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Abstract

This report summarizes the third cycle of annualized inventory of Pennsylvania with field data collected from 2009 through 2014. Pennsylvania has 16.9 million acres of forest land dominated by sawtimber stands of oak/hickory and maple/beech/birch forest-type groups. Volumes continue to increase as the forests age with an average of 2,244 cubic feet per acre on timberland. Sawtimber volume has risen 24 percent in 10 years to 115 billion board feet. Net growth outpaced removals by a ratio of 2.4:1 on timberland. Additional information on land-use change, fragmentation, ownership, forest composition, structure and age distribution, carbon stocks, regeneration, invasive plants, insect pests, and wood products is also presented. Sets of supplemental tables are available online at https://doi.org/10.2737/NRS-RB-111 and contain: 1) tables that summarize quality assurance and 2) a core set of tabular estimates for a variety of forest resources.

Acknowledgments

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Cover: Fall foliage as seen from High Knob overlook near Hillsgrove, Sullivan County.
Photo by Thomas Albright, U.S. Forest Service.

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Pennsylvania Forests 2014

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Foreword

Pennsylvania's 16.9 million acres of forests provide numerous ecological, economic, and social benefits and services. These forests are home to thousands of plant, mammal, bird, fish, reptile, amphibian, insect, and fungi species that are dependent on forest habitats. Pennsylvania forests support more than 2,100 forest product establishments employing approximately 58,000 residents that contribute an estimated $19 billion to the state's economy. In addition, forests provide for clean water, soil stabilization, and opportunities for healthful recreation.

An understanding of current conditions and how they are changing over time is of fundamental importance for sustaining the benefits and services provided by Pennsylvania forests. The report summarizes the latest statewide inventory of Pennsylvania forests and is the result of a cooperative effort between the U.S. Forest Service Forest Inventory and Analysis program and the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry.

This report highlights some encouraging trends for the future of Pennsylvania forests; it also raises concerns that require vigilant monitoring. Encouraging trends include a relatively stable forest land base, a slight increase in tree regeneration, and an increase in annual growth of tree volume. Issues of concern include a dearth of early successional forest habitat, shifts in species composition, an increase in invasive plant species, and the impacts of exotic pests such as emerald ash borer, gypsy moth, and hemlock woolly adelgid.

I hope that you can take some time to read and enjoy this report. Then, I hope that you spend some time in the forests of Pennsylvania with a greater understanding of the wonderful resource we call "Penn's Woods."

Daniel A. Devlin

Pennsylvania State Forester

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Online at https://doi.org/10.2737/NRS-RB-111

Quinn Run in Sullivan County. Photo by Thomas Albright, U.S. Forest Service.

Highlights

On the Plus Side

- The forested area of Pennsylvania remains stable, totaling an estimated 16.9 million acres.
- Sawtimber stands continue to increase in area, representing 67 percent of all timberland.
- The continuing increase in volume results in a total of 2,244 cubic feet per acre on timberland, a 250 percent increase from 1955.
- Timberland sawtimber volume increased 24 percent since 2004 to an estimated 115 billion board feet.
- The net growth-to-removals ratio increased to 2.4:1 overall on timberland.
- Small improvements in regeneration of commercially desirable species were observed.

Issues to Watch

- Development, both industrial and residential, continues to alter the character of Penn's Woods because of forest conversion and fragmentation.
- The area of young, early successional forest continues to decline. Only an estimated 1.5 million acres of timberland (9 percent) are in small diameter stands.
- Timberland continues to age. Stands over 80 years old accounted for 39 percent of all timberland area. Only 15 percent of timberland area is in stands 0 to 40 years old.
- Private landowners continue to control 70 percent of all forest land, but few owners have management plans or receive management advice. Less than 14 percent of the estimated 8.9 million acres owned by family forest owners are under management plans.
- Stocking levels on private timberland continued to shift toward the lower stocking classes. Widening disparities between stocking levels for all live trees and growing-stock trees may indicate a need for more programs to assist landowners with forest management.

- Regeneration remains a challenge. Nearly 20 percent of sample plots had high browse impacts, indicating that white-tailed deer are a factor in regeneration difficulties.
- Old and new insect pests threaten forest health. Gypsy moths have defoliated more than 3 million acres of Pennsylvania since 2000. Emerald ash borer and the hemlock woolly adelgid are having significant impacts on their hosts.
- Invasive plant species remain a concern, choking out native understories and altering habitat and food supplies for wildlife as well as inhibiting regeneration.

Background

Overlooking the Pine Creek Valley in Lycoming County. Photo by Thomas Albright, U.S. Forest Service.

An Overview of Forest Inventory

What is FIA?

The Forest Inventory and Analysis program, commonly referred to as FIA, is the Nation's forest census. It was established by the U.S. Congress to "make and keep current a comprehensive survey and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and range lands of the United States" (Forest and Rangeland Renewable Resources Planning Act of 1974; 16 USC 1601 [note]). FIA has been collecting, analyzing, and reporting on the Nation's forest resources for more than 80 years with the first FIA inventory of Pennsylvania forests completed in 1955. Information is collected on the status and trends of the extent, composition, structure, health, and ownership of the forests. This information is used by policy makers, resource managers, researchers, and the public to better understand forest resources and to make more informed decisions about their future.

What is this report?

This report is a summary of the findings from the seventh survey of the forest resources of Pennsylvania conducted by FIA. This report uses data from the third cycle of plot measurement using the annualized inventory of plots. Data for this survey were collected between 2009 and 2014, but throughout this report, we refer to 2014 as the inventory year. Previous periodic forest inventories of Pennsylvania were completed in 1955 (Ferguson 1958), 1965 (Ferguson 1968), 1978 (Considine and Powell 1980), and 1989 (Alerich 1993, Widmann 1995); full-cycle annualized reports were published for 2004 (McWilliams et al. 2007) and 2009 (McCaskill et al. 2013).

The results of the survey are divided into chapters that focus on forest features, forest health, and forest economics. See "Statistics and Quality Assurance for the Northern Research Station Forest Inventory and Analysis Program, 2016" (Gormanson et al. 2017), available at https://doi.org/10.2737/NRS-GTR-166, for details about data collection, estimation procedures, and statistical reliability. Definitions for FIA terms commonly found in the 5-year reports are available at http://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp. Supplemental tables summarizing the reported results can be found online at https://doi.org/10.2737/NRS-RB-111.

A Guide to Forest Inventory

What is a tree?

Trees are perennial woody plants with central stems and distinct crowns. FIA defines a tree as any perennial woody plant species that can attain a height of 15 feet at maturity. A complete list of the tree species measured in Pennsylvania during this inventory is included in the appendix. Throughout this report, the size of a tree is usually expressed as diameter at breast height (d.b.h.), in inches. This is the diameter, outside the bark, at a point 4.5 feet above the ground.

What is a forest?

A forest is a collection of trees and most people would agree on what a forest is. But in order for statistics to be reliable and comparable, a definition must be created to avoid ambiguity.

FIA defines forest land as land that is at least 10 percent stocked with trees of any size or land formerly having had such tree cover and not currently developed for nonforest use. Generally, the minimum area for classification as a forest is 1 acre in size and at least 120 feet in width. There are more specific criteria for defining forest land near streams, rights-of-way, and shelterbelt strips (U.S. Forest Service 2012).

