technology, transportation, and tastes throughout our hemisphere have had major impacts on the harvesting of trees. For example, the settling of the Midwest, the opening of the Panama Canal, the demand for boxboard in shipping, and the demand for processed leather products all have had major impacts on harvests that are reflected in how NEFA forests look today.

Now, in the global economy, timber sales are offered over the Internet and veneer sawlogs are shipped all over the world. We expect that changes affecting the quantity and species of trees harvested will continue to occur over the next 50 years. Just as we are unsure about the timing and extent of the natural calamities that can impact our forests (insects, fires, hurricanes, disease), we are uncertain about the impacts of globalization on the extent and character of future harvests.

This run was formulated to mimic a gradual building up of harvest levels over the next 50 years, with the same land-use change described earlier. The harvest increase occurs at the rate of 1% annually from the harvest levels modeled in the Constant-Demand Run. Because ATLAS simulates harvests to occur at model period midpoints (years 5, 15, 25, 35, 45), the periodic harvest requests reflect annual compounding to this point. All other assumptions are the same as the "Constant-Demand Run."

Regional Results

- Inventory (all forest land)

As in the other runs, initial merchantable inventory volume totals 74.4 billion cubic feet or 19.2 cords per acre. This increases to a high of 81.8 billion cubic feet by 2030 (20.9 cords per acre), and drops slightly to 77.0 billion cubic feet by 2050 (19.6 cords per acre). The increased harvesting leads to more early successional species, especially promoting hardwoods. In addition, because the majority of the initial harvest comes from the states on the eastern, more coniferous side of the region, the harvest increases affect these states most severely. Therefore, even though overall inventory does increase in this projection, softwood volumes decline by 3% (Figure 8.1).

The state-level distribution of the harvest tells a large part of the story. In absolute terms, Maine and New Hampshire had significant increases in their harvest rates that resulted in decreases in inventory. For these states, reductions in inventory volume were 29% and 19%, respectively. Even with the harvest increases mentioned, New York continued to build inventory (36%) and Vermont had a slight reduction of 1%.

- Growth (timberland only)

Net growth per acre in the decade from 2000 to 2010 averages 34.8 cubic feet per acre per year (0.4 cords), with growth in the last decade (2040-2050) averaging 29.3 cubic feet per acre.

- Harvest (timberland only)

The initial harvest of 1.153 billion cubic feet (bcf) per year includes an increase of 0.056 bcf (5 years of 1% increases) from the Constant-Demand Run, all of which is assigned to the states in proportion to their current harvest level described in earlier sections of this report. By the end of the model run, the regional harvest request has grown to 1.718 bcf annually[11] (Table 8.1). This represents a 56% increase from the

[11] Mathematically inclined readers will notice this 56% increase (.62/1.098) differs from a full 50-year increase (1.01^{50}x 1.098= 1.805 or 65%). Our method approximates the harvest as the average of a 1% increase compounded over each 10-year period. This method better synchronizes the harvest requests with the midpoint artifact of ATLAS's harvest sequencing.

1.098 bcf that is our best estimate of current regional harvests of merchantable inventory volume.

Harvest acreage also increases substantially. One way to evaluate the harvest pressure is to examine a hypothetical "re-entry period." This measure takes the total timberland acres and divides it by the annual acres harvested. The quotient is the number of years before acres cut in one year would be ready for harvest again,
assuming all acres are eventually harvested sequentially. In the first decade of simulation, this re-entry quotient is 40 years. In the last decade, this average re-entry period has dropped to 25 years.

Though this level of harvest would certainly change how the forests in parts of our regions look, it is important to note that there are virtually no unsatisfied harvest requests in this simulation. The plantation management unit does experience some rather small-unmet harvest requests each period (as it decreases in overall acreage), as does the Oak-White Pine habitat type in the last period of the model run.

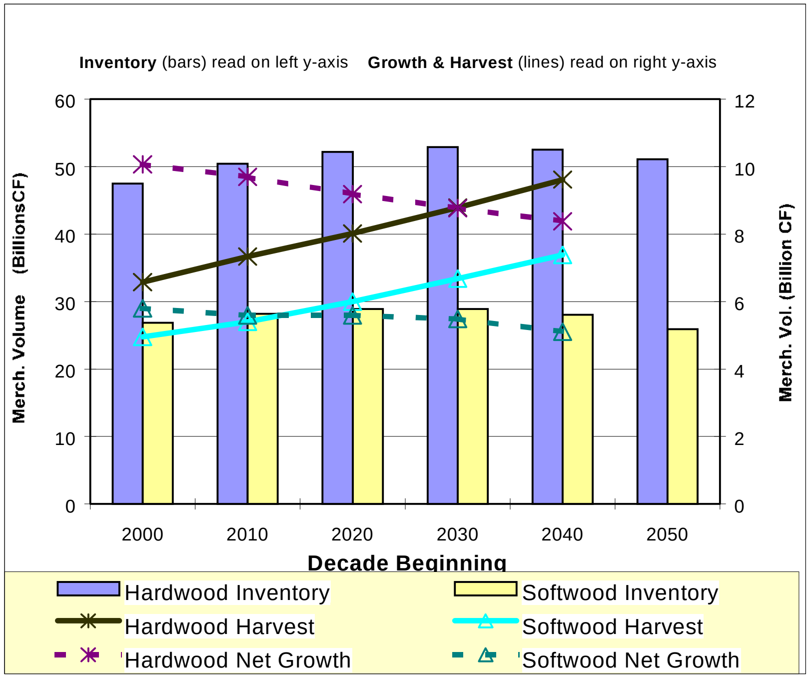


Figure 8.1 Increased demand run: inventory, growth, and harvest (timberland only).

Habitat/type/MU	*2000-2010 Harvest (bcf/decade)*	*2040-2050 Harvest (bcf/decade)*	*Change (bcf/decade)*
Sugar Maple/Ash	2819.3	4232.3	1413.0
Spruce/Fir	2630.9	4038.3	1407.4
Beech/Red Maple	1794.9	2801.5	1006.6
Oak/White Pine	1505.9	1922.1	416.2
Hemlock/Red Spruce	1328.7	1762.2	433.5
Cedar/Black Spruce	659.3	704.7	45.4
Plantation	500.6	1195.5	694.9
Allegheny Hardwoods	165.8	345.2	179.4
Deer Wintering Area	82.0	110.4	28.4
Oak/Hickory	49.3	64.6	15.3
Total harvest (bcf/decade)	**11536.9**	**17176.8**	**5639.9**

Table 8.1 Increased-demand run: summary of harvest requests by habitat, MU or type group (timberland only).

Figures 8.2 and 8.3 compare the distribution of acres by volume class for the increased-demand run and the constant-demand run in 2050. The increased-demand volume class distribution exhibits a general truncation of the volume class distribution. Acres reaching higher volume classes decline, as more acres are being harvested and fewer acres are left to reach older stages of development. A more studied interpretation of the Increased-Demand Run shows that annual harvest increases in the 1% range do not result in immediate and marked decreases in higher-volume stands. After 50 years of increased harvest levels, there are still some high volume stands, but there are fewer. A longer projection, perhaps of 80-100 years, would show more significant truncation of these distributions.

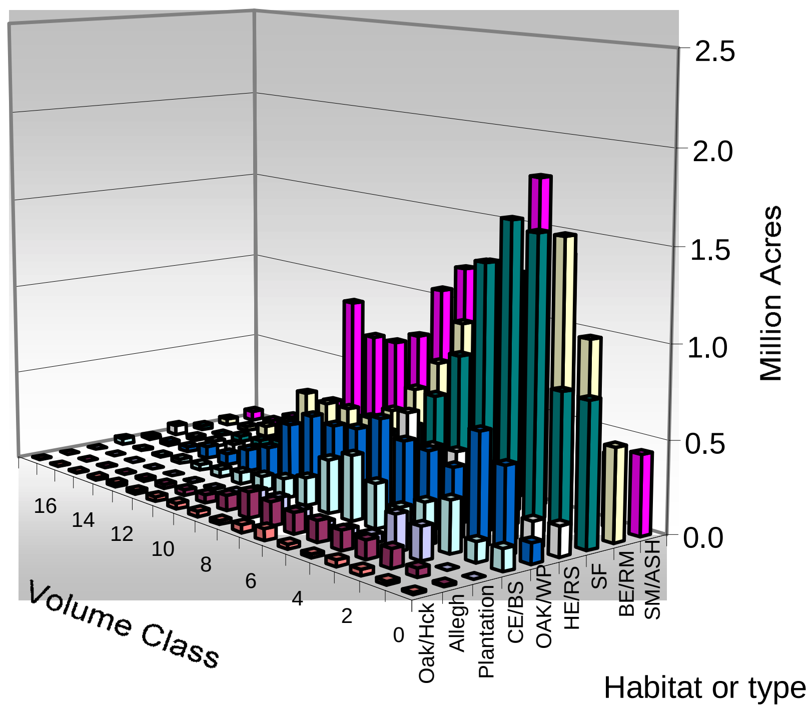


Figure 8.2 Increased-demand run volume-class distribution in 2050 (timberland).

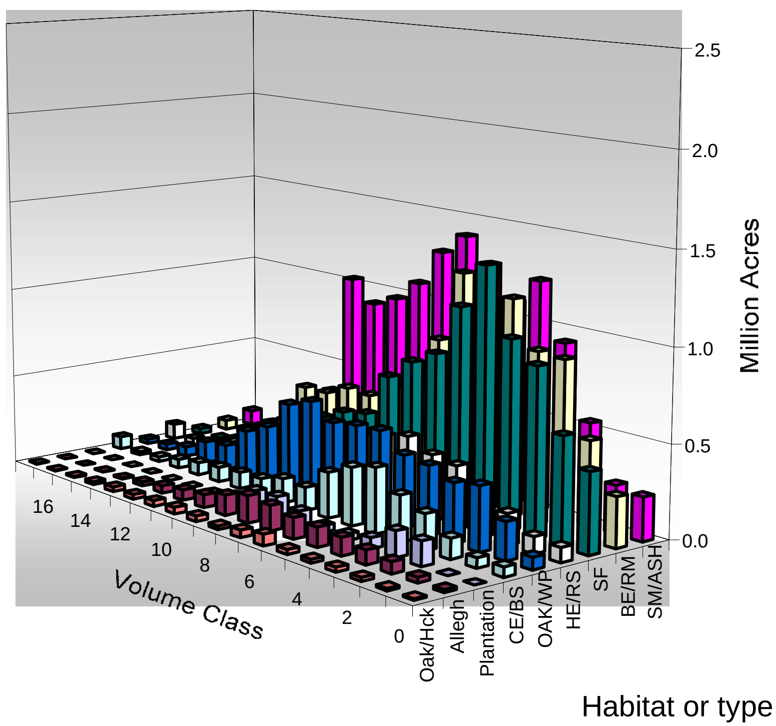


Figure 8.3 Constant-demand run volume-class distribution in 2050 (timberland).

Ecological Measures

The ecological measures presented below reflect forests that are allowed to mature during the first half of the simulation, and begin to come under pressure that is more noticeable during the second half of the simulation. Fine seed (poplar and birch species) and soft mast (miscellaneous berries and cherry species) decrease in the first half of the modeling horizon, while conifer basal area and big trees increase. Conversely, the rising harvest levels resulting from the 1% annual compounding begin to reverse the ecological trends during the second half of the projection period, reflecting a change towards a younger, more frequently manipulated forest.

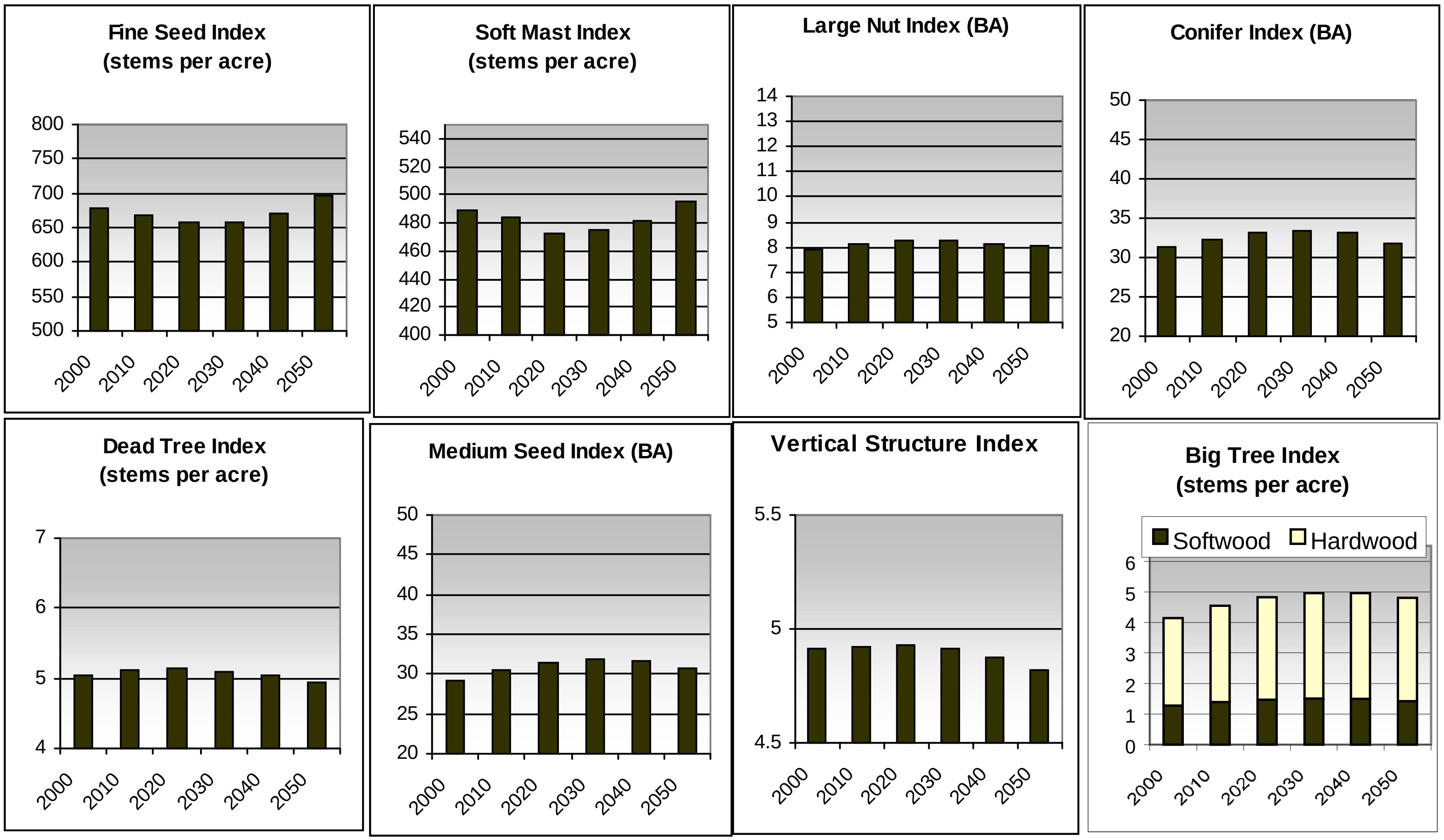


Figure 8.4 Ecological metrics for the Increased-Demand Run.

9. Pessimistic Land Use Run

Background and Assumptions

Forest land conversion and parcel fragmentation are commonly raised concerns for the future of the northern forest. We used the model to address these concerns by making the original assumptions about the rate of forest land loss more pessimistic. All the runs with the exception of this one use the land use change estimates discussed in earlier sections of this report. That original analysis used NRI data and a variety of other statistics to form judgments about future rates of forest land change. In this run, we modify those assumptions as follows:

1. We use the most recent FIA data to establish initial rates of change for the NH South and ME South land-use units. In the original formulation, initial rates of loss were lower and the rate of change was decreased over time to reflect a range of mitigating circumstances. In this run, we assume that *this more severe rate of loss will continue unchanged for the entire 50-year modeling time frame*.
2. Estimates of timberland gain in the southern three New York units were reduced. The amount of these reductions is roughly based on increases in urban and reserved forest land noted in recent FIA data. Estimates of timberland gain in Vermont are reduced by one-half.
3. All states contribute some acres to non-commercial forest. Rather than assume that all land lost from timberland in this scenario was lost to development (non-forest), it seemed reasonable to continue the trend of gains to non-commercial. This choice also allows the volume on acres shifted into non-commercial to be included with other non-commercial volume.

Table 9.1 displays the new assignments of acres over time. This table should be compared with Table 5.3 (page 16). Whereas Table 5.3 predicts a 480,000-acre gain over the period, this scenario suggests a 908,000-acre loss. New Hampshire's loss increases 5-fold. Maine goes from a 1000-acre loss to a 410,000-acre loss in 50 years. New York's previous 645,000-acre gain is reduced to 527,000 acres. Overall, timberland loses 908,800 acres over the 50 years, or over 18,000 acres per year. While this loss is substantial, it represents only 2% of the starting timberland base. Non-commercial forest gains roughly half of this loss.

As in the constant-demand run, changes in land area by unit were applied to the habitat acres (Table 9.2). The oak-white pine habitat (the dominant habitat in southern Maine and New Hampshire) absorbs the largest loss. Sugar maple-ash habitats (with the greatest area) reflect the greatest gain. Other assumptions for this run, including the harvest request, are the same as in the constant-demand run.

50-yr Summary by State	***Timberland (acres)***	***Non-commercial forest land (acres)***
Maine	(410,000)	160,000
New Hampshire	(1,038,000)	175,000
Vermont	12,000	12,000
New York	527,200	118,500
Net change	(908,800)	465,500

Table 9.1 Summary of pessimistic land use assumptions by state (all forest land).

Habitat/type/MU	2000 (acres)	2050 (acres)	Change over 50 years
Sugar Maple/Ash	11,040,653	11,187,936	147,283
Beech/Red Maple	8,758,037	8,646,329	(111,708)
Spruce/Fir	8,672,516	8,495,704	(176,812)
Oak/White Pine	4,757,194	4,271,791	(485,403)
Hemlock/Red Spruce	3,698,805	3,498,586	(200,219)
Cedar/Black Spruce	1,986,166	2,003,121	16,955
Allegheny Hardwoods	1,011,556	1,080,802	69,246
Plantation	865,483	687,075	(178,408)
Oak/Hickory	301,207	311,473	10,266
Deer Wintering Area	254,935	254,935	-
Total timberland area change			(908,800)

Table 9.2 Summary of pessimistic land use assumptions by habitat (timberland only).

Regional Results

Interpretation of the results for this run requires that we keep in mind the following comments. First, the loss in timberland is small relative to the timberland base. From the regional perspective, the impact on inventory is also small. Second, while we lose timberland, and its future productivity, we capture most of the volume that exists on that land at the time of conversion. We specify in the model that one-half of the volume on acres lost is captured in the harvest and satisfies the harvest request. Since we also have directed some of those acres into forested non-commercial, volume on those acres becomes sequestered in non-commercial MUs. These factors dilute the impact of this scenario on the forest resource from a regional scale. Later in this section, we will examine the impacts to New Hampshire, where the greatest impact is projected.

- Inventory

At the start of this run, all inventory values are the same as in the constant-demand run. At the end of 50 years, timberland inventory stands at 80.1 billion cubic feet (bcf), 3% below the constant-demand's 82.3 bcf. Non-commercial totals 15 bcf.

Not surprisingly, volume on oak-pine timberland acres is heavily impacted by this run, losing close to 10% of its area. The constant-demand run shows 2050 volume of 9.7 bcf for this habitat, while this run results in 9.0 bcf standing.