What is the difference between timberland, reserved forest land, and other forest land?

FIA classifies the forest land into three categories:

Timberland—forest land that is producing or is capable of producing crops of industrial wood and is not withdrawn from timber utilization by statute or administrative regulation. These areas are capable of producing at least 20 cubic feet of industrial wood per acre (equivalent to the solid wood content of about ¼ cord) per year. Inaccessible and inoperable areas can be included.

Reserved forest land is all forest land withdrawn from timber utilization through statute without regard to productive status (e.g., state parks, natural areas, national parks, and Federal wilderness areas). All reserved forest land is in public ownerships.

Other forest land consists of forest land that is not capable of growing 20 cubic feet per acre per year and is not restricted from harvesting (e.g., some surface-mined areas with extremely degraded soil and some poorly drained areas where water inhibits tree growth). Sometimes such forest lands are referred to as being “less productive” or “unproductive” with respect to wood fiber production.

Since 2000, the annual inventory design has allowed for reporting volumes on all forest land in Pennsylvania. As a result, there is now one set of remeasured plots across all forest land with associated estimates of growth, removals, and mortality. Before the 2000-2004 inventory cycle (referred to as the 2004 inventory) in Pennsylvania, for most attributes, FIA included only data collected on timberland plots. Therefore, trend analyses that use data prior to 2000 are limited to timberland for many attributes.

A word of caution on suitability and availability…

FIA does not attempt to identify those lands suitable or available for timber harvesting, particularly since such suitability and availability is subject to changing laws, economic and market constraints, physical conditions, adjacency to human populations, and ownership objectives. The classification of land as timberland does not necessarily mean it is suitable or available for timber production. Forest inventory data alone are inadequate for determining the area of forest land available for timber production. Additional factors, such as those listed, need to be considered when estimating the timber base, and these factors may change over time.

How do we estimate a tree's volume?

To estimate a live tree's volume, FIA uses volume equations developed for each tree species group found within the northeastern United States. Individual tree volumes are based on species, diameter, and height. FIA reports volume in cubic feet and board feet (International ¼-inch rule). Board-foot volume measurements are applicable only for sawtimber-size trees. In Pennsylvania, wood often is measured in cords (a stack of wood 8 feet long by 4 feet wide and 4 feet high). A cord of wood consists of about 79 to 85 cubic feet of solid wood, and the remaining 43 to 49 cubic feet are bark and air.

How is forest biomass estimated?

The U.S. Forest Service has developed estimates of specific gravity for many tree species (U.S. Forest Service 1999). These specific gravities are applied to estimates of tree volume to estimate the biomass of merchantable trees (weight of the bole). Regression models are used to estimate the biomass of stumps (Raile 1982), limbs, and bark (Hahn 1984), and belowground stump and coarse roots (Jenkins et al. 2004). Currently, FIA does not report the biomass of foliage. FIA can report biomass as green or oven-dry weight. Green weight is the weight of a freshly cut tree. Oven-dry weight is the weight of a tree with no moisture content; oven-dry weight is used to report biomass in this report. On average, 1.9 tons (2,000 pounds/ton) of green biomass equals 1 ton of oven-dry biomass.

How do we estimate all the forest carbon pools?

FIA does not directly measure the carbon in standing trees; it estimates forest carbon pools by assuming that half the biomass in standing live and dead trees consists of carbon. Additional carbon pools (e.g., soil, understory vegetation, belowground biomass) are modeled based on stand and site characteristics (e.g., stand age and forest type).

Regional analysis

Throughout this report, references are made to regions of Pennsylvania. These ecopolitical regions (Fig. 1) reflect the diverse landscape of the State to facilitate meaningful analysis on a more local scale.

Forest inventory sample design

FIA has established a set of permanent inventory plots across the United States that are periodically revisited. Each plot consists of four 24-foot radius subplots for a total area of about one-sixth of an acre. All plots (i.e., forested and nonforest) are randomly located within a hexagon that is about 6,000 acres in size. Therefore, each plot represents about 6,000 acres of land and can be used to generate unbiased estimates and associated sampling errors for attributes such as total forest land area. Full details of sample design and estimation procedures are available in Bechtold and Patterson (2005).

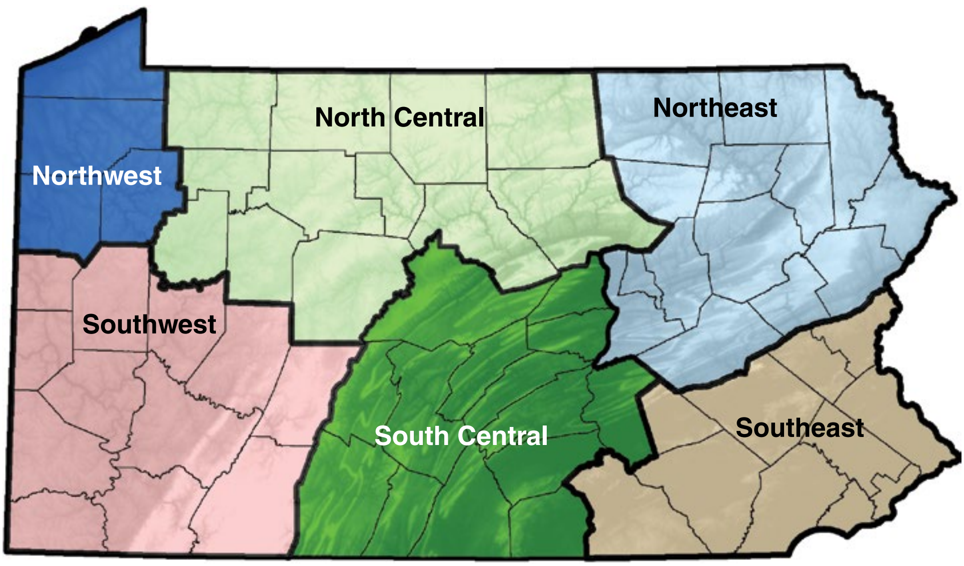

Figure 1.—Ecopolitical regions of Pennsylvania.

Projection: Pennsylvania State Plane North, NAD83. Source: U.S. Forest Service, Forest Inventory and Analysis program, 2009. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: T. Albright, U.S. Forest Service, March 2016.

Understanding FIA data

Before 2000, FIA inventories were completed every 10 to 20 years. With these periodic inventories, it took decades to identify trends. With the new annual inventory, some trends are easier to identify because a subset of observations (about 20 percent) are made every year. It is still necessary to look over long time periods because many trends such as forest succession can be difficult to discern in short timespans. Definitions, methods, location, ownership, precision, scale, and temporal trends are important factors to consider when analyzing FIA data. Estimates are derived from sample plots throughout a state. Larger geographic areas will contain more plots and thus produce more reliable estimates. For example, there usually are not enough plots within a county or single forest type from which to derive reliable estimates. It is also important to consider the degree to which a variable can be measured precisely. For instance, a stand variable, such as age, is not as precise as forest type; and a tree variable, such as crown dieback, is not as precise as diameter. Location and ownership are similarly important considerations when analyzing the status and trends of forests. Forest resources vary by geographic unit and owner group.

Some definitions and procedures have changed between inventories. Because of these changes, some comparisons and estimates should be made with caution. A glossary of FIA terms commonly found in the 5-year reports is available at http://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp.

As previously stated, the annual inventory measures a subset of observations (about 20 percent) every year. After 5 years of data collection, an analysis is completed and a report created based on the full set, or "cycle" of plots. This creates a yearly moving window of 5-year cycles. The last year of each full cycle is used to identify the full set of plots. For example, the cycle of plots measured from 2009 through 2014 are collectively labeled the 2014 inventory and were used to produce this 2014 report. The 2004 inventory was the first annual inventory to include the complete cycle of annual inventory plots (McWilliams et al. 2007) and the 2009 inventory was the first annual inventory to include a complete remeasurement of plots (McCaskill et al. 2013). This report for 2014 encompasses the second complete remeasurement of plots.

In Pennsylvania, 5,010 plot locations were selected for measurement during the 2014 inventory cycle. Of these, 3,023 contained forest land, 1,516 were nonforest, and 471 were not sampled due to access constraints. All estimates of current forest area, composition, volume, and other forest statistics are based on the 4,539 sampled plots. Estimates of change (e.g., change in forest area, growth, mortality, and removals) are based on the 4,207 plots sampled during both the 2009 and 2014 cycles.

To improve the consistency, efficiency, and reliability of the inventory, procedures and definitions have been updated over time. Major changes occurred with the annual inventory begun in 1999. For the sake of consistency, a new, national plot design was implemented by FIA units throughout the United States in 1999. See "Statistics and Quality Assurance for the Northern Research Station Forest Inventory and Analysis Program, 2016" (Gormanson et al. 2017), available at https://doi.org/10.2737/NRS-GTR-166, for more information on sampling, sources of error, and determining statistically significant differences between estimates. Estimates for the 2014 inventory use the most recent updated protocols.

What is P2+?

In 2012 Northern Research Station FIA began implementation of the Phase 2 Plus (P2+) protocol. This 12.5 percent subset of all plots is sampled during the leaf-on portion of the field season (May through September). The suite of additional measurements consists of an advanced tree seedling regeneration (ATSR) survey, vegetation profile (Veg), invasive plant species (Invasives) survey, down woody materials (DWM) tally, and additional tree crown variables (Crowns). Half of P2+ plots (6.25 percent of all plots) are selected for soils measurements during the summer window. In Pennsylvania, state-agency funding provides for a doubling of the sample for ATSR, Veg, and Invasives, maintaining historical sampling intensity and providing consistency with historical estimates of regeneration, vegetation, and invasive plants.

What is the National Woodland Owner Survey?

The National Woodland Owner survey is conducted periodically by the Forest Service (NWOS; http://www.fia.fs.fed.us/nwos). It is aimed at increasing our understanding of woodland owners, who are the critical link between forests and society (Butler et al. 2016). The most recent survey was conducted from 2011 through 2013. Questionnaires were mailed to individuals and private groups who own the woodlands where FIA has an established inventory plot. Results from Pennsylvania, included in this report, are based on 214 responses from family forest owners in the most recent survey (Butler et al. 2016).

Where can I find additional information?

Detailed information on forest inventory methods, data quality estimates, and important resource statistics can be found in Gormanson et al. (2017), available at https://doi.org/10.2737/NRS-GTR-166. Tables that summarize quality assurance, as well as a core set of tabular estimates for a variety of forest resources, are available in

Microsoft® Excel format at https://doi.org/10.2737/NRS-RB-111. Most data used in this report can be downloaded from the FIA Web site (http://www.nrs.fs.fed.us/fia) and are also accessible using the Web tools for Forest Inventory Data Online (FIDO) and EVALIDator (Miles 2015). These tools allow public access to all FIA databases. This enables anyone to generate tables and maps of forest statistics through a Web browser without having to understand the underlying data structures. These programs are available at http://www.fia.fs.fed.us/tools-data/. Some graphs and tables in the printed portion of this report show only a sample of the prominent categories and values available for summarizing data. More categories may be found in online summary tables and custom tables created with FIDO and EVALIDator. Definitions of tables and fields are available in the database users manual (Woudenberg et al. 2010). Other FIA maps and tables for Pennsylvania's forest inventories are available at http://www.nrs.fs.fed.us/fia.

Forest Features

Mountaintop natural gas well pad in Lycoming County. Photo by Thomas Albright, U.S. Forest Service.

Area and Land Use

Background

Demand for residential and commercial development places increased pressure on forest ecosystems, which provide habitat for forest-dwelling species, protect water and soil quality, mitigate air pollution, sequester carbon, and offer a wide range of economic and other benefits. The northeastern United States experienced a period of rapid growth in the 1990s, which raised a great concern about the effects of increased urban pressures on forest resources. Some areas in this region experienced significant forest loss and forest fragmentation due to land-use change as population and urban development increased. Current census data, however, suggest that the southern and western regions of the United States are now experiencing relatively more population growth and urban development than the Northeast. Between 2010 and 2015, Pennsylvania's population increased only an estimated 0.8 percent compared to the 4.1 percent national average. This modest growth may indicate there is less pressure from urban development and less risk of permanent forest loss due to land-use change.

Forest land area in Pennsylvania remained relatively stable between 2009 and 2014; however, some areas of the State experienced forest loss, while other areas saw increases in forest land. To better understand Pennsylvania's forest land dynamics, it is important to explore underlying land-use changes. FIA characterizes the areas of the State using several use categories which are generalized to the following classes: forest, agriculture (including pasture and cropland), developed land (including residential and commercial areas, and rights-of-way), water, and other nonforest land. Estimates for land use are produced from all measured plots in an inventory cycle. Land-use change is analyzed by comparing the land use on current inventory plots with land uses recorded for the same location during the previous inventory. Understanding land-use change dynamics helps land managers make informed policy decisions.

What we found

An estimated 16.9 million acres of Pennsylvania was classified as forest land in 2014 (Fig. 2). This represents about 58 percent of the total area of the State. The overwhelming majority of forest land (16.3 million acres) was also considered timberland, that is, land meeting minimum productivity standards that is not reserved from harvesting by statute (Table 1). The 16.9 million acre estimate represents a continuation of a trend observed in 2004 of about 1 percent increases in forest land during each 5-year period. Forest land has remained fairly stable since the 1960s; the estimate for forest land peaked at 17.0 million acres in 1965 (Fig. 3). Historical estimates of forest land area are available from FIA reports (Alerich et