- Growth (timberland only)

Net growth per acre in the initial decade is the same as in the constant-demand run (35.3 cubic feet/acre/year). By the end of the simulation (2050), growth per acre had declined to 31 cubic feet/acre/year, compared to 32.8 in the constant-demand run. Reasons for this decline in growth are complex. In the constant-demand run slightly more acres are partially harvested. These acres respond with increased growth. In this run, a larger component of the harvest comes from acreage loss. This results in fewer timberland acres in vigorously growing volume classes and fewer timberland acres overall contributing to growth.

- Harvest (timberland only)

Figure 9.1 differs little from figure 7.1. Overall, since the harvest request is the same as in the constant-demand run, a similar amount of total volume is harvested. As stated above, one-half the volume collected on acres lost is included in total harvest. The other half is lost to the model.

In all MUs that lose acres, recovered volume partially satisfies the harvest request. In the oak-pine habitat, volume from acres lost more than satisfies the harvest request. (This was also the case in the constant-demand run.). As the simulation proceeds and SRTS performs its periodic harvest reallocation, it examines changes in growth and inventory. Since growth and inventory decline in oak-white pine habitats, SRTS gradually shifts harvest requests to other units. Table 9.3 summarizes this shifting.

Sugar maple-ash and spruce-fir combine for more than 75% of the harvest and their proportions change little over the run. Plantation gains harvest share because it sustains the highest per-acre growth and, particularly in New York and Maine, offers considerable volume. Oak-white pine loses a greater share in this run than in the constant-demand run, but overall the shifts are small. Across-state shifts are similar to those described in the constant-demand run.

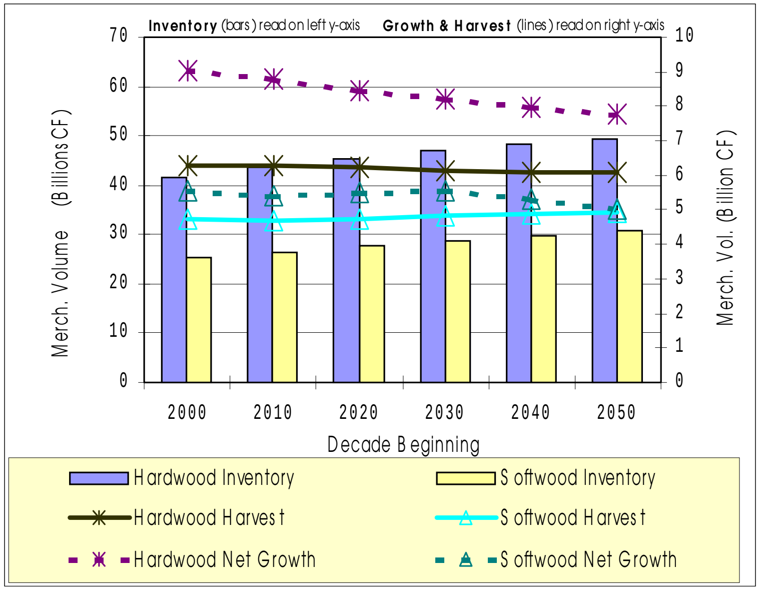


Figure 9.1 Pessimistic land use run: inventory, growth and harvest (timberland only).

Decade Beginning	*Acres harvested*	*Harvest volume per acre (cu.ft.)*	*Harvest volume per acre (cords)*
		Decade	
2000	9,848,495	1,115	13.1
2010	9,722,663	1,128	13.3
2020	9,803,175	1,120	13.2
2030	9,740,745	1,127	13.3
2040	9,679,530	1,134	13.3

Habitat or type	*2000-2010*	*2010-2020*	*2020-2030*	*2030-2040*	*2040-2050*
Sugar Maple/Ash	24.4%	24.9%	25.0%	25.0%	24.9%
Spruce/Fir	22.8%	23.1%	22.7%	23.1%	23.7%
Beech/Red Maple	15.6%	15.9%	16.0%	16.1%	16.2%
Oak/White Pine	13.1%	12.5%	12.0%	11.3%	10.7%
Hemlock/Red Spruce	11.5%	11.1%	10.6%	10.3%	10.1%
Cedar/Black Spruce	5.7%	5.1%	4.6%	4.3%	4.2%
Plantation	4.3%	4.7%	6.3%	6.8%	7.1%
Allegheny Hardwoods	1.4%	1.7%	1.8%	2.0%	2.1%
Deer Wintering Area	0.7%	0.7%	0.7%	0.7%	0.7%
Oak/Hickory	0.4%	0.4%	0.4%	0.4%	0.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9.3 Pessimistic land use run: harvest share percentage by habitat over time.

Acres harvested to meet the harvest request and harvest volume per acre are shown in table 9.4. Harvest volume per acre harvested averaged 1117 cubic feet (13.1 cords) at the start of the simulation and 13.4 cords at the end. Increases in inventory over time results in a decline in the number of acres harvested, with a slight increase in harvest volume per acre. This table includes acres lost in the total acres harvested, thus these numbers are slightly higher than those in the constant-demand run.

Table 9.4 Pessimistic land use run: Acres harvested and volumes harvested per acre.

The volume-class distribution is also similar to the constant-demand run. When acres are lost, we have specified that they be taken evenly across all volume classes. Remaining acres see harvest pressure similar to the constant-demand run and a similar broadening of the volume-class distribution results.

Ecological measures

The ecological measures show very little change from those presented for the constant demand run. From the regional perspective, the size of this land use disturbance has little impact on these measures. In specific locations where timberland loss occurs, changes of this magnitude would likely be accompanied by factors that normally reduce ecological condition, including wildlife habitat loss, forest fragmentation, reductions in air and water quality, invasion of non-native invasive species, and other factors associated with land-conversion and habitat fragmentation.

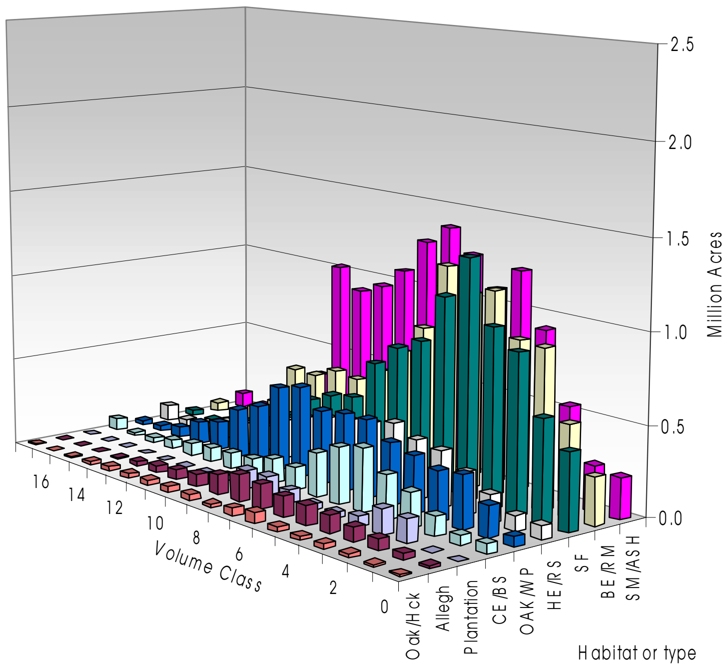


Figure 9.2 Pessimistic land use run: acres by habitat and volume class (all forest land).

State-level Results

Displayed below is summary information that compares the pessimistic land use scenario (left side) with the constant demand run (right side) for *New Hampshire only*.

In the pessimistic land use run, inventories and growth decline. Harvests exceed growth by the end of the 50-year period.

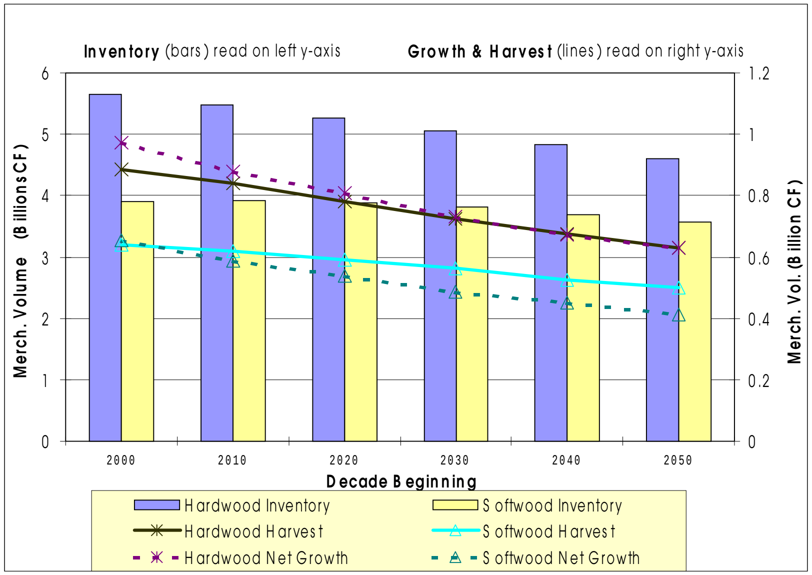


Figure 9.3 New Hampshire, ***pessimistic land use run***: inventory, growth, and harvest (timberland only).

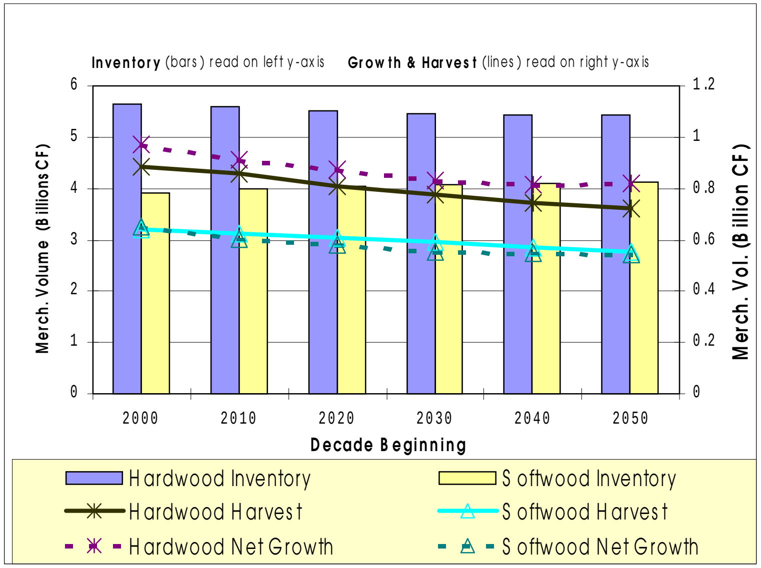


Figure 9.4 New Hampshire, ***constant-demand run***: Inventory, growth, and harvest (timberland only).

Year	*Inventory volume (million cf)*	*Harvest Volume (mcf/decade)*	*Growth volume (mcf/decade)*	*Growth/ acre (cf/year)*	*Growth-to-removal ratio*
2000	9.544	1.525	1.627	36.1	1.07
2050	8.175	1.202	1.124	30.5	0.94

Table 9.5 New Hampshire, ***pessimistic land use run***: summary of selected measures.

Year	*Inventory volume (million cf)*	*Harvest Volume (mcf/decade)*	*Growth volume (mcf/decade)*	*Growth/ acre (cf/year)*	*Growth-to-removal ratio*
2000	9.544	1.525	1.625	36.0	1.07
2050	9.558	1.312	1.362	31.4	1.04

Table 9.6 New Hampshire, ***constant-demand run***: summary of selected measures.

Figure 9.5 reflects timberland only and illustrates the downward trend in harvest sustainability for most habitats. Oak-white pine shows the steepest decline.

Figures 9.6, 9.7 and 9.8 represent all forest land and include the considerable number of acres in non-commercial forest. All habitats suffer declines. Some higher volume-class acres are retained on reserved oak-pine land. It should be noted that the ecological metrics are *per acre* values on remaining forest land acres. Facing this magnitude of land conversion, these metrics distort the state-wide character of the landscape by not including conditions on acres of forest land *lost*.

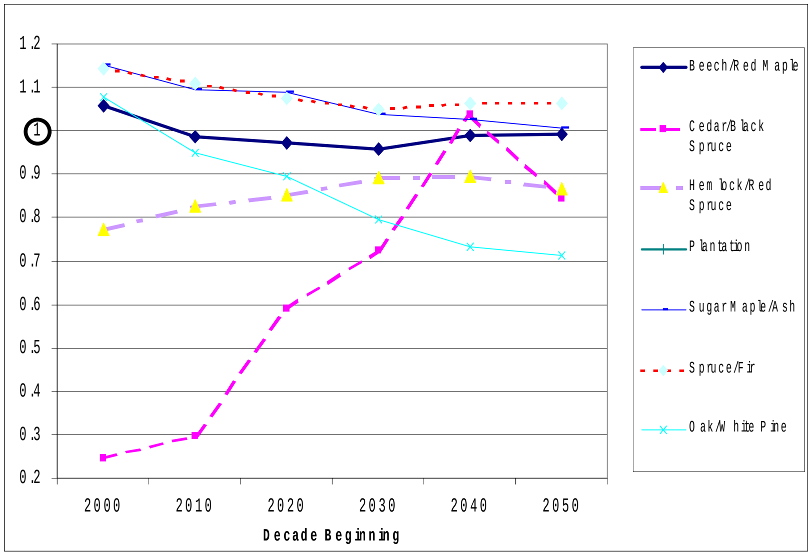


Figure 9.5 Pessimistic land use change, New Hampshire: growth-to-removal ratios (timberland only).

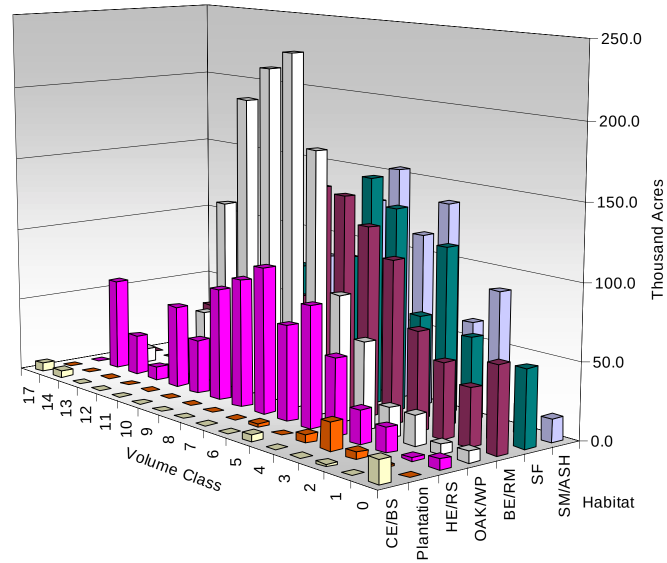


Figure 9.6 Pessimistic land use run, New Hampshire:Year-2000 acres by habitat and volume class (all forest land)

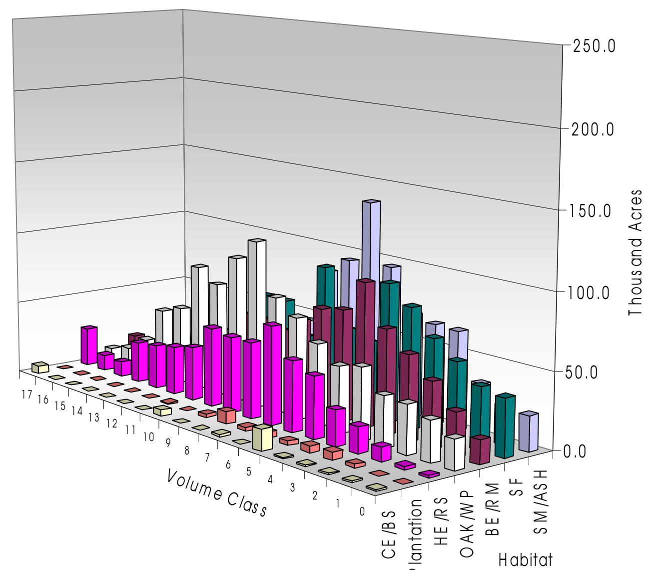
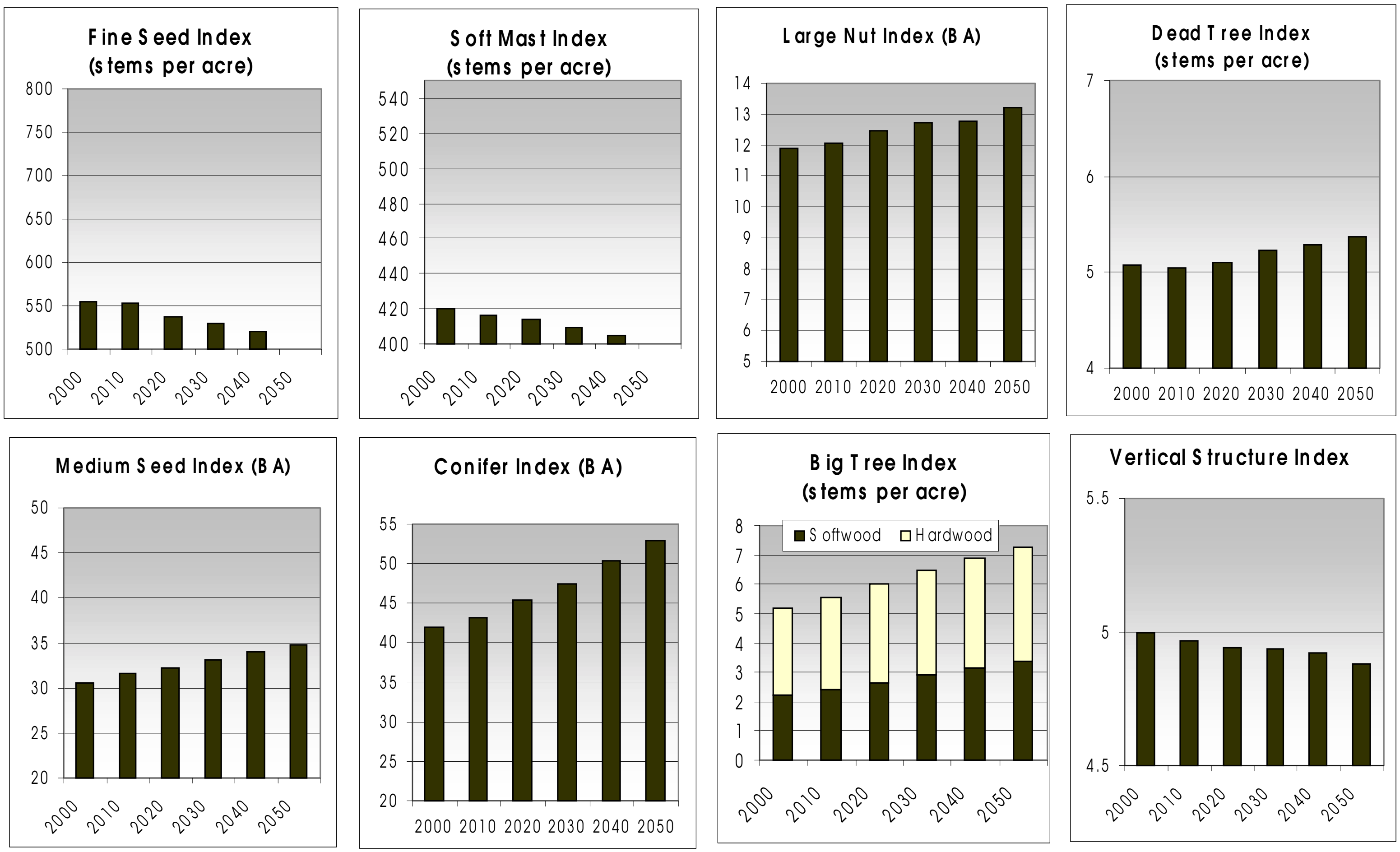


Figure 9.7 Pessimistic land use run, New Hampshire:Year-2050 acres by habitat and volume class (all forest land)



7Figure 9.8 Pessimistic land use run, New Hampshire: ecological metrics (all forest land)

10. No Clearcutting Run

Background and Assumptions

NEFA chose to mimic the effects of a ban on clearcutting. A series of Maine ballot referenda over the past 6 years have all had some mention of curtailing or regulating the practice. These referenda have all failed, the most recent one quite decisively. However, the debate has forced the issue into the minds of many throughout the region.