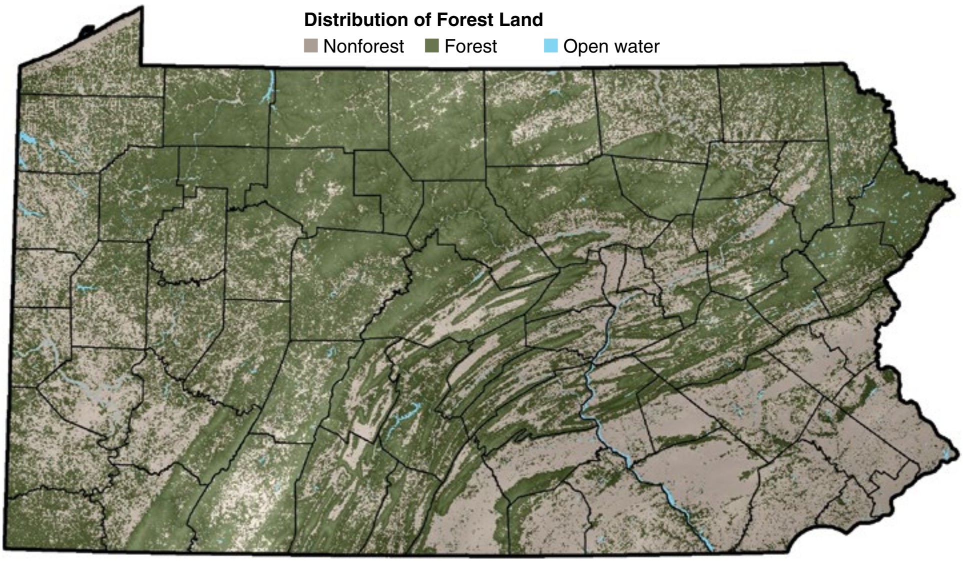

Figure 2.—Distribution of forest land, Pennsylvania, 2009.

Projection: Pennsylvania State Plane North, NAD83. Sources: U.S. Forest Service, Forest Inventory and Analysis program, 2009; National Land Cover Database 2011. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/. Cartography: T. Albright, U.S. Forest Service, March 2016.

Table 1.—Area of forest land (acres) by land class, Pennsylvania

Forest land class	2004	2009	2014
Timberland	15,951,811	16,122,058	16,325,199
Reserved forest land	522,102	542,788	566,987
Other forest land	99,072	74,349	23,999
Total forest land	16,572,981	16,739,199	16,916,190

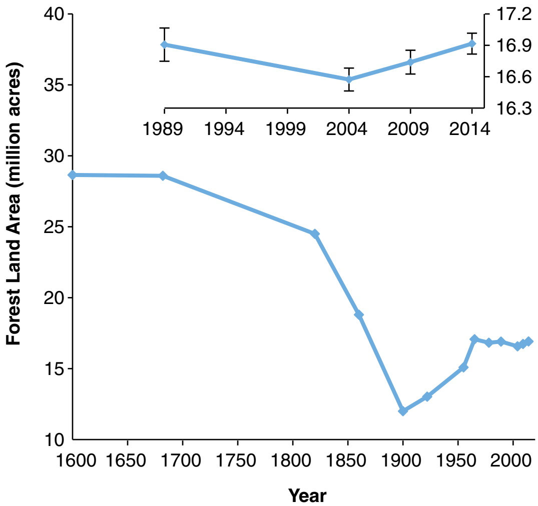

Figure 3.—Historical estimates of forest land area, Pennsylvania. Error bars represent a 68 confidence interval around the estimated mean.

al. 1993; Considine and Powell 1980; Ferguson 1958, 1968; McCaskill et al. 2013; McWilliams et al. 2007) and Illick (1923).

Relative to the total area of the State, there was little land-use change in Pennsylvania from the 2009 inventory to the 2014 inventory. Most of the State either remained forested or stayed nonforest (57 and 41 percent, respectively; Fig. 4). Pennsylvania lost 321,000 acres of forest land and gained 399,000 acres from 2009 to 2014, resulting in a slight net gain in forest land area (Fig. 5). The majority (48 percent) of the gross forest loss is from forest land converting to developed land, specifically commercial and residential development (Fig. 5A).

FIA data can be used to characterize the forest land lost and gained to see if it differs from forest land that remained forested. Pennsylvania forests are dominated by stands in the large (68 percent) and medium (23 percent) diameter size classes. Only 10 percent of forest area is in small diameter and nonstocked stands. The forest area lost had 52 percent of its area in small diameter and nonstocked stands and the forest land gained had 46 percent in small diameter and nonstocked stands. Lands moving to forest land classification are generally in early successional development, and these gains are typically attributed to changes in agricultural use representing true reversions to forest land. Forty-eight percent of the forest area lost was from large and medium diameter stands. These losses generally represent lands converted to a nonforest land use. However, 54 percent of the land representing forest gain was in large and medium diameter size classes. These "new" forest lands result from small changes in use, making previously unqualified areas meet FIA's forest size requirements. Forest that was lost or gained was also more likely to be in private ownership.

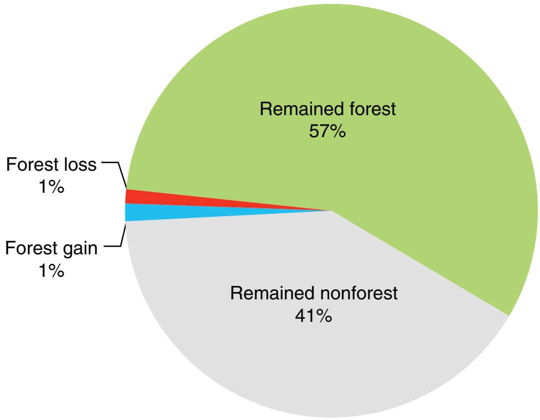

Figure 4.—Change dynamics showing proportion of unchanged area, forest loss, and forest gain, Pennsylvania, 2009 to 2014.

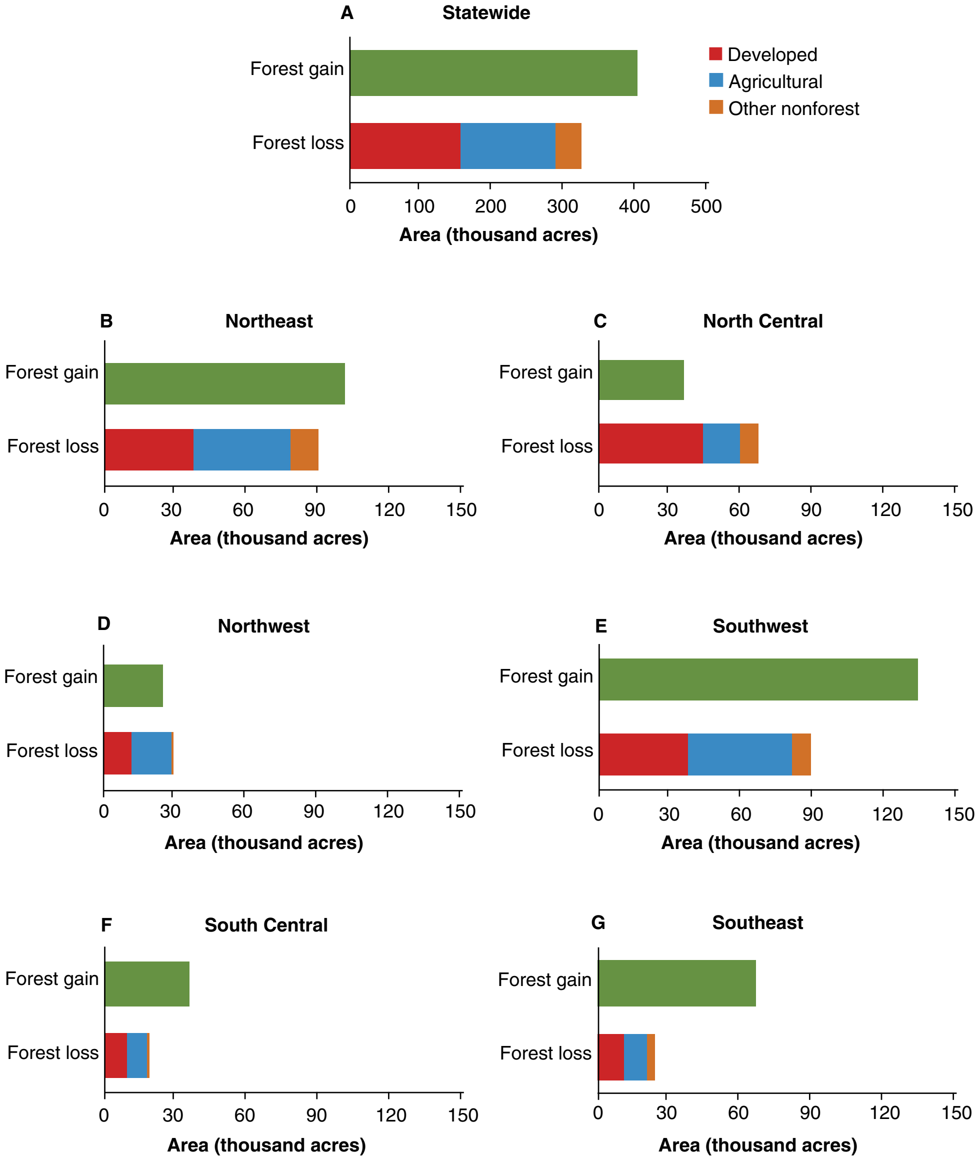

Figure 5.—Gross forest loss and forest gain by land-use category for the State (A) and regions (B-G), Pennsylvania, 2009 to 2014.

Estimates of forest loss and gain varied by Pennsylvania region (Fig. 5 B-G). Gains in forest land were greater than losses in nearly all regions with the exception of the Northwest and North Central regions. Net loss of forest land was greatest in the North Central region, but this is also the largest and most forested region of Pennsylvania, so the amount of forest land lost (32,000 acres) was small relative to the total amount of forest land and resulted in only a 0.6 percent decrease. Most of the forest land lost was converted to developed uses (67 percent) (Fig. 5C), including activities associated with Marcellus shale development (Fig. 6).

The greatest net gain in forest land area was in the Southeast region, where there was a 5 percent increase in forest area (Fig. 5G). The Southwest region experienced the greatest fluctuation in forest area with the highest gross gains and losses of any region. In this region, loss of forest land area totaled more than 91,000 acres, but was offset by forest gains of 132,000 acres (Fig. 5B).

Persistent forest land is concentrated primarily in central Pennsylvania (Fig. 7). There appears to be a cluster of forest gain plots, on which 10 percent or more of the area has gained forest land, in the Southeast region of the State near the Philadelphia suburbs. This result is consistent with the net increases in forest land area observed in the summary for this region.

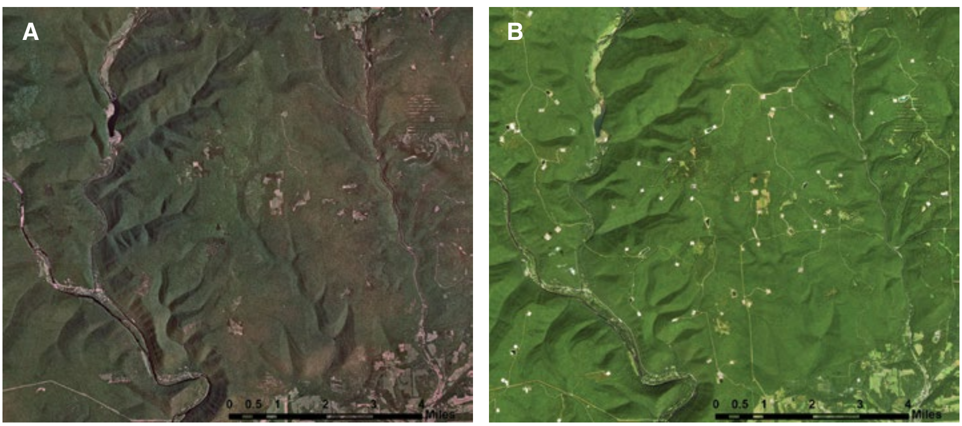

Figure 6.—Land-use change due to Marcellus shale development, Lycoming County, Pennsylvania, 2006 (A) and 2015 (B).

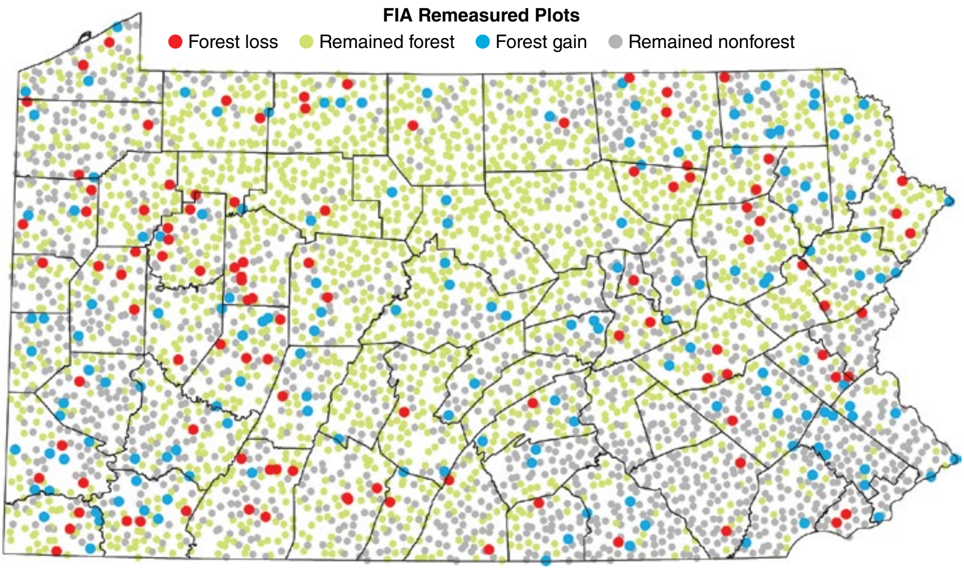

Figure 7.—Distribution of remeasurement inventory plots showing forest gains and losses, Pennsylvania, 2009 to 2014. Plot locations are approximate.

What this means

Overall, there was a small net gain in forest land in Pennsylvania from 2009 to 2014, which suggests continued conservation and valuation of the State's forest resources. Some of these gains are likely to have come from residential and commercial open land allowed to return to forest and from reverting agricultural land. Gains and losses of forest land in Pennsylvania may also be from marginal forest land moving into and out of the forest land base. This movement between forest and nonforest classifications may result from small changes in understory disturbance, forest extent (i.e., minimum size requirements), or forest cover (i.e., minimum canopy cover requirements), which can lead to lands not meeting FIA's definition of forest land.

Net gain in forest land area was greatest in the Southeast region, and forest land gains were greater than or nearly equal to losses in almost all other regions of the State. The stability of the forest land base may be due in part to policies and programs, such as conservation easements and the Clean and Green tax program, which Pennsylvania has in place to promote forest conservation.