Clearcutting is included in the methods characterized by the 80% to 100% removal class in our model (known as "final harvests" as opposed to “partial cutting” in the other removal classes). Also in this group are overstory removals of the shelterwood system and other less formal methods of stand removal and regeneration. We use the term clearcutting to describe a harvesting method that removes nearly all the vegetation from a site and leaves the growing space available to trees not present prior to cutting.

Our simulation of a clearcutting ban incorporates a single major change from the constant-demand scenario: we distinguish between banning all regeneration harvests and banning clearcutting. In our model, we accommodated shelterwood final harvests by allowing complete overstory removals to continue occurring on lower-volume stands (stands with 5 to 12 cords per acre). Acres with higher volumes (the most likely candidates for clearcutting) were reassigned to the heavier partial cutting management units (50-80% removals) within the same habitat type. To be consistent, we also shifted precommercially thinned and herbicide acres from final-harvest to partial harvesting regimes.

This reassignment of acres affects the states differently, as shown in Table 5.1. Maine contains the most original final harvest acres and thus the largest shift occurs here. FIA data is particularly reflective of the heavy harvest pressure on spruce/fir habitat types over the re-measurement period (1982-1995). New York has little final harvesting evident in the FIA plot data, and sees little shifting. No changes are made to reserved or unproductive forest land, since these acres experience no harvest.

Constraining acres to MUs with lower per-acre removal rates requires more acres to be harvested to meet the same harvest request. Compared to the constant-harvest run, approximately 629,000 additional acres are harvested in the first period, rising to 714,000 additional acres in the final period (periods 2,3, and 4 are 645,000, 655,000, and 627,000 respectively). Overall, this represents a 7% increase in acreage harvested compared to the constant demand scenario. This increase would have been higher had we assigned the shifted acres to lighter cutting regimes. Seen regionally, this is not a large percentage impact; but if the impact is focused in certain locales where clearcutting may be more prevalent, other acres in the same locale could see added harvest pressure.

Table 10.1 Summary of reassignment of acres from final harvest MUs to partial cutting MUs.

State	*Original Final Harvest Acres*	*Acres Shifted to 50-80% Removals*	*No Clearcutting Final Harvest Acres*
Maine	4,767,601	2,736,479	2,031,122
New Hampshire	841,669	611,820	229,849
Vermont	690,619	492,723	197,896
New York	438,596	268,444	170,152
Region Total	6,738,485	4,109,466	2,629,019

Impacts on growth are less obvious. In the first period, net growth declines. Over time, as fewer stands are allowed to move into mature and over-mature volume classes, growth increases. Table 5.2 shows the change in periodic net growth by habitat or type group for the no-clearcutting run as compared to the constant-demand scenario. Increased net growth in latter periods contributed a gain of approximately 4.5 million cords to inventory volume by 2050.

Habitat Type	*Decade* 2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
Allegheny Hardwoods	-0.222	-1.811	-0.925	-0.746	-0.317
Beech-red maple	-25.259	-40.081	-37.987	-38.08	-33.766
Cedar-black spruce	2.221	8.44	20.816	20.389	13.961
Hemlock-red spruce	-0.267	12.357	11.509	8.188	2.315
Oak-hickory	0.131	-0.205	-0.703	-0.692	-0.064
Oak-white pine	-7.979	-2.848	2.118	18.094	23.59
Spruce-fir	-29.029	0.193	10.4	70.228	144.448
Sugar maple-ash	-5.673	25.259	70.626	75.760	63.414
Total Change	**-66.077**	**1.304**	**75.854**	**153.141**	**213.581**

Table 10.2 Comparing the no-clearcutting run to the constant-demand run: changes in net growth (millions of cubic feet per decade).

The area distributions at the beginning and end of the simulation are profiled in figure 10.1 and 10.2 respectively. These charts show a slight decrease in acreage for the lower volume classes, particularly for the spruce/fir and sugar maple/ash habitat types. Fewer acres are going through the younger (i.e., lower volume) phases of regeneration that follow a clearcut or other final harvest. This is particularly noticeable in those habitat types with more acres in the final harvest MU.

The regional ecological metrics show only subtle changes in the no-clearcutting run, compared to the constant-demand run.

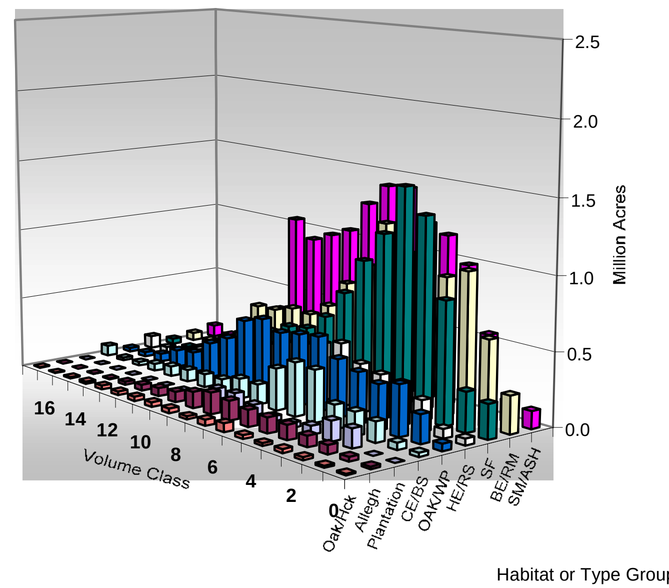


Figure 10.1 No-clearcutting run: year 2000 acres by volume class and habitat (timberland).

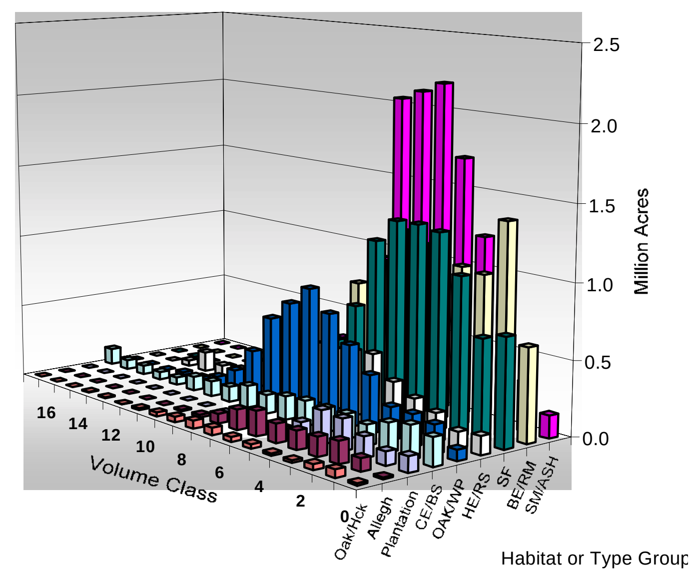


Figure 10.2 No-clearcutting run: year 2050 acres by volume class and habitat (timberland).

11. Hemlock Woolly Adelgid Run (HWA)

We chose this particular phenomenon (modeling the infestation and mortality of large amounts of eastern hemlock in our region) for three main reasons. First, the threat posed by hemlock woolly adelgid (*Adelges tsugae*) is very real. Second, hemlock occurs over most of the study area at a level that could be represented by our model. Finally, actual data on HWA does not exist for our specific region, making it a good candidate to illustrate the value of modeling to simulate a future "what if…?" situation. Though the potential for serious HWA damage in our region does exist, our goal with this run was primarily illustrative.

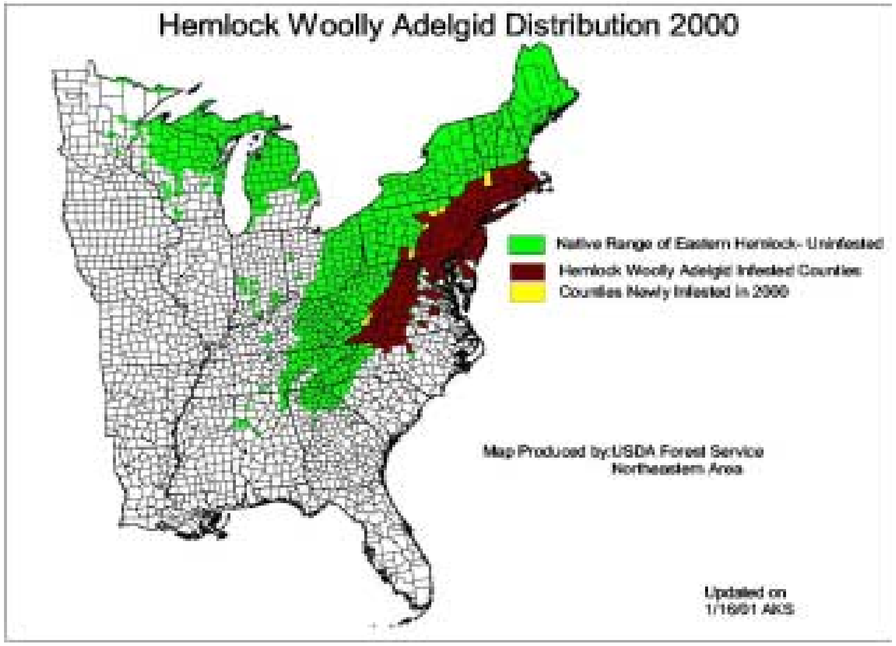
The eastern hemlock (*Tsuga canadensis*) is a long-lived, shade-tolerant, conifer species with a range covering and extending beyond the 4-state NEFA region (Harlow et al 1996). Because of its ability to intercept precipitation and light, as well as its evergreen status, hemlock ecosystems play a very important role in many forests. Hemlock provides thermal cover for birds and mammals, it reduces stream, soil, and air temperatures on hot days, it reduces winter snow depths, and it adds vertical and horizontal forest structure.

Historically, regional harvest pressure on hemlock has been moderate, with exceptions of heavy use by the tanning industry in the 19th century and its recent use as a pulpwood substitute for spruce and fir in Maine and New York. Though it has been and still is used in a wide variety of forest products such as barn beams, ties, dimension lumber, bark mulch, and nursery stock, the properties of its wood have limited the scale of its use, giving this somewhat slower growing species time to develop and mature in many northeastern forests. The most recent FIA estimates of the live-tree, hemlock volume on NEFA region forest land total 5,094 million cubic feet, or an estimated 7.8% of all live tree volume on forest land. While New York has the greatest absolute volume of hemlock volume among the NEFA states, Vermont and New Hampshire have the highest amount of hemlock as a percent of total state volume (9.2% and 9.1% respectively). Regionally, hemlock is a very important species both ecologically and commercially; however its prevalence and importance does vary among different specific locales.

The hemlock woolly adelgid is an exotic pest whose native range includes temperate forests in China, Japan, and India. In the East, this pest was first observed in Virginia during the 1950s. It has since expanded its range to 11 eastern states, including Connecticut, Massachusetts, New York, and Pennsylvania (Figure 11.1). HWA infests counties bordering southern NEFA counties and has been spreading at the rate of 20-30 km per year in these areas. Recently, it has been found in southern Maine and New Hampshire. Virtually all hemlock trees infested by this insect die within 5 years, with no evidence of any mitigating conditions (e.g. site or vigor) that aid their recovery (Orwig, pers. comm.).

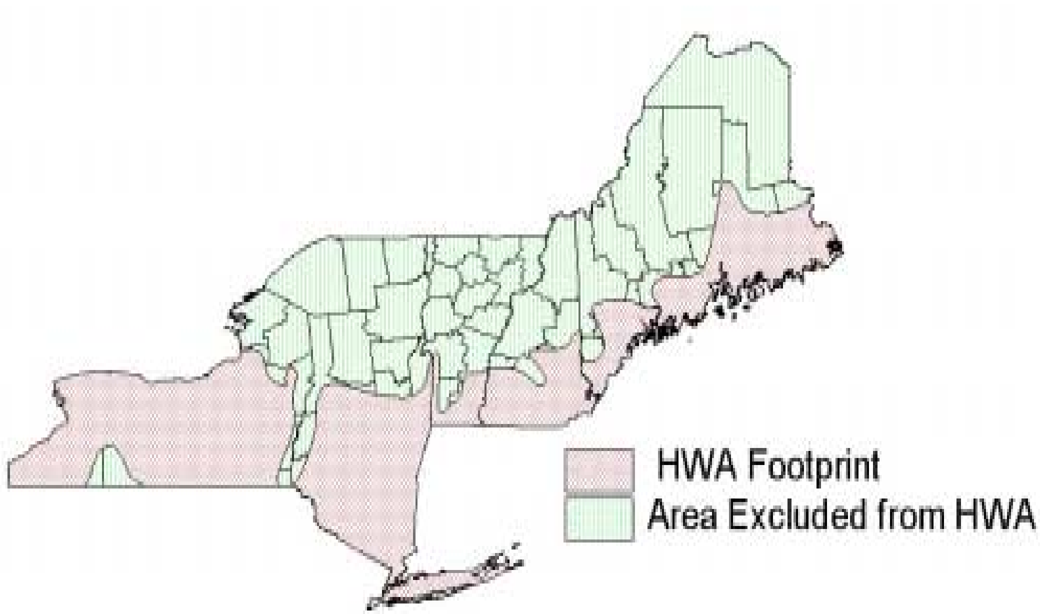
In the absence of hard data for our region, we were forced to look outside the region for modeling insight. After exploring the literature, looking at plot data from southern New England, and communicating with several people involved with HWA, we made a number of pragmatic assumptions. These assumptions identify the area chosen for HWA infestation; define the likely timing of this infestation; quantify the extent of the damage on infested acres; and predict the harvesting response from landowners.

Figure 11.1 USDA Forest Service's most recent HWA distribution map.



We assumed that HWA would only cause mortality in stands falling in the USDA’s average annual minimum temperature hardiness zone 5a or higher (> -20° F). We based this assumption on several things. First, Souto and Shields (1999) cite Miller’s (1988) report that the severe cold wave experienced by Virginia in the winter of 1984-85 killed off all HWA in stands above 2000 feet elevation where temperatures of –20°F and colder were recorded. There was also a very significant reduction in HWA numbers in stands below 2000 feet where it did not get quite as cold. Secondly, research by Montgomery et al. (1999) supports the idea that all the Asian hemlocks grow in climates that are warmer than the extremes of the range of eastern hemlock. HWA, as an insect that overwinters on hemlock needles, may not have adapted to survive the coldest winter temperatures of the northern United States. Therefore, our modeling assumption remains that HWA will only infest stands where average annual minimum temperatures are above –20°F. This footprint is shown in Figure 11.2 and has an estimated 17.7 million acres of forest land in it, roughly the lower 40% of the study region’s forested area. Within this region, we targeted HWA infestation on all acres within the hemlock-red spruce habitat type, approximately 1.4 million acres. The hemlock-red spruce habitat type has the majority of hemlock volume within the infestation footprint, and 1/3 of the hemlock volume within the entire NEFA region.

Figure 11.2. The hemlock woolly adelgid (HWA) footprint area



The second assumption specifies the infestation timing and subsequent hemlock mortality. Foster (1999) and Orwig (personal communication 2000) state a spreading rate of 20-30 kilometers per year for HWA through Connecticut and Massachusetts. Because our model has 10-year periods, this rate becomes 200-300 kilometers per period. The USDA Forest Service’s 2000 HWA distribution map shows HWA to exist in counties of the lower Hudson Valley and Catskill region of New York, as well as Lycoming and Sullivan counties in north- central Pennsylvania. Assuming a rate of 200-300 kilometers per decade, it seemed possible for HWA to spread across south-western New York and cover the HWA footprint zone in the first period of model time (2000 to 2010). With counties in northern Massachusetts also infested, it seemed possible for the HWA footprint in Vermont, New Hampshire, and western Maine to be infested in the first period. The more distant northern and eastern Maine counties of Penobscot, Piscataquis, Hancock, and Washington also had forest land within the HWA footprint; however, because of their remoteness, infestation in this part of the footprint was delayed until the second period of model time (2010 to 2020). The true rate of dispersal for this pest will obviously be affected by many factors, including weather and large scale weather events such as hurricanes, vehicular movement of infested hemlock including landscaping stock, contiguity of infested stands, and the effect of eradication efforts.

The next major assumption involved the amount of hemlock mortality we would introduce to hemlock-red spruce acres within the HWA footprint. Here we attempted to mimic the complete loss of all hemlock on candidate acres over the 50-year modeling horizon, beginning immediately. We did this by creating yield curves from FIA data that simulated growth rates of these stands with the hemlock eliminated and not allowed to regenerate. We then used the ATLAS density change parameters to grow the initial inventory, which currently includes hemlock, down to these curves. The result is several periods of negative growth for these acres, followed by remaining periods of reduced but positive growth. When compared to similar runs (e.g. the constant-harvest run) with no yield curve reductions, the hemlock losses to mortality over the 50-year modeling horizon are substantial, representing a dim scenario.

The last major assumption involved the human response to the event. Though this could surely be argued a number of ways, we chose not to introduce a massive salvage harvesting effort into our model. The primary reason for this was that the market for hemlock stumpage over the last 30-40 years has experienced negative real price change (Howard et al 1999). This suggests that the demand for hemlock has been limited with respect to its supply. Our model assumes that this trend continues, curtailing any extra harvesting effort beyond the level already explicit in our model. Viewed from a different angle, the same level of harvesting in these stands may just be targeted more towards the hemlock species than other accompanying species.

	Decade					
State	***2000-2010***	***2010-2020***	***2020-2030***	***2030-2040***	***2040-2050***	***Total***
Maine	-39.6	-203.3	-104.1	-90.2	-88.9	-526.1
New Hampshire	-222.1	-150.6	-107.8	-85.8	-76.7	-643.0
New York	-352.2	-224.6	-162.2	-127.2	-104.9	-971.1
Vermont	-33.0	3.4	15.7	10.5	19.1	15.7
Region	**-646.9**	**-575.1**	**-358.4**	**-292.7**	**-251.4**	**-2124.5**

Table 11.1 Simulated additional hemlock mortality losses due to hemlock woolly adelgid (millions of merchantable net cubic foot volume).

The major assumptions define a scenario of widespread, persistent decline in eastern hemlock, severely diminishing its prevalence inside the footprint area, while leaving the hemlock outside this area unharmed by the pest. The results of this scenario are offered at a coarse level of resolution. They focus on more traditional timber supply estimates than trying to describe the ecological implications of a wave of dying hemlock trees on ecosystem health. The latter issue is certainly very important, but goes beyond the scope of this study.

The model output showed that in the first decade of simulation, 646.9 million cubic feet of additional hemlock mortality occurs, a loss of approximately 25% of the hemlock volume within the HWA footprint and 18% of the hemlock volume within the 4-state region. The second period experiences an additional loss of 575.1 million cubic feet of hemlock to mortality, which when added to first period losses are equivalent to approximately 47% of the current hemlock volume within the HWA footprint. Additional hemlock mortality over the next 30 years totals 886.7 million cubic feet (358.4, 292.7, and 251.4 per decade). At the end of 50 years, losses of hemlock sum to 2,124.5 million cubic feet. This volume is equivalent to approximately 80% of the merchantable hemlock volume estimated to currently exist within the footprint, and represents a regional inventory loss of 2.2% by the end of the modeling horizon, 2050.