Urbanization and Fragmentation Impacts on Forest Land

Background

The expansion of urban lands that accompanies human population growth often results in the fragmentation and urbanization of remaining natural habitat (Wilcox and Murphy 1985). Fragmentation, parcelization, and urbanization can be barriers to stewardship if forest tracts are too small or isolated for effective management (Shifley and Moser 2016). Forest fragmentation affects forest ecosystem processes by changing microclimate conditions and limiting the ability of tree species to move in response to climate change (Iverson and Prasad 1998). Intact functioning forests are critical for protecting both the quantity and quality of surface and groundwater resources (McMahon and Cuffney 2000, Riva-Murray et al. 2010), and can enhance the ability of forest systems to adapt to temperature and rainfall pattern changes and relative phenological shifts associated with climate change.

Forest fragmentation and habitat loss diminish biodiversity and are a major threat to animal populations worldwide (Honnay et al. 2005, Rosenberg et al. 1999). This is particularly true for species that require interior forest conditions for all or part of their life cycle (Donovan and Lamberson 2001), or are wide-ranging, slow-moving, or slow reproducing (Charry and McCollough 2007, Forman et al. 2003). Changes in forest patch size, in connectivity, and in the amount of forest-nonforest edge all directly affect the amount and quality of interior forest. These factors also affect the ease with which nonnative invasive or generalist species gain a foothold and spread across the landscape. Landscape pattern metrics help quantify the characteristics of fragmentation, and the addition of spatial census data contributes information on types and levels of urbanization.

We adapted a spatial integrity index (SII) developed by Kapos et al. (2002) for the 2000 Global Forest Resources Assessment (FRA2000) to create a single metric where 1 indicates highly fragmented area and 10 represents the highest forest spatial integrity. The SII integrates three fragmentation components—patch size, local forest density, and patch connectivity to core forest areas—that affect forest ecosystem functioning.

Forest ecosystem processes operate at different scales, similar to the way that animal species see the landscape very differently depending on the scale at which they operate; thus, it is important to evaluate forest integrity at varying scales. We calculated spatial integrity at two scales using reliable and widely available datasets: 2006 National Land Cover Database (NLCD) at 30 m (Fry et al. 2011) and 2009 FIA forest cover at 250 m (Wilson et al. 2012). Both scales fall within the 10 to 1,000 km^2 range at which linkages between patterns and processes are often of greatest management interest (Forman and Godron 1986).

In the SII calculation, core forest is defined by a minimum patch size and minimum local forest density within a defined local neighborhood (Table 2). A forest fragment (unconnected area) is defined by a maximum patch size, maximum local forest density, and minimum distance to core forest. The spatial integrity of remaining forest land is scaled between fragmented and core forests (low, medium, and high integrity). At the 250 m scale, core forest requires a minimum forest patch size of 1,544 acres, and patches less than 30 acres are fragments. At the 30 m scale, the analogous minimum area is 22 acres, and patches less than 2.5 acres are fragments.[1] These scales capture a relatively broad range of definitions for core forest and spatial integrity that are expected to bracket the appropriate scales for understanding forest fragmentation impacts on a wide range of wildlife species and ecosystem processes.

SII is just one piece of the fragmentation puzzle. Because it does not consider underlying housing density or proximity to roads, additional metrics are necessary. The wildland-urban interface (WUI) is the zone where human development meets or intermingles with undeveloped wildland vegetation (Radeloff et al. 2005). It is associated with a variety of human-environment conflicts. Radeloff et al. (2005) have defined WUI by housing density ("intermix" areas, which have a minimum of 16 houses per square mile), proximity to developed areas ("interface" areas), and percentage of vegetation coverage (minimum 50 percent). We intersected WUI intermix areas (U.S. Census Bureau 2011) with forest land from the 2011 NLCD

Table 2.—Spatial Integrity Index (SII) parameters used in calculations at each scale

	Scale	
Definition of Core	**250 m**	**30 m**
patch size	>1,544 acres	>22 acres
local forest density	≥90%	≥90%
(neighborhood radius)	0.78 mile	0.09 mile
Definition of Unconnected Fragment	**250 m**	**30 m**
patch size	<30 acres	< 2.5 acres
local forest density	≤10%	≤10%
(neighborhood radius)	0.78 mile	0.09 mile
distance to core	>4.2 miles	>0.5 miles

[1] Riemann, R. 2014. Adaptation of a spatial integrity index to 30 m and 250 m scales, and its application across the northeastern United States. Unpublished paper on file at: U.S. Forest Service, Northern Research Station, Forest Inventory and Analysis Program, Troy, NY.

(Homer et al. 2015) to examine changes in forest land area by WUI housing density. In addition, the coincidence of SII core forest (based on forest canopy) and WUI intermix was identified.

Neither of the previous indices captures the full impact of roads on forest land. Roads can have a variety of effects: direct hydrological, chemical, and sediment impacts; anthropogenic impacts; invasive species; habitat fragmentation; and wildlife mortality. We identified the amount of forest land (2001 NLCD; Homer et al. 2007) within 650 and 1,310 feet from a road (U.S. Census Bureau 2000). In general, when more than 60 percent of a region is within 1,310 feet of a road, cumulative ecological impacts from roads are an important consideration (Riitters and Wickham 2003).

What we found

Considering SII at the 250 m scale, 56 percent of Pennsylvania forest land is core forest, 24 percent has high integrity, 11 percent has medium integrity, 1 percent has low spatial integrity, and 8 percent of the forest is in unconnected fragments. At the 30 m scale, 69 percent of Pennsylvania forest land is core forest, 19 percent has high spatial integrity, 6 percent has medium or low integrity, and 6 percent of the forest is in unconnected fragments (Table 3). Forest connectivity at the 250 m scale is highest in the North Central region, and lowest in the Southeast region (Fig. 8); note how the remaining large areas of relatively continuous forest clearly stand out. At the 30 m scale, the lower threshold of 22 acres for defining core forest results in more forest patches considered core (Fig. 9). It is important to note that the SII is depicting tree cover only and may not incorporate the presence of local development associated with or underlying this tree cover. Addressing this requires the use of census-derived housing density.