Figure 11.3 shows the growth to removal ratios for the hemlock-red spruce habitat type, compared to the entire region, under both the HWA and constant-demand scenarios. In the constant-demand run, the hemlock-red spruce habitat had a growth-to-removal ratio of 1.04 for the first period. In this run the hemlock-red spruce ratio for the same period is 0.53. The effect is dampened significantly for the region as a whole, with all acres in the HWA scenario having a combined ratio of 1.40 compared to the constant-demand ratio of 1.46. In subsequent periods, this gap diminishes, but it is important to note that the growth rate on the hemlock-red spruce habitat type does not totally recover. Hemlock's shade tolerance and persistence allows stands with this species to support higher levels of stocking.

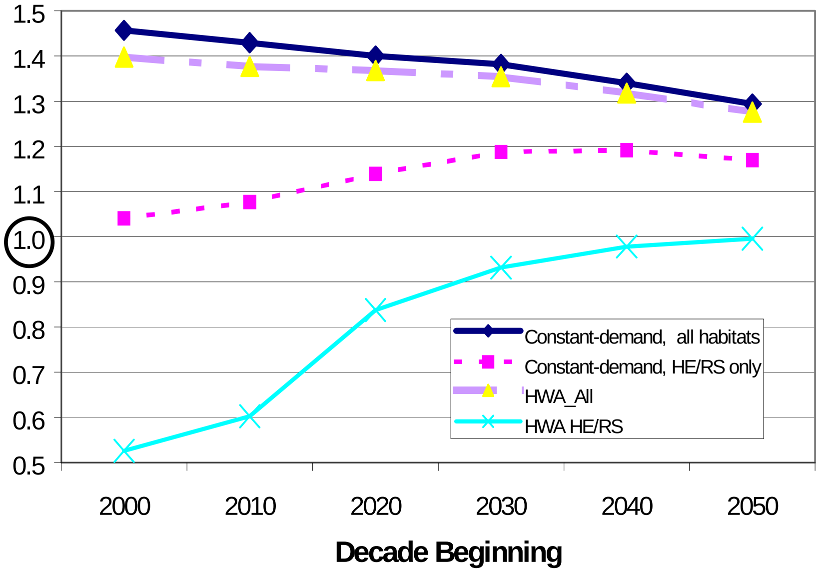


Figure 11.3 Growth-to-removal ratios for hemlock-red spruce habitat type for the HWA run and the constant-demand run.

With the hemlock component removed, the remaining species (white pine, yellow birch, beech, and the maples) support lower stand densities and growth per acre suffers. It may be true, however, that in locales where red spruce represents a substantial level of stand stocking, growth may rebound.

12. Evaluation

In general, modeling might be described as an attempt to predict future events based on complex relationships gleaned from scientific investigation and historical experience. While some models are highly complex and designed to predict, the reasons we choose to build models is broader. Starfield and Bleloch (1986) suggest we build models "because they help us to (1) define our problems, (2) organize our thoughts, (3) understand our data, (4) communicate and test that understanding, and (5) make predictions. Pragmatic models (Starfield 1997; Walters 1986) emphasize decision-making. We may not have ideal data. We may be unable to specify the relationships among complex natural phenomena and dynamics with precision. We may not feel comfortable representing the model results as the "true" course of future events. Nevertheless, decision makers use formal and informal models frequently to explore aspects of the system we can model with confidence; to test understanding by experimenting with a range of assumptions; and to improve insight into complex issues. The modeling team for this project wanted to build a tool that would serve these purposes to the benefit of the NEFA member states.

We have built a structure upon data familiar to us in ways that characterize the NEFA forests in ecological terms. We have included aspects of importance to evaluating the sustainability of future timber supplies, but we have also included consideration of non-commercial forests and a range of ecological measures. By defining the "problem" of modeling the NEFA resource in this way, we have been forced to organize our thoughts and better understand the data.

In truth, we have only begun to evaluate whether we have been "successful" in building a suitable model, but then, we don't see this model as static. The scenarios we chose to model were intended as much to evaluate and demonstrate the agility and performance of the model as they were to explore issues of policy interest. We have presented only a small fraction of the data from any of the model runs, partly because, while these runs are useful, they are by no means definitive. Before making important decisions based on the model's results, the decision-maker would be strongly advised to investigate (and modify) the assumptions made by us. To build confidence in what the model is saying, this model should be customized to the needs of the decision and the decision-maker. In the years since the completion of a similar model for Maine, the Maine Forest Service has done just that and has employed the model in the evaluation of a number of important policy scenarios.

While this paper describes the model's assumptions in some detail, proper use by others will take some additional training and a period spent becoming familiar with the "nitty-gritty" details of formulating assumptions, specifying key parameters, and interpreting the output. We have developed a number of custom routines designed to ease the learning curve. We also believe the core of the model (most yield curves, harvest methods, habitat and volume classifications) will not need major modification for most purposes. The decision-maker or analyst should be able to focus on the larger details of alternative runs.

Is the set of routines and models we have developed "user-friendly?" While not designed for widespread distribution and use by the general public, anyone with a background in computers, databases, and spreadsheets can quickly learn the "ropes." The NEFA model is designed so the states can use it to deal with broad policy issues -- in order to test the limits of our understanding of these issues.

One can certainly point to limitations that remain in our formulations. There is little spatial control over what happens in harvesting. Acres associated with individual plots lose that identity once they are harvested. The specificity of harvesting methods and resulting products could be improved. It would be useful to track sawlog material and pulp material separately. Improvements could be made in the determination of harvest requests based on econometric forecasting. Research on this topic is ongoing. Data could always be more current and more specific.

If the prediction of the future were the goal, these would be important, perhaps limiting concerns. If improved knowledge of the forest system drives our interest in modeling, the identification of these limitations becomes an important act in itself. We can now communicate our knowledge of this system in ways we could not do before.

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Appendices

Appendix A: Methods used to develop ecological metrics.

Overview

The modeling team's interest in tracking and reporting on a broader range of ecological metrics began with brainstorming the types of measures to be included. Among those discussed were measures of diversity and vegetative species richness; wildlife mast measures; indicators of structural complexity in the forest; and others. Two major constraints of the ATLAS model had to be considered. First, neither species-level data nor spatial locations are handled by this model. This limited what could be done within the ATLAS model alone. Second, while the FIA data set was recognized as a rich initial data source, no clear mechanism was available to predict change over time. These two limitations dictated the need for a process that was built outside of ATLAS but was capable of being linked.

Additional questions were raised: What information is each measure designed to convey? How do we calculate them? What kinds of measures or indices can be legitimately calculated from FIA data? At what level are they appropriate: by habitat across states? By state across habitats? By state and habitat? By region across habitats? What kinds of variability are present in these measures? Is this noise resulting from our choice of measure or legitimate variability inherent in the measure? Does the "snapshot" nature of the FIA data from a single point in time introduce a bias if these data are used for prediction? Are interpretations of the measures clear?

As a first step, we generated and charted a number of sample measures to explore these questions further. Discussion of these sample measures with ecologists on the modeling team helped to refine the choice of appropriate measures and the methods by which they should be calculated. Once a final set of measures was chosen, a scheme was developed to estimate change in each measure over time by linking to ATLAS results.

Each measure is briefly described below, followed by the methods used for calculation. We describe how the link to ATLAS output was constructed and review some of the caveats for interpretation and use of the ecological metrics. Finally, we offer some insights gained and opportunities for additional research.

Measures calculated

Data for each of the following measures was drawn from the FIA data set assembled for this project:[12]

- Large-nut mast
  This measure summed the basal area per acre of tree species yielding large nuts (oaks, beech, hickory, etc.). It was constrained to include only trees in upper canopy positions (dominant and co-dominant) and equal to or greater than 8 inches in DBH.
- Medium-seed mast
  This calculated the basal area per acre of trees producing medium-seed mast (dominated by the maples and ashes). Only trees equal to or larger than 5 inches DBH were counted.
- Soft mast
  Soft-mast producing stems (berries, cherry, apple, mountain ash, dogwood, etc.) were included in this count (stems/acre). No diameter restrictions were applied.
- Fine-seed mast
  This calculated the stems per acre of trees and shrubs producing fine-seed mast (mostly the aspens and birches). No diameter restrictions were applied.
- Conifer-seed mast
  All conifers were included in this basal area per acre measure. Only trees equal to or larger than 5 inches DBH were counted.
- Large trees
  All trees on a plot equal to or greater than 20 inches DBH were counted for this measure (stems/acre)
- Dead trees
  This measure counted all standing dead stems on a plot equal to or greater than 10 inches DBH.
- Vertical structure
  All stems on the plot were assigned one of seven height classes (0-3'; 3-10'; 10-20'; 20-40'; 40-60'; 60-80'; 80'+) based on either the actual height (available when DBH=>5") or by an estimate of the

[12] Since FIA data were not collected on 2.5 million acres of New York state-owned land in the Catskills and Adirondacks, data for those acres are not included. The implications of this are considered below.

height. The actual measure summed the number of height classes present (maximum=7) on the plot.

Methods

The calculations followed these steps:

1. For each plot condition, the particular measure of interest was summed (basal area) or counted (number of stems or height classes). Totals were converted to per-acre estimates, then averaged for all occurrences of habitats and volume classes (VCs) across the region. Thus, each occurrence of volume class and habitat contained an average for the measure. (e.g. spruce-fir, VC 11= 150 square feet of conifer seed basal area). We call these the "base-level" values.
2. The base-level values were charted and reviewed. Figure A-1 displays basal area of conifer-seed mast for the major habitats/types. Inspection of this chart shows the spruce-fir habitat at the top and oak-hickory at the bottom, with the remaining habitats distributed logically according to their expected proportion of softwood. The chart also shows data gaps in a number of the VCs for the oak-hickory type and a lack of data in the upper volume class cells for most habitats. Each set of calculated measures was reviewed for data consistency. Missing values were interpolated or projected after considering the nature of the measure, the ecology of the habitat, and apparent trends in the available data.
3. The measures were calculated at the habitat/VC level because this mirrors the finest level of resolution available in ATLAS. The result is a matrix of habitat/VC measures calculated from the data. The elements of this matrix (or cells) could now be linked to corresponding cells in ATLAS. The indexes reported in the body of this report represent the sum of the measure for each VC and habitat, weighted by the acres in that cell, for each period.[13] This can be expressed as follows, using the conifer mast index for 2010 as an example:

Conifer Index for 2010 =

$$\Sigma_{i,j} (M_{i,j} \cdot W_{i,j}) \quad \text{where:}$$

i= VCs 0-17
j= each habitat
M = base value for the metric and
W = acreage weight (2010 i,j acres /2010 total acres).

The index thus tracks the weighted average value of the measure for each period in the model. As the simulation progresses, if the acres in a particular VC increase, the value for that VC's measure will receive greater weight. If harvesting sends a large number of acres from higher classes to lower classes, the index will reflect the values of those lower classes.

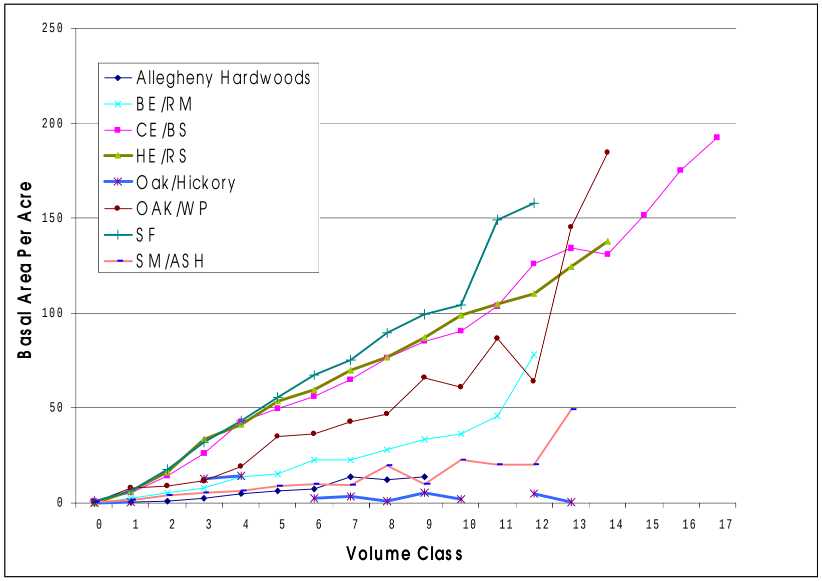


Figure A-1. Base-level values for conifer seed mast by volume class and habitat.

Discussion

Certain aspects of these methods deserve further consideration. First, we must recognize an assumption that anchors the logic of this approach: the base values calculated from current FIA data will not change substantially over time and thus can be applied to future acres

[13] A similar index was calculated at the habitat level. This measure was used to evaluate the "reasonableness" of the aggregate measure, but is not reported here.

in similar VCs. Generally, this is a reasonable assumption. Most base values represent the average of many acres. Trends are generally consistent. Furthermore, VCs with the most acres in them now maintain those acres under most of the scenarios modeled; those with fewer acres have a small influence on the final index.

In certain cases, however, the assumption that current conditions remain static is problematic. An obvious example involves the number of dead trees on spruce-fir acres in Maine. The FIA data reflect the impact of the recent budworm epidemic and also a substantially higher level of spruce and balsam mortality than is expected in the next 20-40 years. The impact of this phenomenon is mitigated by reporting across all habitats, but it is reasonable to assume the dead-tree index overstates mortality by some amount.

The mast indices are reasonably straightforward in their development and interpretation. Each stem in the dataset was assigned a mast category based on its species. The accumulation of the base values was constrained to the most appropriate measure (basal area or stems per acre) and the pertinent individuals (e.g. >8" DBH and in the upper canopy for large nut). This aids in the interpretation but, because the data lack spatial specificity, the index is useful only in the most general sense: there may be more or less mast available across the region but its use by wildlife depends on many site-specific factors unavailable at this level of aggregation.

The big-tree index is similar to the mast indices—more trees of larger size do not necessarily predict higher levels of ecological complexity in stands, but do provide for the possibility.

The vertical structure index seems to articulate the least amount of information, partly because of the particular methods used in its construction. One issue here is: How many stems must exist to constitute the existence of a "level?" Because of the plot sampling methods, a single 3" stem expands to 60 stems per acre. Each occurrence of a tree above 5" DBH typically counts as 5 trees per acre. How many trees per acre represent a "level" in the upper height classes? We assumed a minimum of 10 trees per acre in classes above 10 feet tall.

The vertical index makes no distinctions about which of the seven classes are present. Acres with classes 4,5,6 are considered equal with classes 1,2,7—each has 3 classes represented. The limited movement of this measure across the various scenarios and the relatively high absolute level (close to 5) makes this measure more difficult to interpret.

While we calculated each index at the habitat level (across all states), we felt the potential advantages of reporting at this level were outweighed by the complexity of interpretation and the potential for anomalies in by-habitat calculations. We do feel there is additional information at this level, but its interpretation must be considered more carefully.

Opportunities for additional study

The development of the ecological metrics for this study was an attempt to place the "generic" reporting of the timber supply details from ATLAS in a broader context. Given the kinds of questions the model was designed to explore, we feel the indices report at an appropriate level. Linking ATLAS with summaries of the FIA data is a useful exercise and should be explored further. Numerous measures were discussed and, for a variety of reasons, were not pursued. We feel confident additional refinements could be made in the metrics we did develop that would aid interpretation.

One area deserving particular attention is the calculation of measures using output from FIBER. FIBER output contains specific information that could augment or replace values from the FIA. The primary advantage would be the integration of FIBER's time series simulation with ATLAS's, thus reducing the drawbacks associated with static FIA data.

Appendix B. Structure of the multi-state FIA plot database used in the NEFA modeling study.

The description of 3 tables is included here. The format of these tables is similar to the format of the published Eastwide database format (EWDB). Users of FIA data are strongly encouraged to review the FIA field manuals and the EWDB data manuals for coding and interpretations of fields.

The tables below refer to "plots" and "conditions." Conditions can be thought of as subdivisions of plots based on substantially different ground characteristics. Conditions attempt to capture additional detail on these plots. For example, a plot may land on the edge of a clearing and contain a portion of its area in forest and a portion in field. Each would be recorded as a separate condition.

Table: Plot
This table has PLOT-level fields (In contrast to the two tables that follow.)

Variables

Name	Type	Size	Brief description
STATE	Long Integer	4	
UNIT	Long Integer	4	
COUNTY	Long Integer	4	
PLTNUM	Long Integer	4	Plot number
SMPKIND	Long Integer	4	Sample kind
PICLS	Long Integer	4	Photo Interp class
MONTH	Long Integer	4	Of collection
DAY	Long Integer	4	
YEAR	Long Integer	4	
PRELU	Long Integer	4	Previous collection dates (The prefix "P" generally designates data from the previous inventory.)
PREMON	Long Integer	4	
PREYEAR	Long Integer	4	
PTHIST	Long Integer	4	Previous tree history
DISTURB	Long Integer	4	
REMPER	Long Integer	4	Remeasurement period
EXPCUR	Long Integer	4	Acreage expansion factor used for non-volume estimates (land cover, ownership, etc.)
EXPGRO	Long Integer	4	Acreage expansion factor used for growth volume estimates
ELEV_METERS	Long Integer	4	Approximate
X_COORD	Long Integer	4	Approximate
Y_COORD	Long Integer	4	Approximate
SCOUNTY	Long Integer	4	

Table: Ecoattribs

This table contains data at the CONDITION level. Each plot can have up to 4 different mapped conditions. Condition-level data was collected in ME, NH, and VT, but not in NY.

Columns

Name	Type	Size	Brief description
STATE	Long Integer	4	
UNIT	Long Integer	4	
COUNTY	Long Integer	4	
PLTNUM	Long Integer	4	
CNDTN	Long Integer	4	Plot condition. Records in this table include data on *subplots* of different conditions.
LU	Long Integer	4	Land use
TYPCUR	Long Integer	4	Current forest type (detailed, field call)
STORCUR	Long Integer	4	Stand Origin
STDSIZE	Long Integer	4	Stand Size
STDAGE	Long Integer	4	Stand age (usually missing)
MGTCLS	Long Integer	4	Management Class
PHYSIO	Long Integer	4	Soil Physiography
STDHIST	Long Integer	4	Stand history
OWNER	Long Integer	4	Owner Type
CNDTNPCT	Double	8	Percent of plot in this condition
STKAL	Long Integer	4	Stocking, all live trees
STKCLAL	Long Integer	4	Stocking class, all live
STKGS	Long Integer	4	Stocking, growing stock
STKCLGS	Long Integer	4	Stocking class, growing stock
FTYP	Long Integer	4	General forest type, calculated
PREV_FTYP	Long Integer	4	Previous forest type
MFTYP	Long Integer	4	Calculated forest type group
CSTDSIZE	Long Integer	4	Calculated Stand Size
EXPACR	Long Integer	4	Same as EXPCUR at the CNDTN level—used for non-volume area estimates
EXPVOL	Long Integer	4	Same as above—CNDTN-level
ELEV_METRES	Long Integer	4	Same as above-- CNDTN-level

Table: spp

This is the tree-level file, though many plot-level and condition-level variables are repeated for convenience.