Table 3.—Spatial Integrity Index (SII) by region, scale, and with and without wildland-urban interface (WUI) intermix as core forest, Pennsylvania

	30-m Scale						250-m Scale					
	Forest fragment	Low SII	Medium SII	High SII	Core forest	Core forest if WUI removed	Forest fragment	Low SII	Medium SII	High SII	Core forest	Core forest if WUI removed
Region	*percent*						*percent*					
North Central	2	0	3	15	81	68	1	1	4	17	77	66
Northeast	4	1	4	18	73	48	4	1	10	28	58	39
Northwest	7	1	8	29	55	34	16	3	28	26	28	18
South Central	5	1	3	14	76	56	6	1	5	27	60	49
Southeast	32	3	13	22	30	13	56	1	9	17	17	11
Southwest	6	1	8	28	57	33	11	3	22	30	35	25
State total	**6**	**1**	**5**	**19**	**69**	**49**	**8**	**1**	**11**	**24**	**56**	**44**
State total after removing WUI areas	6	2	6	37	49		8	3	12	33	44	

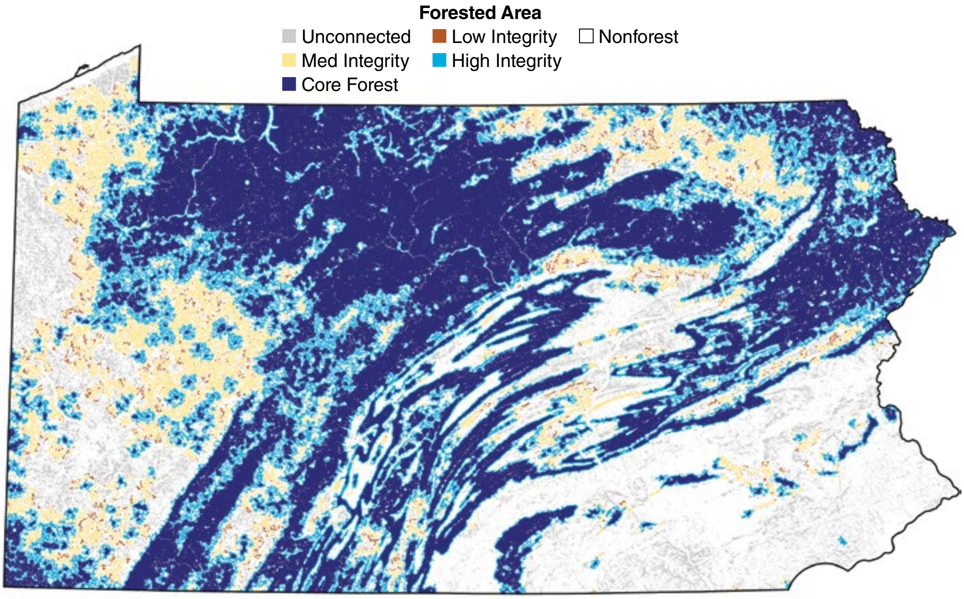

Figure 8.—Forest land by Spatial Integrity Index at the 250 m scale, Pennsylvania, 2009. Data source: Wilson et al. (2012).

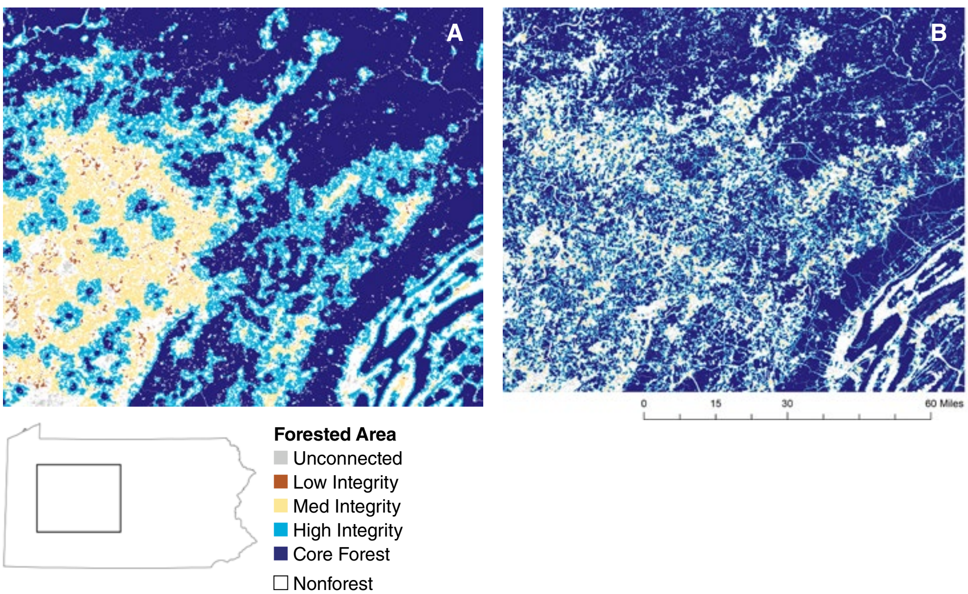

Figure 9.—Forest land by Spatial Integrity Index at the 250 m scale (A) and 30 m scale (B) in west-central Pennsylvania, 2009 and 2006, respectively. Data source for 250 m scale: Wilson et al. (2012); for 30 m scale: Fry et al. (2011).

Between 2000 and 2010, Pennsylvania's population increased by 3.4 percent, to 12.7 million. During that same time period housing units increased by 6.1 percent (U.S. Census Bureau 2011). Stated another way, between 2000 and 2010 housing units increased at a pace 1.8 times the rate of population increase, a trend not unique to Pennsylvania. In recent decades this housing growth has occurred in suburban rings around urban centers and in rural areas. Lepczyk et al. (2007), Theobald (2005), and Hammer et al. (2004) observed that among the areas currently facing rapid housing density increases are amenity-rich rural places around lakes and forest recreation areas. The 2010 Census reported a 9 percent increase in second homes from 2000, which partially explains housing increases (U.S. Census Bureau 2011). This can put additional pressure on forested areas even above the general increases in population density and housing density.

Forest land with sufficient underlying housing density to qualify as WUI has shown slow but steady increases. In 1990, 31 percent of Pennsylvania forest land was in low and medium density WUI. This increased to 34 percent of the forest land in 2000, and further to 35 percent in 2010, although there is substantial local variation. Chester, Delaware, and Montgomery Counties, in the Southeast region, all experienced between 10 and 20 percent increases in WUI forest land between 2000 and 2010. Bucks, Cumberland, Franklin, Lancaster, and York Counties experienced increases of between 5 and 10 percent. Thirty-three counties experienced no change or negative change, indicating that no increase in WUI areas occurred or previously classified WUI forest land was converted to nonforest. As can be expected, WUI areas are concentrated adjacent to population centers; the less densely populated central portion of the Commonwealth has relatively little WUI (Table 4, Fig. 10). By integrating SII results at the 250 m scale with WUI, core forest drops from 56 percent to 44 percent statewide. At the 30 m scale, core forest drops from 69 percent to 49 percent of forest land when WUI areas are accounted for (Table 3). This represents a substantial change in core forest land due to underlying or nearby house densities. When WUI status is incorporated into SII results for southeastern Pennsylvania, core forest at the 30 m scale decreases from 30 percent to 13 percent of forest land (Fig. 11).

Roads are pervasive in the landscape, often hidden from aerial view throughout large areas of continuous canopy. In 2000, 73 percent of Pennsylvania forest land was within 1,310 feet of a road, and 46 percent was within 650 feet. In the North Central region, 39 percent of forest was within 650 feet of a road versus 67 percent for the Southeast region (Table 4, Fig. 12). Since 2000, additional road and pipeline infrastructure has been built, and road use has increased, due to industrial gas development in north-central Pennsylvania.

Table 4.—Distribution of forest land with respect to several urbanization and fragmentation factors, expressed as a percentage of the forest land in each region, Pennsylvania

Region	Forest land as a percentage of total land in region[a]	Percentage of forest land in wildland-urban intermix[b]	Percentage of forest land <650 feet from a road[c]
North Central	77	19	39
Northeast	68	40	45
Northwest	56	42	43
South Central	62	31	42
Southeast	29	52	67
Southwest	62	49	55
State total	**62**	**35**	**46**

[a] Percent forest estimate based on NLCD 2011 (includes woody wetland). Values are generally higher than estimates from FIA plot data.