Columns

Name	Type	Size	Brief description
STATE	Long Integer	4	
UNIT	Long Integer	4	
COUNTY	Long Integer	4	
PLTNUM	Long Integer	4	
POINT	Long Integer	4	
REPNO	Long Integer	4	
TREE	Long Integer	4	Each tree on the plot has a number.
SPP	Long Integer	4	Species code
HDIST	Long Integer	4	Tree location data
AZI	Long Integer	4	“ “
TRHIST	Long Integer	4	Tree history
DBHCUR	Double	8	Current DBH
CNDTN	Long Integer	4	1-4 (NY plots all given 1, since CNDTN not measured in NY)
STEMS1	Long Integer	4	Number of tree seedlings
TRECND	Long Integer	4	Tree condition class
TGRADE	Long Integer	4	Tree grade
SAWHT	Long Integer	4	Sawtimber height
BOLEHT	Long Integer	4	Bole height
BFCULL	Double	8	Board foot cull estimate
BFSND	Long Integer	4	Percent soundness of BFCULL
CFCULL	Double	8	Cubic foot cull estimate
CFSND	Long Integer	4	Percent soundness of CFCULL
CRRATIO	Long Integer	4	Crown ratio
CR7OWNCL	Long Integer	4	Crown class
DAMAGE	Long Integer	4	General damage type
SDAM1	Long Integer	4	First damage agent
SDAM2	Long Integer	4	Second damage agent
TREECLS	Long Integer	4	Tree class (preferred, acceptable, rough cull, rotten cull, dead, snag)
MERCHCL	Long Integer	4	Merchantability class
PRDBH	Double	8	Previous DBH
PRHIST	Long Integer	4	
PTREECLS	Long Integer	4	
PMERCHCL	Long Integer	4	
NOTES	Long Integer	4	
COMM	Long Integer	4	Commercial tree species or non-commercial, shrub, vine, or other.
SGRP18	Long Integer	4	The next 3 fields represent various levels of species grouping.
SGRP28	Long Integer	4	
SGRP4	Long Integer	4	
TSIZEC	Long Integer	4	Size class, current
TSIZEP	Long Integer	4	Size class, previous
KDBHC	Long Integer	4	
KDBHP	Long Integer	4	
TREESC	Double	8	Tree expansion factor, current
TREESP	Double	8	Tree expansion factor, previous

TREESG	Double	8	Tree expansion factor, for growth estimates
LU	Long Integer	4	Land use
OWNER	Long Integer	4	0wner
CFGVOL	Double	8	Gross volume in cubic feet (this tree)
CFNVOL	Double	8	Net volume in cubic feet
BFGVOL	Double	8	
BFNVOL	Double	8	
UPSTEM	Double	8	
LOSTEM	Double	8	
GMSWTDW	Double	8	Biomass measures
GTTWTDW	Double	8	
NMSWTDW	Double	8	
NTTWTDW	Double	8	
NTOTLDW	Double	8	
NWTUPDW	Double	8	
NWTLODW	Double	8	
NWTTBDW	Double	8	
NWTTFDW	Double	8	
NWTTSDW	Double	8	
GTTWTGW	Double	8	
NMSWTGW	Double	8	
NTTWTGW	Double	8	
NTOTLGW	Double	8	
NWTUPGW	Double	8	
NWTLOGW	Double	8	
NWTTBGW	Double	8	
NWTTFGW	Double	8	
NWTTSGW	Double	8	
GMSWTGW	Double	8	
CFGVLP	Double	8	Measures of volume from previous inventory
CFNVLP	Double	8	
BFGVLP	Double	8	
BFNVLP	Double	8	
CFGVLG	Double	8	Measures of growth
CFNVLG	Double	8	
BFGVLG	Double	8	
BFNVLG	Double	8	
GRTHCLSC	Long Integer	4	Growth class
REMPER	Long Integer	4	
SMPKIND	Long Integer	4	
TREND	Long Integer	4	
PRELU	Long Integer	4	
EXPCUR	Long Integer	4	Plot level
EXPACR	Long Integer	4	Condition level (equal to EXPCUR when CNDTN=1)
EXPVOL	Long Integer	4	
SCOUNTY	Long Integer	4	
BA	Double	8	Basal area
CNDTNPCT	Double	8	

Appendix C: Habitat Assignments: Rationale and Results

Overview

This appendix briefly outlines the process and results for assigning FIBER ecological "habitat" classes to FIA plots. The goal was to use information available in the FIA database along with classing algorithms in the FIBER model to assign all acres (plot conditions) to a finite set of habitats or forest types. The FIBER manual describes the rationale for habitats and the habitat classes as follows:

> Ecological habitats are land units defined by landform, soils, and typical climax tree species (Leak, 1982). These units exhibit a characteristic successional pattern, indicative of the tree species that will most likely regenerate and compete on a given ecological unit. The relationship between tree species and soil/landform conditions vary with climate and bedrock mineralogy. Heavy disturbance, such as agricultural use and fire, may change the successional stage, but not the characteristic successional sequence. In developing FIBER, the basic remeasurement plot data were classified into habitat based on the maximum basal area of the species composition at the beginning of any single remeasurement period. Each growth and ingrowth rate used to implement the model was developed by habitat. The six habitats used in FIBER are:

1. Sugar maple-ash. This habitat includes sites supporting typical northern hardwood, beech-birch-maple, as well as richer sites supporting white ash and high proportions of sugar maple. The soils vary from deep, well drained fine tills to moderately well drained soils and enriched sites. Fine tills are typical till deposits without any evidence of working water. All particle sizes are present; many surface rocks and irregular topography are characteristic. Textures are sandy loam or finer, sometimes silty feeling. Enriched sites usually occur as coves or benched within areas of tills or occasionally compact tills. The distinguishing feature is organic matter or organic-coated fine material incorporated into the mineral horizon. Sugar maple-ash sites have very good growth rates for both softwoods and hardwoods, however, softwoods are uncommon due to hardwood competition. These sites are well suited to hardwood sawlog and veneer production. On the basis of species composition, FIBER identifies this habitat as a hardwood type (less than 25 percent softwood species), supporting more sugar maple than red maple, and at least 10 percent of the species composition in sugar maple and white ash.

2. Beech-red maple. Also a hardwood type, this habitat occurs on sandier and rockier well drained tills than sugar maple-ash. Species composition tends towards beech, red maple, and birches with small amounts of sugar maple and very little ash. Softwoods, usually hemlocks, are more common here than on sugar maple ash sites. These sites are generally course or washed fine tills. Course tills were heavily rinsed as they were deposited, removing much of the fine material. The substrate is a loose sand/gravel or loam sand/gravel. These tills resemble gravely outwash, except that they have a broader gradation in particle sizes and some evidence of silt caps. Washed fine tills are unsorted glacial drift, which may or may not have been water worked. These tills are loosely deposited, usually contain levels or small blocks of stratified material and have few surface rocks on rolling topography. The washed fine till exhibits prominent silt caps. Beech-red maple sites have good growth rates for softwood and hardwood species. However, softwood may be difficult to establish due to hardwood competition. Hardwood competition on Beech-red maple sites is lower than on Sugar maple –ash sites and as such softwoods may establish themselves. FIBER identifies this habitat as a hardwood type when the criteria for sugar maple-ash or oak-white pine are not satisfied.

3. Oak-white pine. This habitat typically includes areas of sandy outwash, shallow bedrock, or very sandy tills supporting eastern white pine and northern red oak. Sandy outwashes are generally sands and gravel that have been stratified, at least to some extent, and deposited by moving water. Stones are generally clean without silt caps. Outwash areas are flat to gently rolling or hommocky, free of surface rocks, and associated with streams or old drainage ways. Shallow bedrock sites generally contain bedrock, angular boulders, or nearly pure weathered granite found as deep as 2 feet below the surface of the mineral soil. These areas were plucked and scoured by glaciers, and may be on steep or moderate slopes. Ledges and rectangular boulder are often evident. Shallow bedrock sites that should be classified as an oak white pine habitat are generally on a southern exposure. Oak-white pine habitats have slow to medium growth rates for softwood and hardwoods, with white pine being the most productive species. Softwoods are

more productive than hardwoods on these sites. However, past agricultural disturbance may result in an oak-white pine community on better soils. Over time hemlock become the predominate species.

4. Hemlock-red spruce. This habitat is characterized by shallow, wet, dry, or rocky soils supporting a mixedwood or softwood cover type (more than 25 percent softwood) where hemlock and red spruce are more abundant than white pine red spruce, white spruce, and fir combined; or cedar and black spruce combined. Hemlock-red spruce sites are generally silty or sand sediments or dry or wet compact tills in the more southern and coastal areas covered by FIBER. Silty and sandy sediments are generally poorly graded sand and silt deposited by slack water. Soils tend to be loose and dry (sandy sediment) or moist and sticky (silty sediments), with a mostly rock free surface on flat or gently rolling topography. Wet compact tills are platy basal tills compacted by the glacier at the base of the B-horizon, and mottling or free water is very evident. These sites are generally flat or concave and gently sloping with boulders pressed into the surface. Dry compact tills are similar to wet compact tills except there is very little evidence of mottling or free water in the B-horizon, however the C-horizon usually is wet. These sites are generally found on moderate upper slopes and knolls, usually above areas of wet compact tills. Softwoods are the most productive and usually the most abundant on hemlock-red spruce habitat, although hardwoods (red maple, paper birch, and yellow birch) are common in successional stands.

5. Spruce-fir. Shallow, wet, dry, or rocky soils typify this habitat. This habitat is identified in FIBER as a mixedwood or softwood type where red spruce, white spruce, and balsam fir combined are the predominant softwood species as compared to white pine, cedar, and black spruce combined, or hemlock and red spruce combined. Spruce-fir sites are generally silty/sandy sediments or dry/wet compact tills in the more northern locations covered by FIBER and shallow bedrock, outwash, and poorly drained site throughout FIBER's range. Silty/sand sediments and dry/wet compact tills are described under the hemlock-red spruce habitat, these sites should be deemed spruce-fir habitat in areas outside the range of hemlock. Shallow bedrock and outwash sites are described under the oak-white pine habitat, these sites should be deemed spruce-fir habitat were white pine and oak are not commonly found. Poorly drained sites are generally flat area with heavy mottling and gray mineral soils throughout the B-horizon. Substrate may be difficult to classify due to standing water or shallow water table during much of the year. Poorly drained sites found in the more northern locations cover by FIBER may be better classified as cedar-black spruce. Spruce-fir habitats have slightly lower growth rates than hemlock-red spruce for softwoods and hardwoods. Softwoods are the most productive on these sites.

6. Cedar-black spruce. These are generally poorly drained areas in northern New England where cedar, black spruce, and tamarack are the predominate softwood species in mixedwood or softwood types. The basal area of these species is more than the basal area of white pine; hemlock and red spruce combined; red spruce, white spruce, and balsam fir combined. Poorly drained sites are described under the spruce-fir habitat and should by classified as cedar-black spruce in the more northerly location covered by FIBER. This habitat has the slowest growth rate of all of the FIBER habitats. Softwoods are more productive than hardwoods. However, even softwood productivity is limited by excess water and poor drainage.

Assigning acres to habitats added to the robustness of the model in two ways. First, by making the assumptions that habitat transcended the "type" of the *current* vegetative conditions, the model was able to accommodate acres in vegetative transition—the variables used in determining habitat were important in describing how those acres might change over the 50-year projection. Second, since most yield curves were built through FIBER simulations, it made sense to group plots in classes that were consistent with FIBER's growth-projection schema.

<u>Methods</u>

FIBER was developed with plots from across NY, VT, NH, and ME. While studies have shown FIBER represents typical species found in these areas well, we were concerned that FIBER's data set may under-represent some of the less typical species associations found across the southern part of the NEFA region, especially along the Allegheny highlands in southwestern New York. After discussing this issue with a variety of knowledgeable individuals, we isolated FIA plots with greater than 10% of their basal area in "central" species[14]. Initially, this accounted for 1,119 plot conditions across the four states.[15] The remaining plot conditions (6573) were processed as follows:

1. All forestland conditions were processed individually through FIBER. This process assigned a habitat based on algorithms that examined species concentrations on the plot. Plots were assigned an "overstory" habitat using the basal area of trees larger than 4.9" DBH. Plot conditions were also assigned an "understory" habitat based on the stem count of trees smaller than 4.9" DBH.

2. The result of this assignment placed all conditions in one of 3 categories: a) overstory and understory assignments agree (41%), b) overstory and understory assignments disagree (51%), and c) Conditions with no overstory (8%).

3. It was assumed that we would be unlikely to improve on the assignment given to conditions where the overstory and understory assignments were the same; thus, these were classified as FIBER had determined.

4. Where over- and understory disagreed, a series of additional variables (current and former FIA type, soil characteristics, geographic region, total plot volume, and others) were reviewed for each plot. With additional guidance from the developers of FIBER, we developed rules that assigned habitat to these ambiguous conditions.

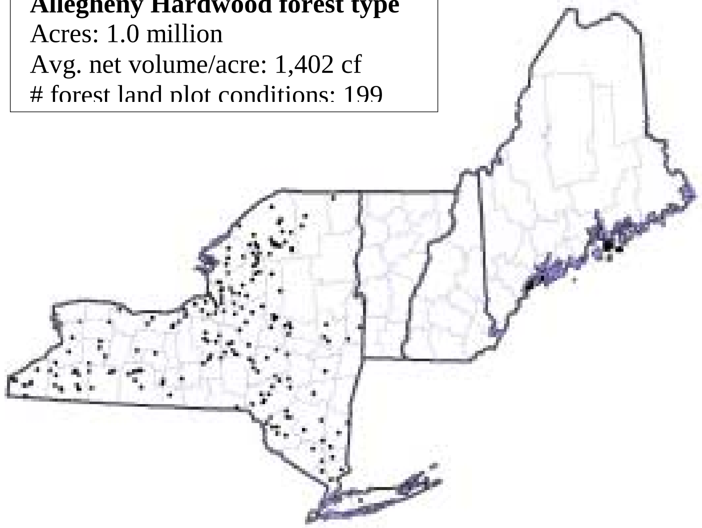
The "central species" conditions were reviewed in detail. Most of these were determined to be disturbance-modified conditions on the standard FIBER habitats and were assigned to appropriate FIBER habitats (72%). The remainder (all in New York) were assigned to two new *types*: Allegheny hardwoods (18%) and oak/hickory (10%).

One additional issue complicated the assignment of all acres to habitats. Since the FIA data set in New York did not include plots in the Adirondacks or Catskills, we used ancillary data from the New York Office of Real Property Services to represent this non-timberland forest in our model. Trees in these data were run through FIBER and plot information was used to refine the habitat assignment for these acres.

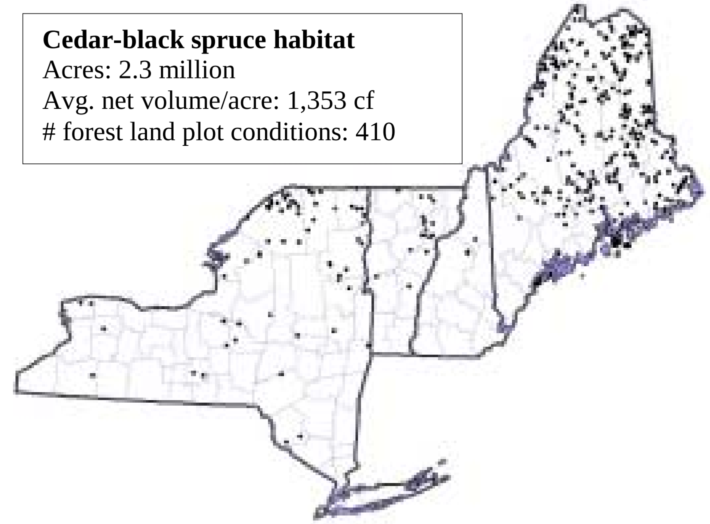
Maps showing the spatial distribution of final habitat assignments are show below. Plots in the state-owned lands of the Adirondack and Catskill Parks of New York are not shown because plot locations were not available. Also not shown are FIA plots depicting plantations.

[14] Our definition of "central species" included the oaks, hickories, black cherry, catalpa, buckeye, black maple, yellow poplar, black gum, and others.
[15] Appendix B that explains the distinction between plots and conditions.

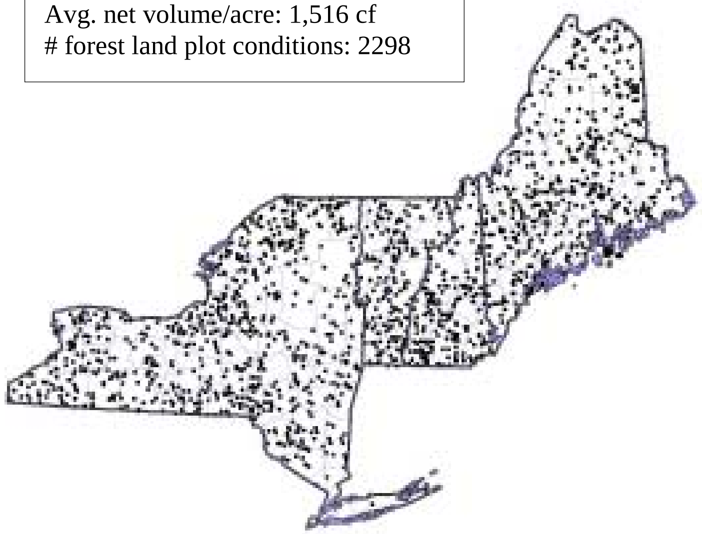
Allegheny Hardwood forest type
Acres: 1.0 million
Avg. net volume/acre: 1,402 cf
forest land plot conditions: 199



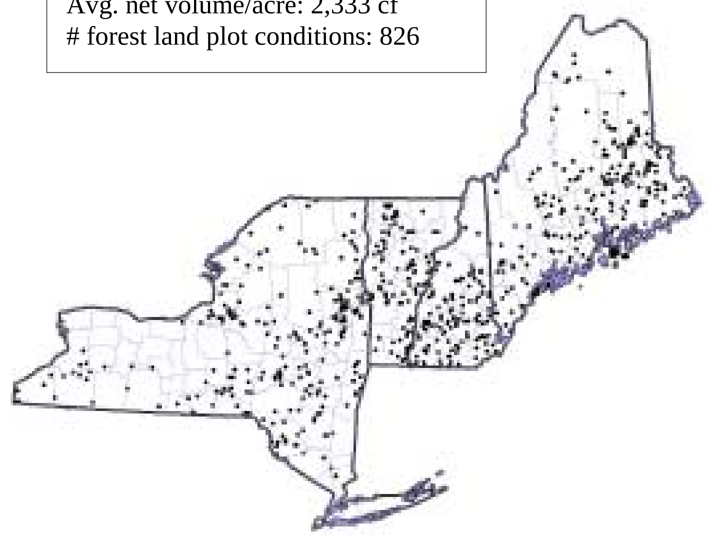
Cedar-black spruce habitat
Acres: 2.3 million
Avg. net volume/acre: 1,353 cf
forest land plot conditions: 410

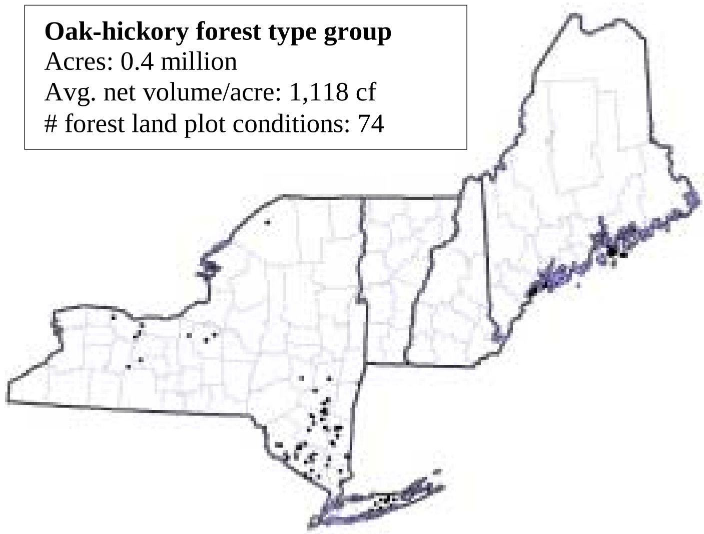


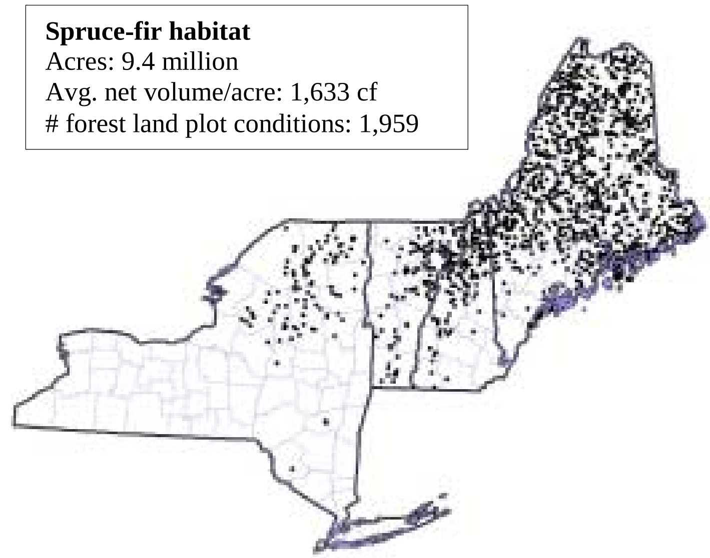
Beech-red maple habitat
Acres: 10.0 million
Avg. net volume/acre: 1,516 cf
forest land plot conditions: 2298

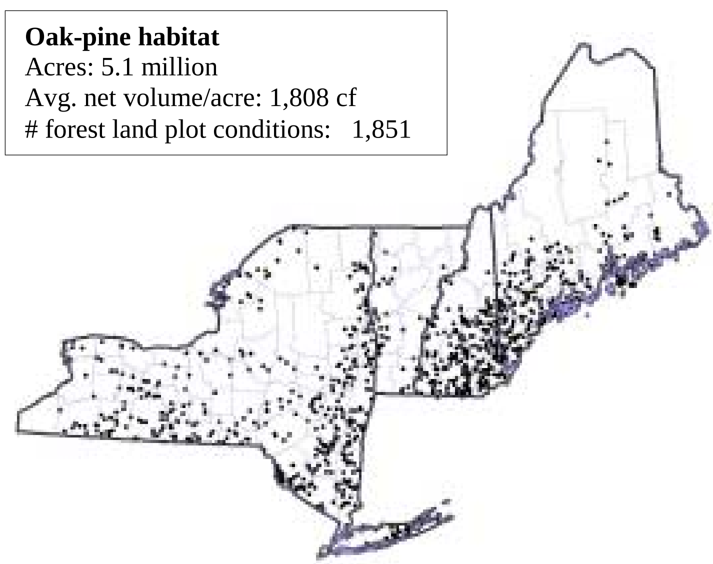


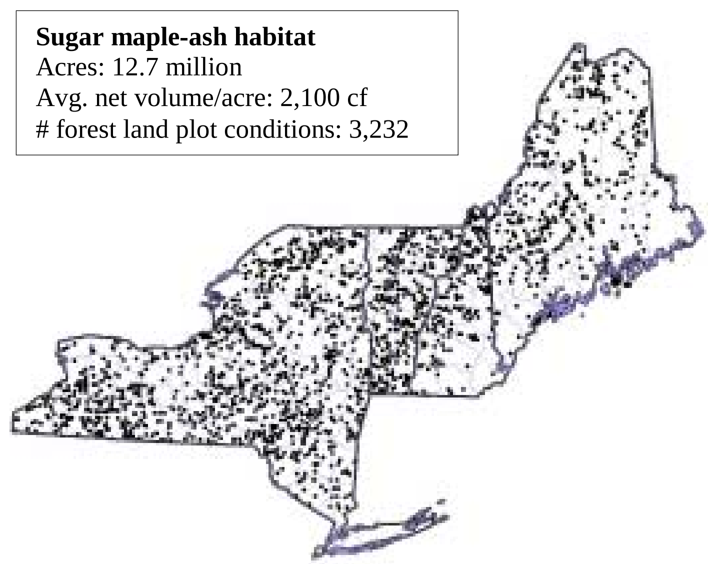
Hemlock-red spruce habitat
Acres: 3.8 million
Avg. net volume/acre: 2,333 cf
forest land plot conditions: 826




Oak-hickory forest type group
Acres: 0.4 million
Avg. net volume/acre: 1,118 cf
forest land plot conditions: 74


Spruce-fir habitat
Acres: 9.4 million
Avg. net volume/acre: 1,633 cf
forest land plot conditions: 1,959


Oak-pine habitat
Acres: 5.1 million
Avg. net volume/acre: 1,808 cf
forest land plot conditions: 1,851


Sugar maple-ash habitat
Acres: 12.7 million
Avg. net volume/acre: 2,100 cf
forest land plot conditions: 3,232

Appendix D: Land Use Change: Summary of Data Used

The following sources and documents were examined as part of the land-use change analysis. Since our units of analysis were multi-county groups, we required county-level data that could then be aggregated into our land-use change units.

Data sources

- US Department of Commerce, Census Bureau, Census of Agriculture. Land area by land use type, 1945-1992.
- US Department of Commerce, Census Bureau, Census Abstracts: population, education level, households, income, building permits, worker travel data, payroll.
- County-level transportation data for each state: road densities.
- County-level population estimates for each state. Most were based on the 1990 census; some states were updated more recently than others.
- USDA Natural Resource Inventory (NRI) data. Detailed estimates of land use change and components of change. 1982-1997.
- USDA, Forest Service FIA data for each state. The most recent inventory has estimates of previous land use for each plot. Also, published FIA statistical reports for previous inventories in each state provided additional historical information for certain land use categories.

Publications and other studies consulted

Banta, J.; Hood, E. 1989. Long-range planning: an evaluation of selected land use change 1967-1987. Internal memo of the Adirondack Park Agency.

Harper, S.C.; Falk, L.L.; Rankin, E. W. 1990. The northern forest lands study of New England and New York. Rutland, VT. USDA Forest Service. 206 p.

Levesque, C.; Berti, R.; Hahn, T. 1995. New Hampshire Forest Inventory Project: Timber Availability Analysis. Report to the New Hampshire Forest Inventory Project Steering Committee.

Mauldin, T.E.; Plantinga, A.J.; Alig, R.J. 1998. Determinants of Land Use in Maine with Projections to 2050. College of Forest Resources, Univ. Maine, Orono, ME. Pub.2282. 89 p.

Northern Forest Lands Council. 1994. Finding common ground: conserving the northern forest. Recommendations of the Northern Forest Lands Council.

Pelsue, N.H., Jr. 1985. Trends in rural land prices in Vermont, Part IV. Bull. 693, Burlington, VT: University of Vermont, Vermont Agricultural Experiment Station. 12 p.

SAL. 2000. Spatial modeling of past and future land use in Vermont towns. Preliminary report for the Orton Family Foundation, Woodstock, VT.

SPNHF. 1999. New Hampshire’s Changing Landscape: Population Growth, Land Use Conversion, and Resource Fragmentation in the Granite State. Society for the Protection of New Hampshire Forests. Concord, NH. 110 p.

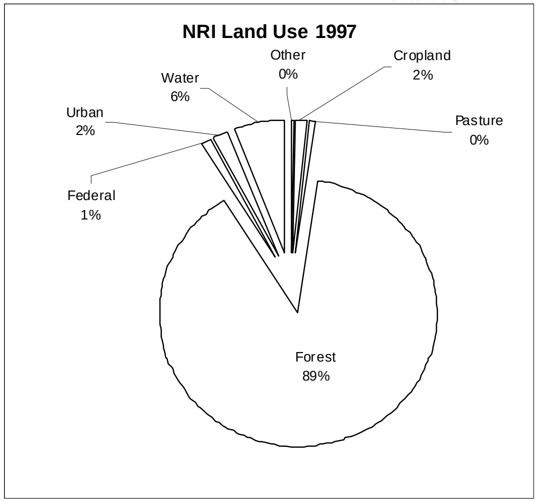
Stavins, R. N.; Plantinga, A.J.; Lubowkski, R.N. 1998. Land use change and carbon sinks: econometric estimation of the carbon sequestration supply function. Proposal for Ph. D. research project (research ongoing)

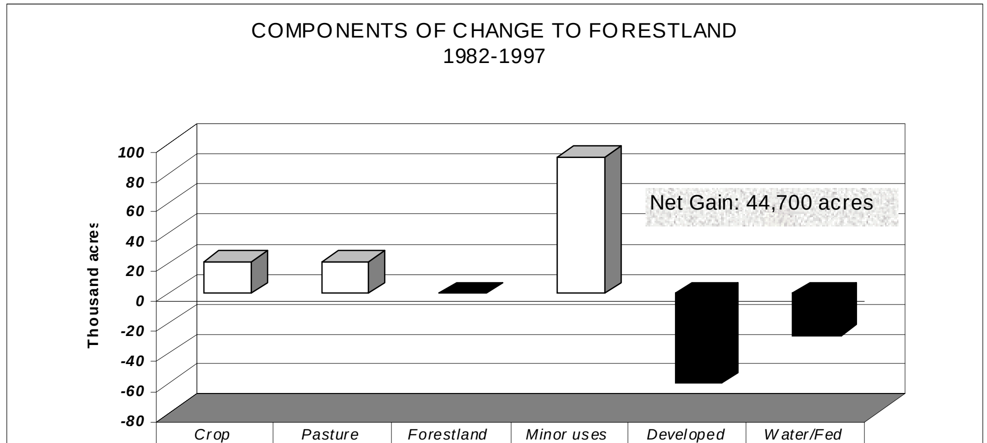
White, G.K.; Ribaudo, M.O. 1980. Factors affecting the value of Maine’s Rural Land. Bull. 767. Orono, ME: University of Maine, Maine Agricultural Experiment Station. 30 p.

Stavins, R. N.; Plantinga, A.J.; Lubowkski, R.N. 1998. Land use change and carbon sinks: econometric estimation of the carbon sequestration supply function. Proposal for Ph. D. research project at Harvard University (research ongoing).

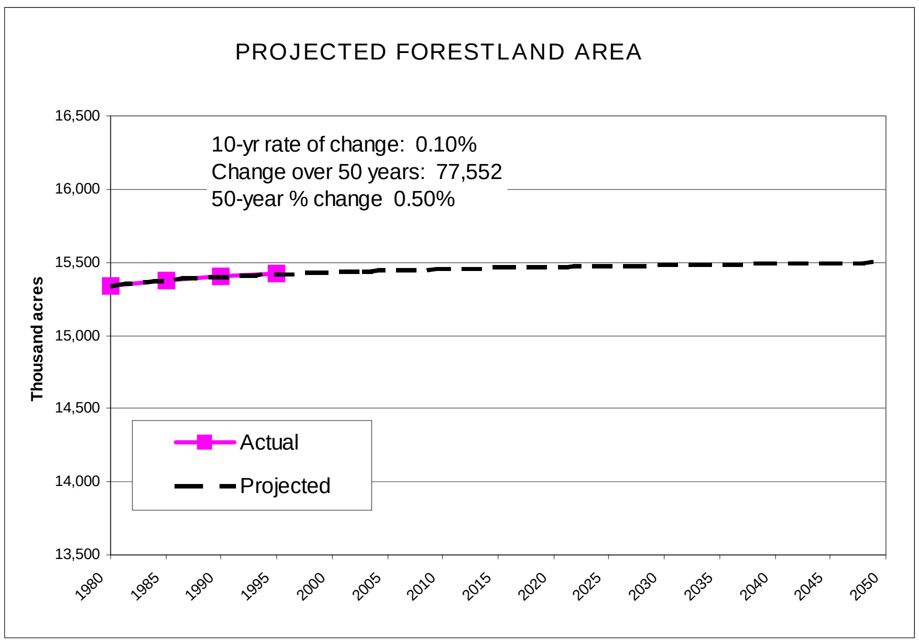
The following pages represent a summary of pertinent data and observations for each of the ten land use units in the study area. The projections shown are an attempt to capture recent trends, while considering the stocks of land available to become forestland and the forces likely to increase or decrease forest land. It should be noted that definitions of "forest land" differ among data sets, which makes direct comparisons difficult. The charts that follow include public land as forest land. The reader is further cautioned to pay attention to the y-axis scales on charts.

Maine North



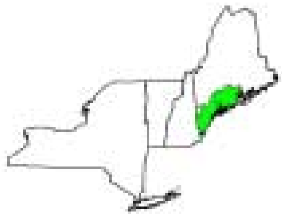


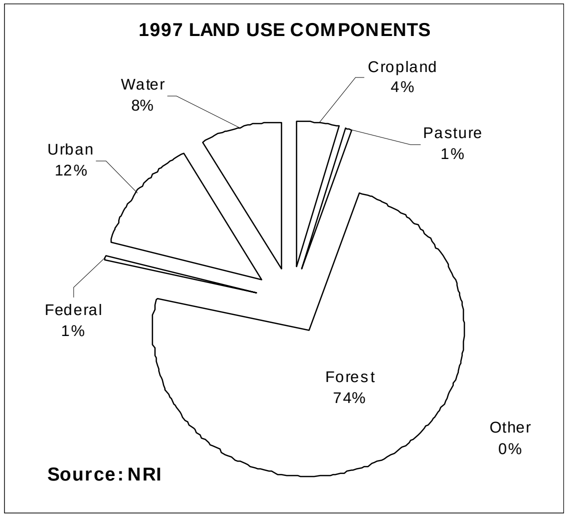
	Crop	Pasture	Forestland	Minor uses	Developed	Water/Fed
Forestland	20.7	20.8	0	91.6	-60.4	-28

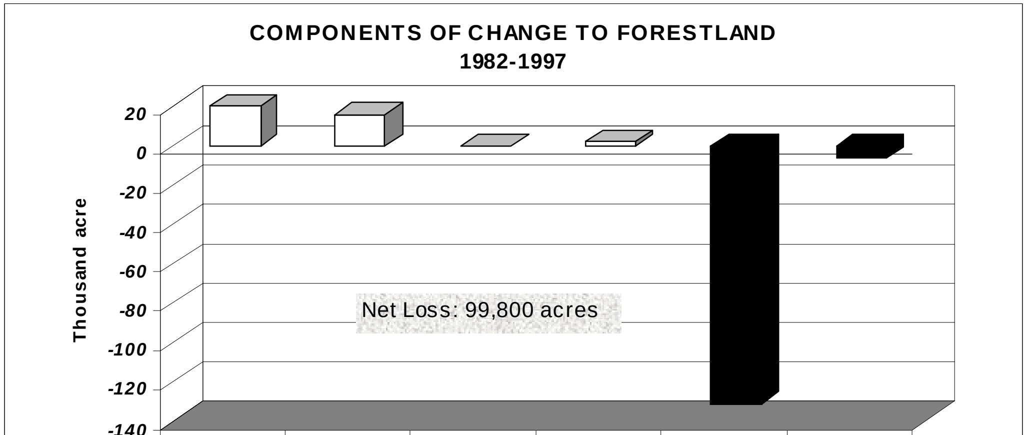


- Population increased 6% since 1960 and is expected to grow an additional 5% by 2010.
- Population density: 18 persons/sq. mi.– lowest in the study area
- Moderate decline in new building permits issued between 1991 and 1997.
- Among the lowest PCI for any unit in the study area, but with substantial growth in PCI since 1969.
- Significant increase in % of population with >= 4yrs of college: 22%, 1980-1990
- Including Federal lands brings the proportion of forestland to 90%
- Lowest road density.

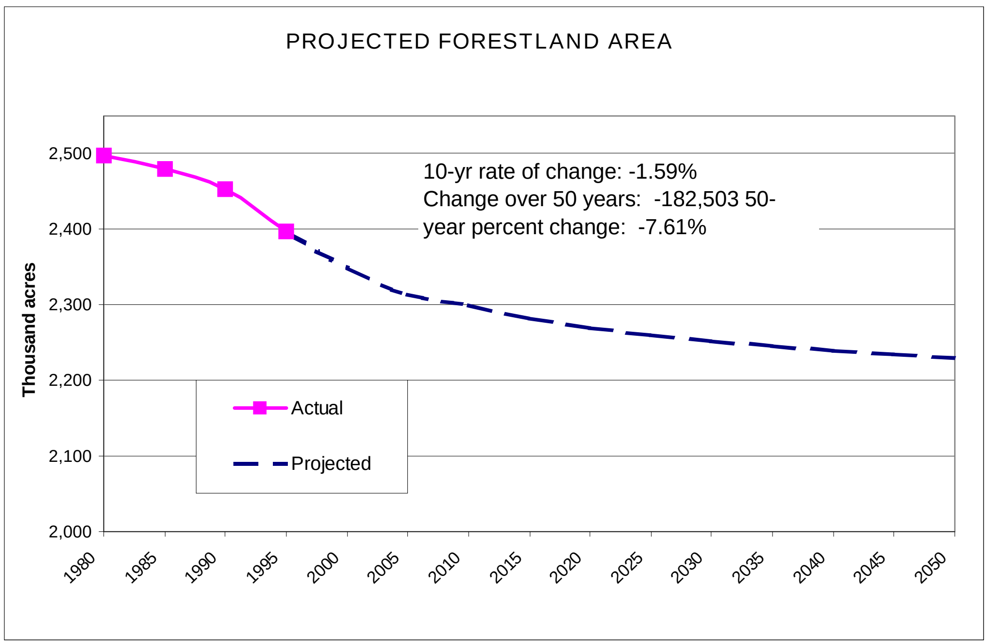
Maine South





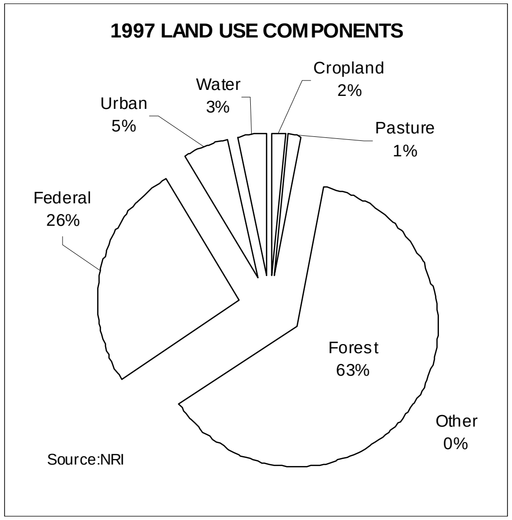


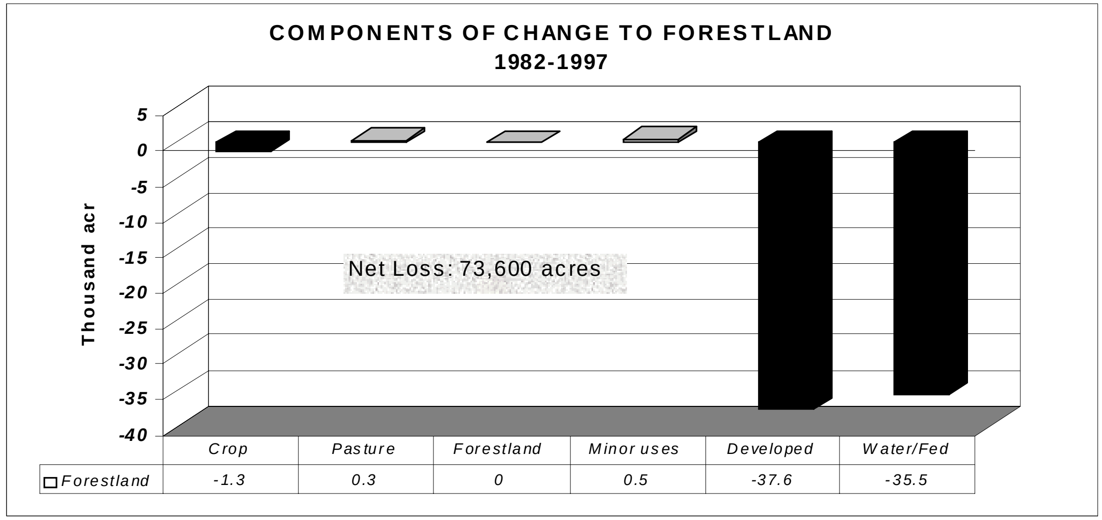
	Crop	Pasture	Forestland	Minor uses	Developed	Water/Fed
Forestland	19.6	16	0	1.8	-130.9	-6.3

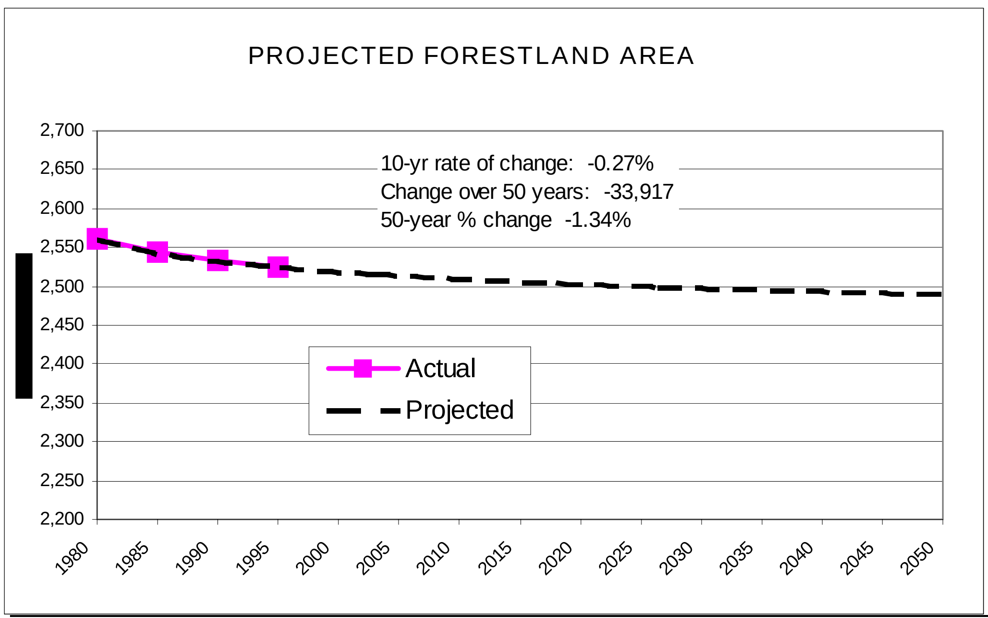


- Population increased 43% since 1960 and is expected to grow an additional 10% by 2010.
- Second highest population density among VT, NH, and ME units: 155
- $20,000 PCI (1994), 4th among VT, NH, ME units.
- Second highest road density among VT, NH, and ME units.
- Growth and prosperity cycles more tied to economic health of the regional economy and of Boston in particular.

New Hampshire North

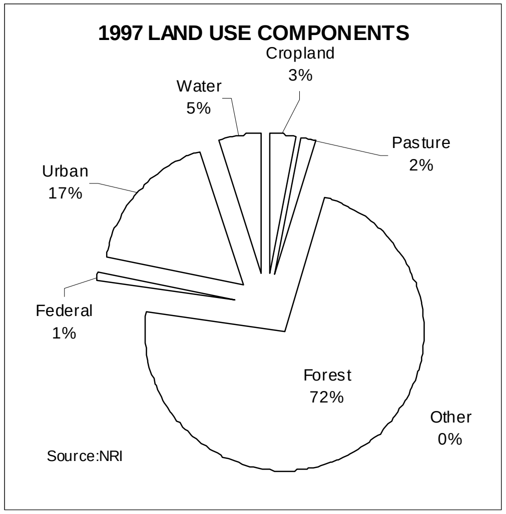


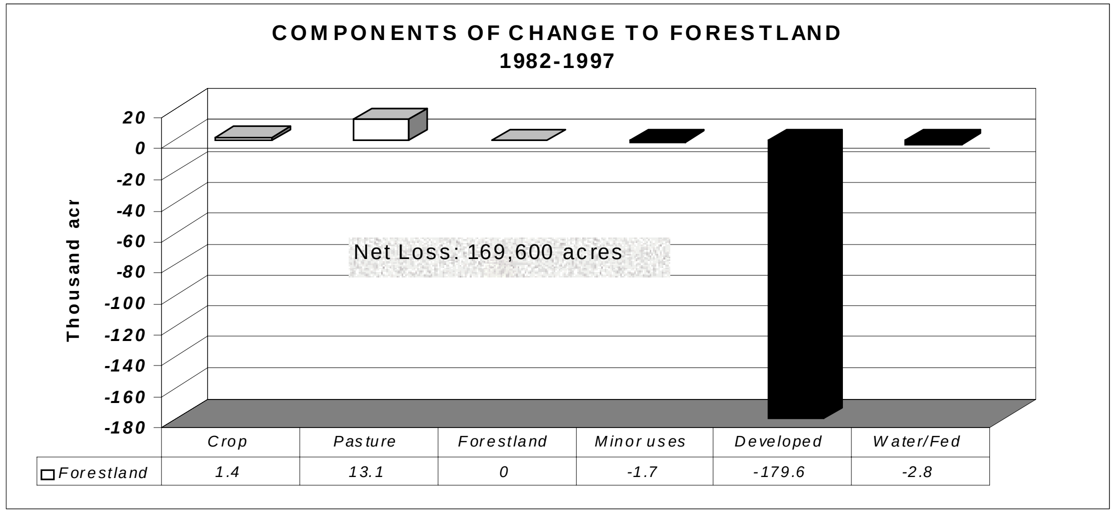


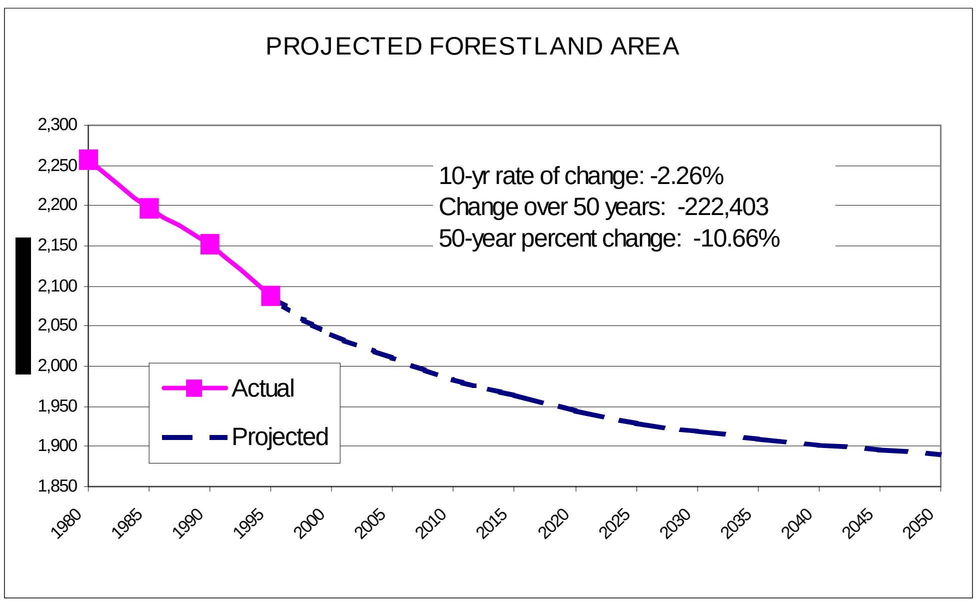


- Population increased 50% since 1960 and is expected to grow an additional 11% by 2010.
- Population density: 34 persons/sq. mi.
- Highest increase in new building permits issued between 1991 and 1997 (all study units)
- Recent TNC study predicts loss of 26,600 acres of forestland over the next 20 years.
- 5% of workers working at home (1990). Among the top tier in this category
- Contains the Lakes Region and good interstate access to metropolitan areas
- Highest growth in PCI (81%, ’84-’94) for any unit in the study area.
- Including Federal lands brings the proportion of forestland to 89%

New Hampshire South

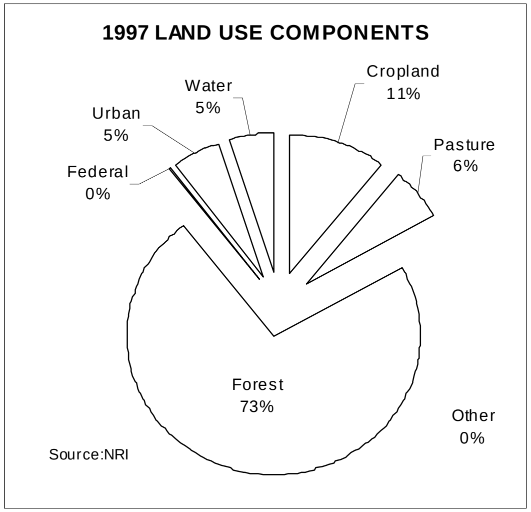


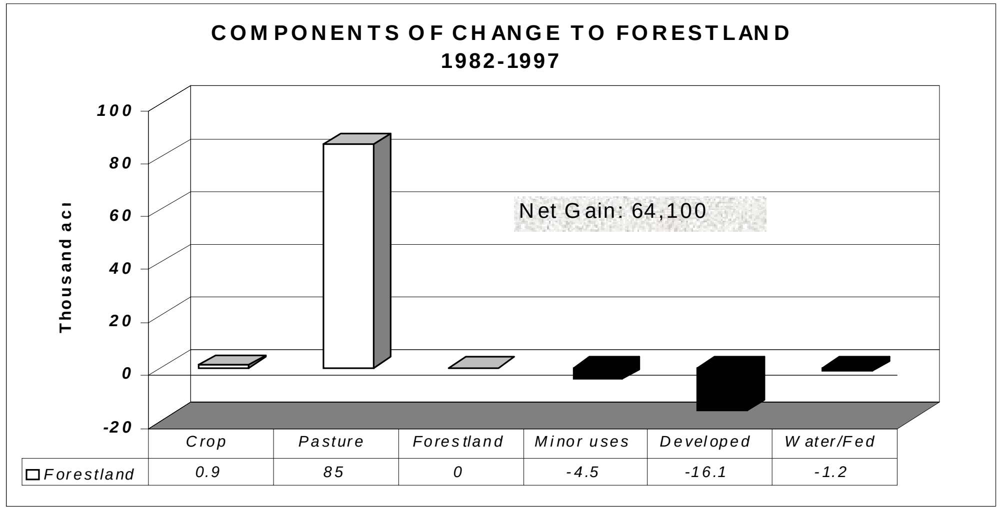


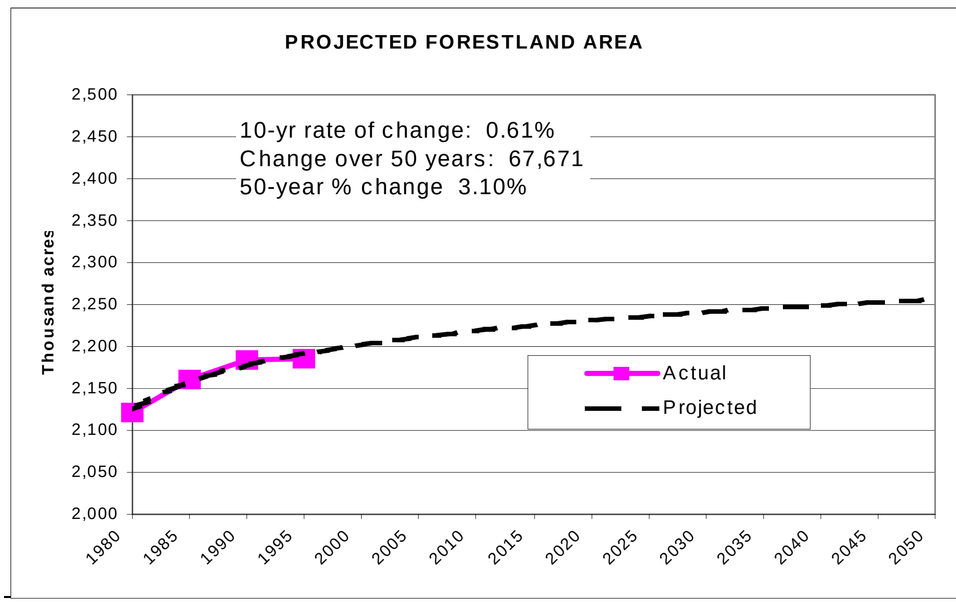


- Population doubled since 1960 and is expected to grow an additional 15% by 2010.
- Highest population density among VT, NH, and ME units: 228 p/sq mi..
- $23,000 PCI (1994) second only to the Catskill/Lower Hudson unit
- Highest road density among VT, NH, and ME units.
- Growth and prosperity cycles more tied to economic health of the regional economy and of Boston in particular.
- Recent TNC study predicts loss of 116,000 acres of forestland over the next 20 years.

Vermont North

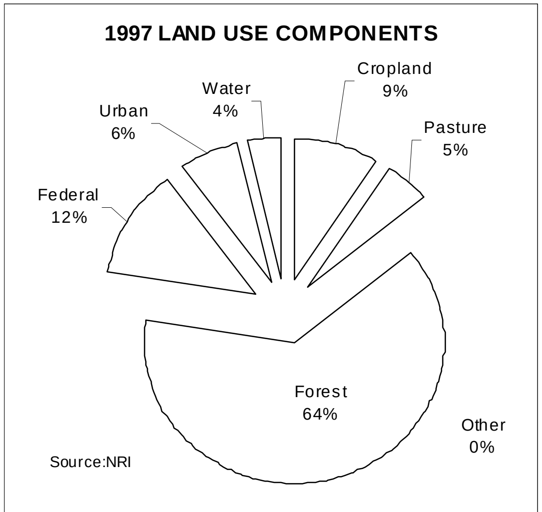


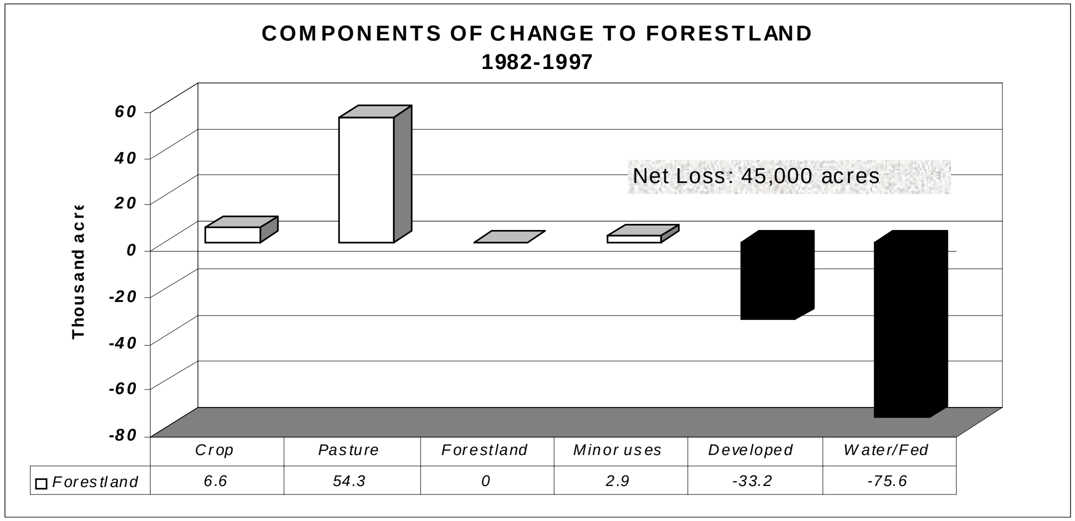


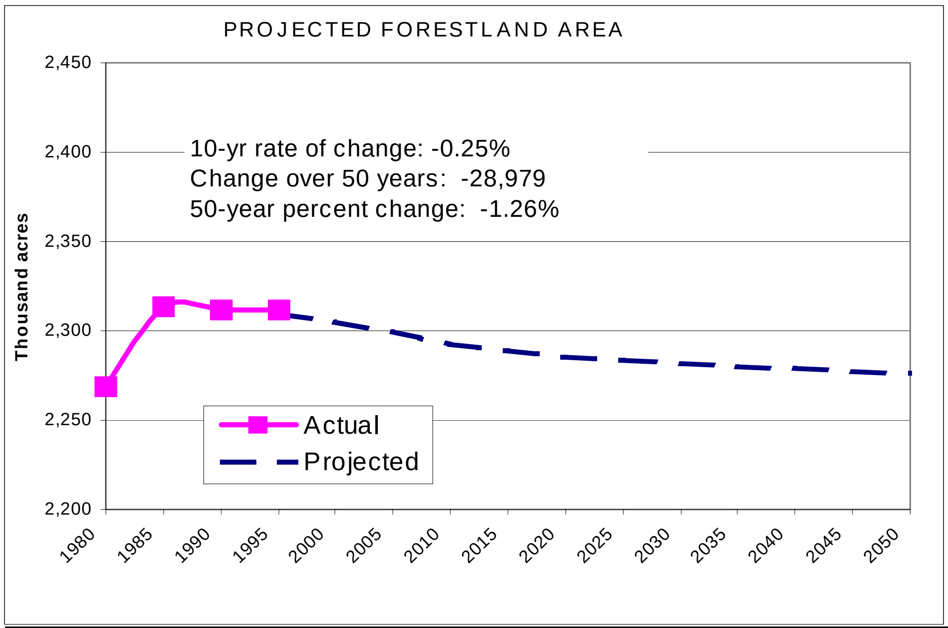


- Population increased 43% since 1960 and is expected to grow an additional 5% by 2010.
- Little change in building permit activity in ’91-’97.
- At 7.2% of workers working at home (1990), this is the highest of all study units in this category.
- Reasonably good interstate access to metropolitan areas. Easterly region is 4-5 hrs from Boston; westerly is 1-2 hrs to Montreal.
- Slightly below average growth in PCI on a below average base.
- Population density: 47 persons/sq.mi.

Vermont South

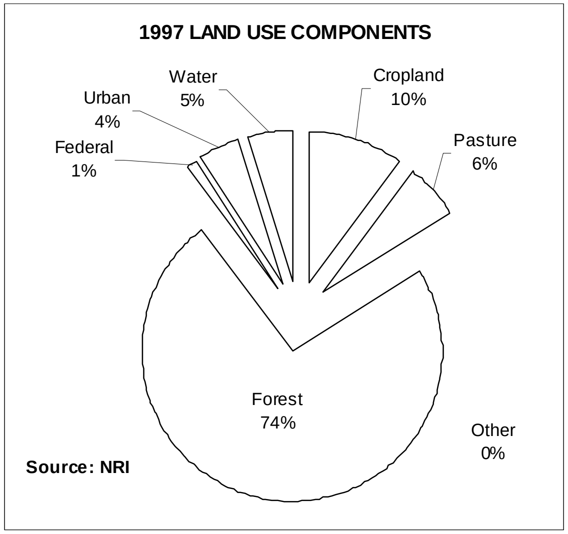


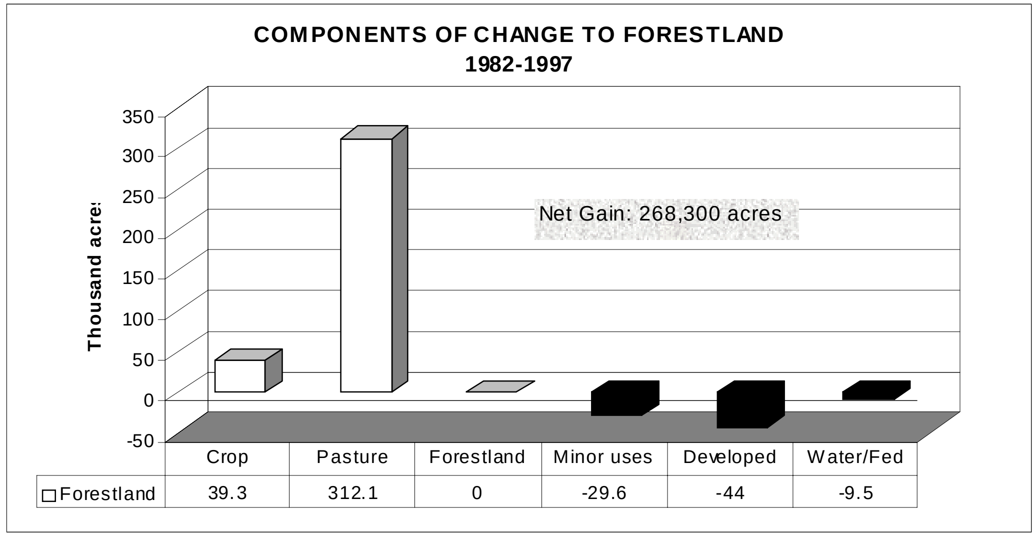




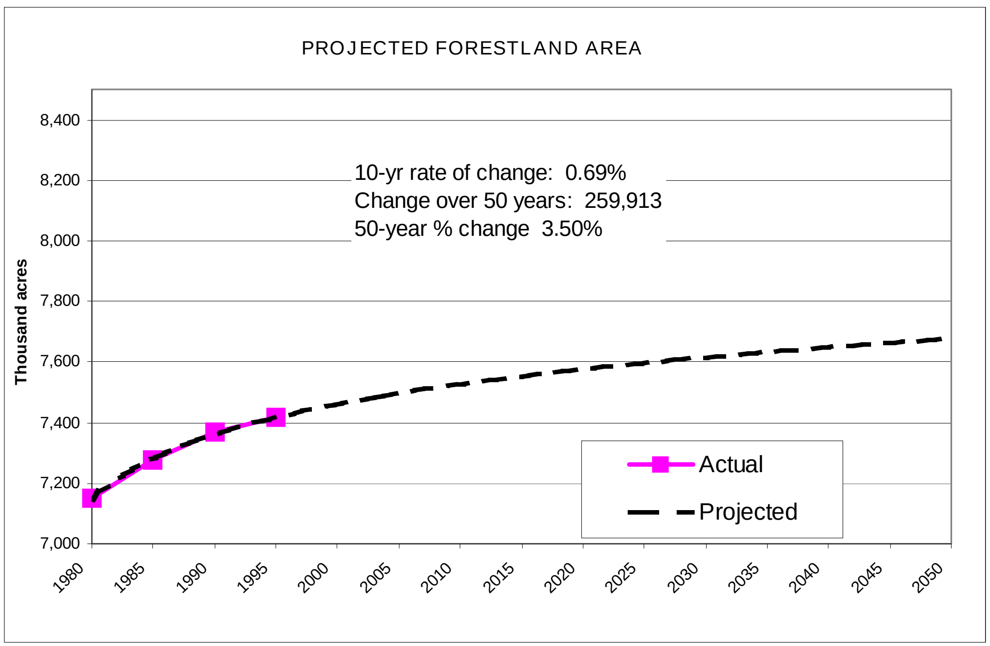
- Population increased 57% since 1960 and is expected to grow an additional 9% by 2010.
- Building permits declined by 16% between 1991 and 1997
- Good interstate access to metropolitan areas from eastern and western sections. Rail access to NYC.
- Slightly below average growth in PCI (‘90-’94) on an above average base.
- Population density: 80 persons/sq.mi. This is close to the median for the study area.
- Combining “forestland” and “Federal” results in 86% forested land use.

New York Adirondacks



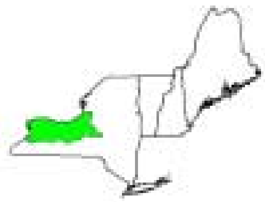


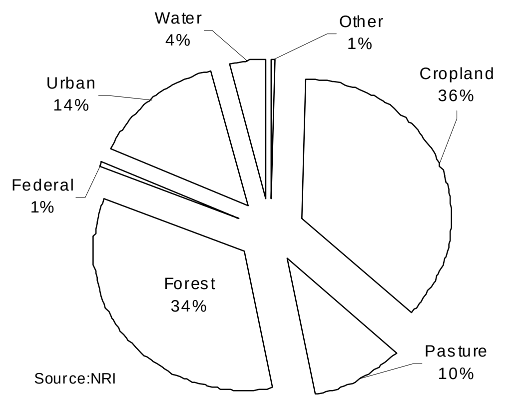
	Crop	Pasture	Forestland	Minor uses	Developed	Water/Fed
Forestland	39.3	312.1	0	-29.6	-44	-9.5

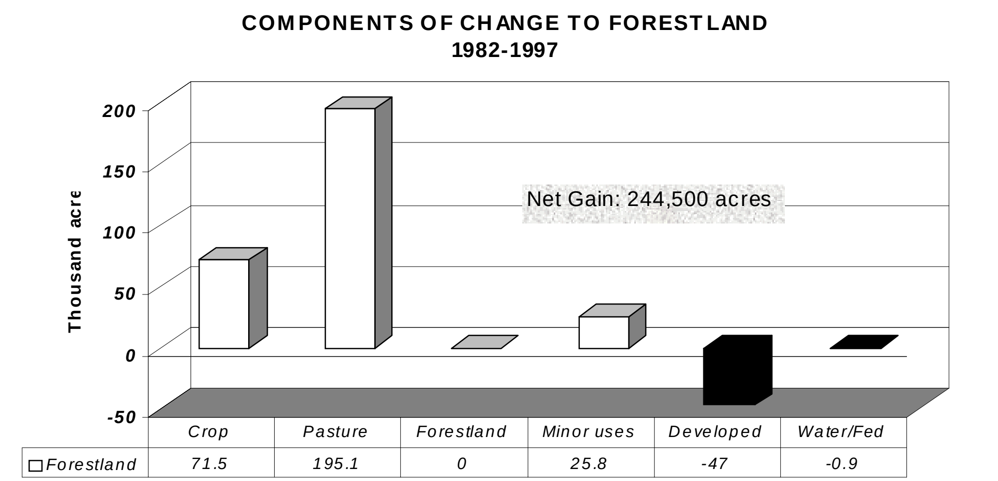


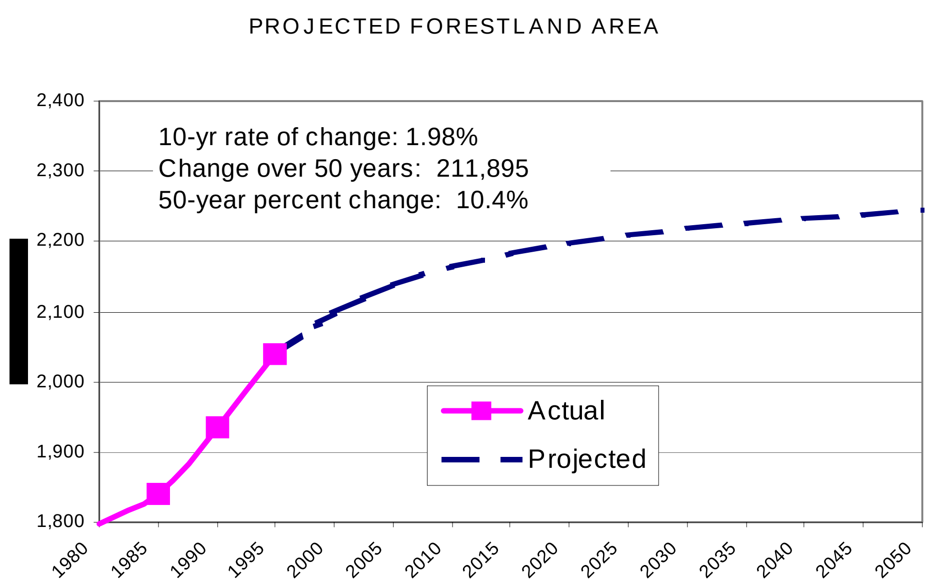
- Population increased 2% since 1960. Population projections for this region are dated and do not reflect actual population declines for all but the eastern Adirondack unit. Overall population will likely continue to decline slightly over the next 10 years.
- Population density: 53. Cities of Rome and Utica in southwestern region, Plattsburgh in the northeast.
- Average $18,000 PCI (1994), with above average increases ’89-’94. St. Lawrence/northern Adirondack unit has the lowest PCI in the study area.
- Substantial base of agricultural land available for conversion, especially in the St. Lawrence region.
- Low road densities; limited interstate access except along the eastern and southern perimeter. some areas.

New York Lake Plain



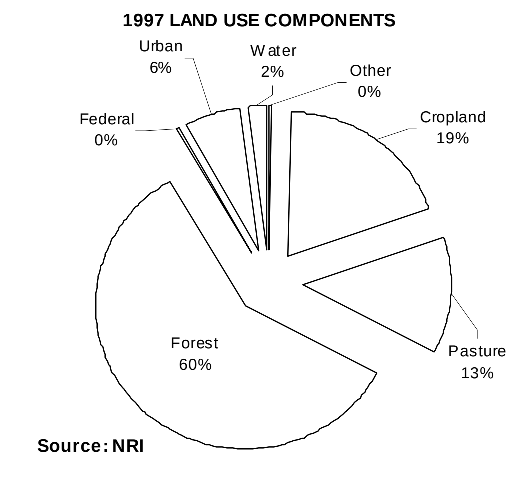


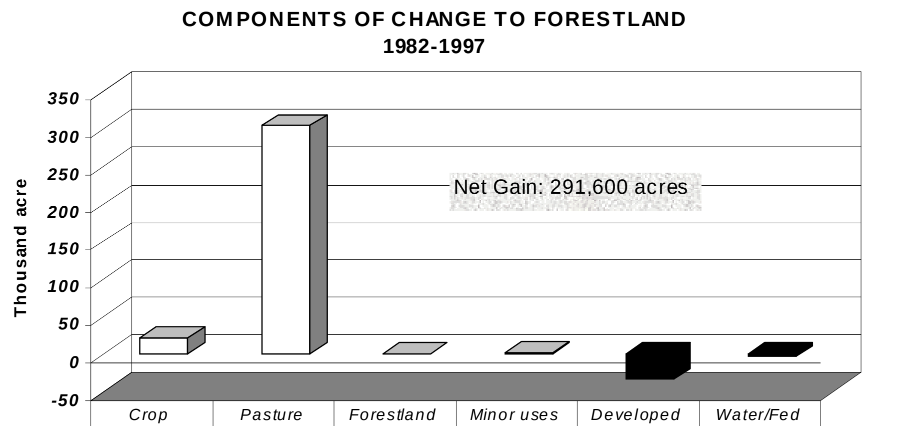




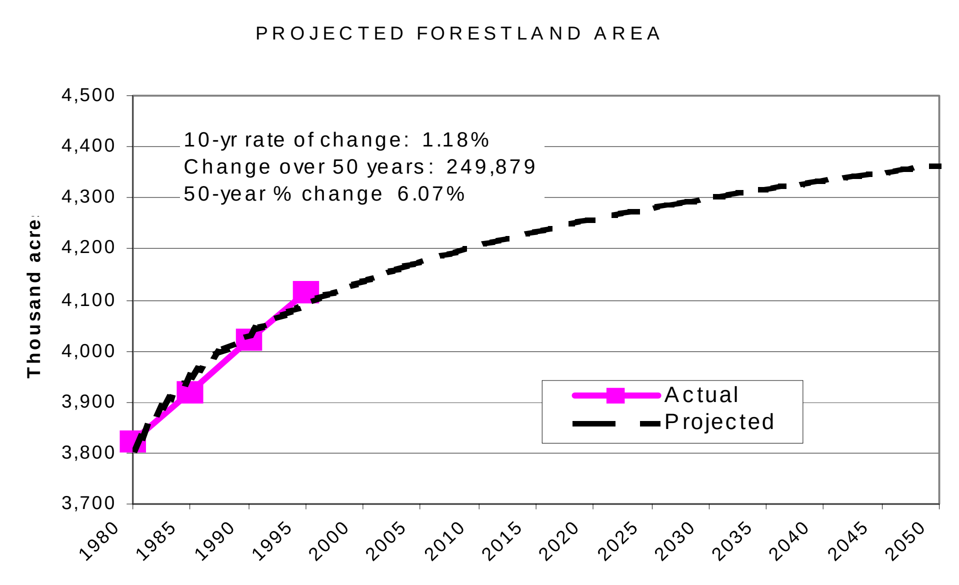
- Population increased 7% since 1960 and is expected to grow an additional 7% by 2010, mostly in the southwest..
- Population density: 328. High density due to the cities of Rochester and Buffalo.
- $21,000 PCI (1994), has seen moderate increases during '89-'94.
- Largest proportion of agricultural land of any unit in the study area. Declines in agricultural lands in the order of 15% since 1982.(493,000 acres)
- Second highest road density for any NY unit. Good interstate access, access to Canada, and Lake Ontario. Developed lands gained 177,000 acres between '82-97' (26%).

New York Southern Highlands



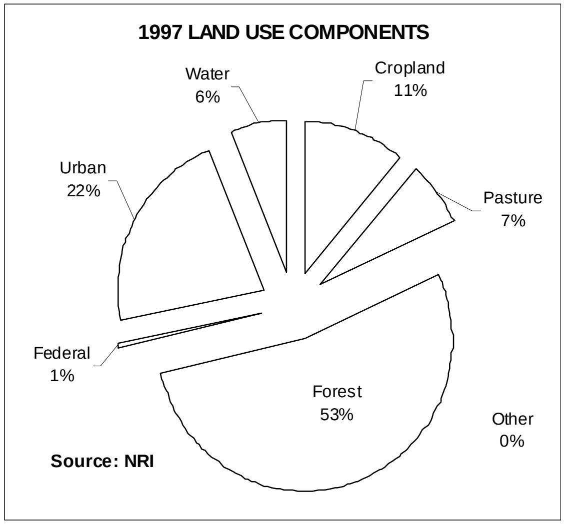


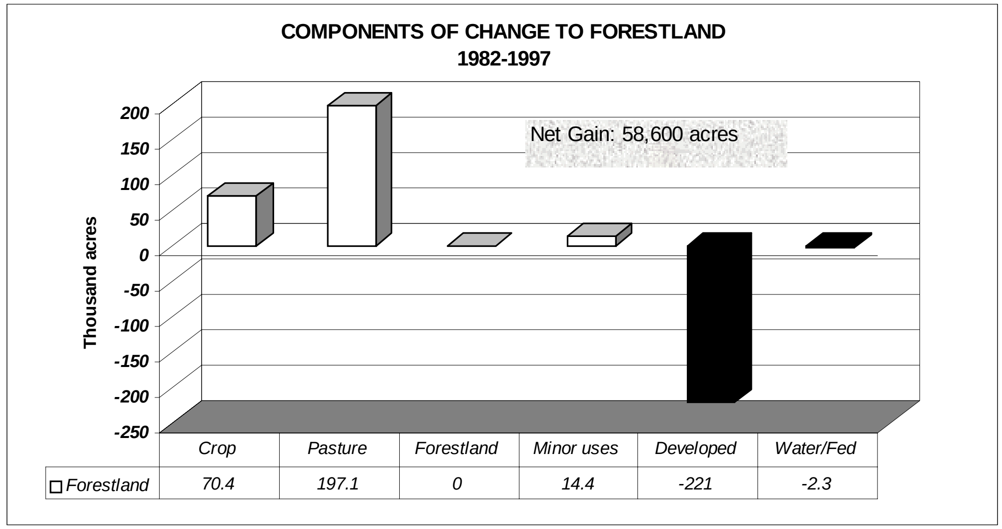
	Crop	Pasture	Forestland	Minor uses	Developed	Water/Fed
Forestland	22.3	304.3	0	2.4	-33.9	-3.5

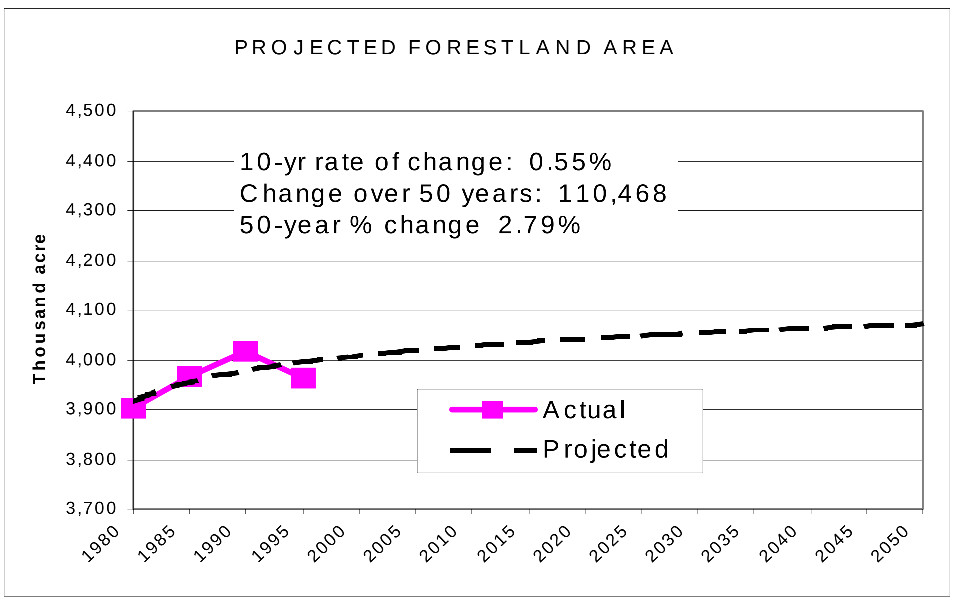


- Population increased 7% since 1960 and is expected to grow an additional 13% by 2010, mostly in the southwest..
- Population density: 88
- $18,000 PCI (1994), with above average increases '89-'94.
- Substantial base of agricultural land available for conversion.
- Moderate road densities; reasonable interstate access to some areas. Few large cities.

Southern New York







- This unit combines the Catskills/Lower Hudson (CLH) unit and the Capital Region (CR) unit.
- Population density: CLH: 1690, CR: 229. This unit includes the cities of Albany and all those of the lower Hudson basin.
- PCI: CLH: $28,466; CR: $22,315 both regions have seen the highest rate of increase during '89-'94: 23%
- Still substantial ag land in the Hudson valley, but also substantial declines in pasture and crop area since 1982 (CLH: -30%; CR: -18%)
- Highest road density for any NY unit. Good interstate access. Developed lands gained 346,000 acres between '82-97', mostly in the CLH unit.