[b] Approximating the forest land potentially affected by underlying or nearby development. Data source: U.S. Census (2011).

[c] Approximating the forest land potentially affected by roads. Data source: U.S. Census (2000).

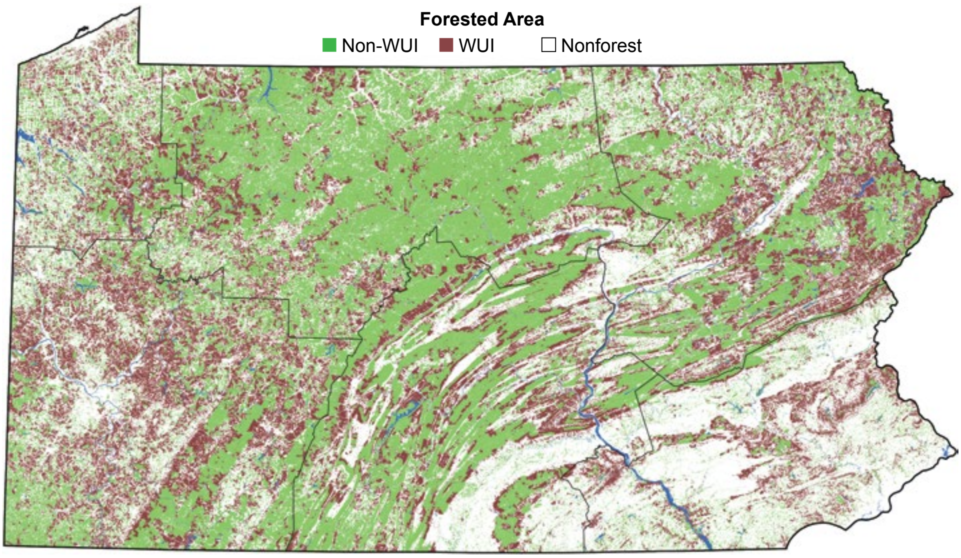

Figure 10.—Forest land by wildland-urban interface status, Pennsylvania, 2010.
Data sources: WUI data are based on the 2010 Census and NLCD 2011.

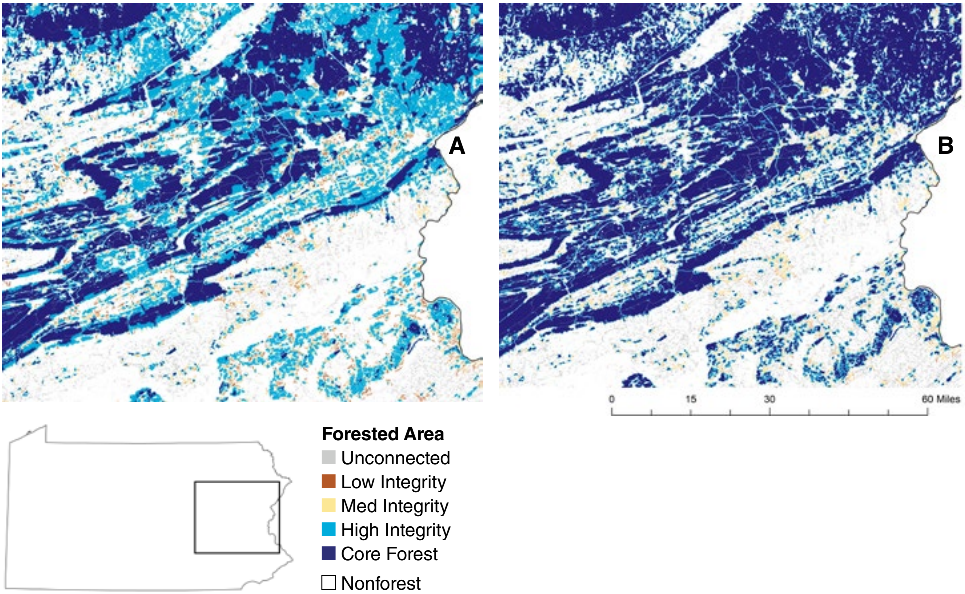

Figure 11.—Forest land by Spatial Integrity Index (SII) at the 30 m scale, with (A) and without (B) incorporating wildland-urban interface status into SII, in east-central Pennsylvania, 2010.

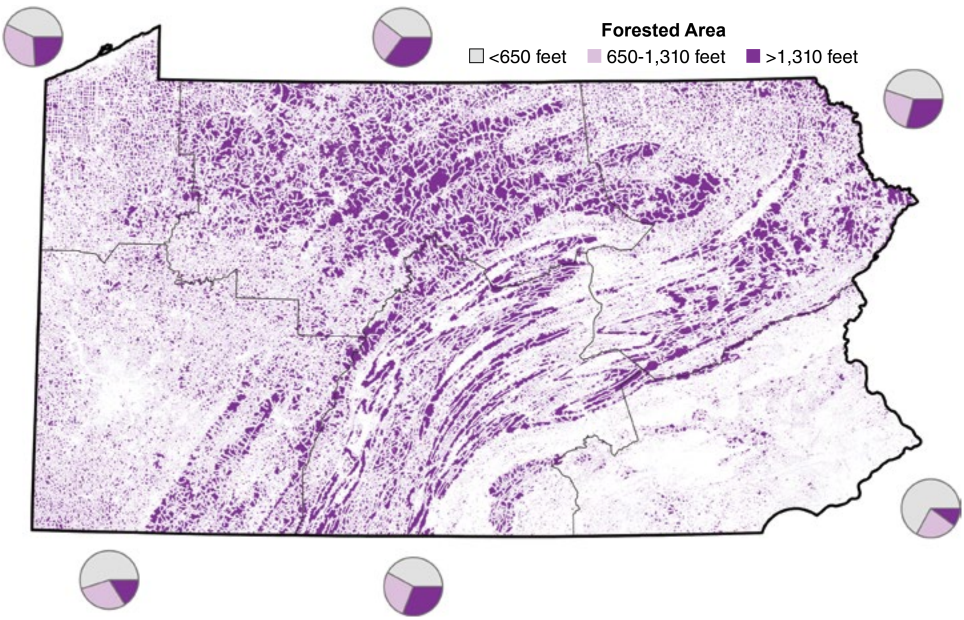

Figure 12.—Forest land by distance from the nearest road with summary pie charts for each region, Pennsylvania, 2000 roads (restricted to 2001 NLCD forest).

What it means

Pennsylvania has a diverse landscape, ranging from the heavily forested North Central region (77 percent forested) to the heavily agricultural and urban Southeast region (29 percent forested) (Jin et al. 2013). Urbanization affects all regions by increasing population density, development, and other anthropogenic pressures on natural habitats. Both urbanization and forest fragmentation change forest land use, frequently decreasing the likelihood that forest land will produce forest products and potentially increasing its use for outdoor recreation; frequently, however, urbanization increases "posting" of forested land, which decreases outdoor recreation opportunities and alters local cultural use of forest land (Butler 2008, Kline et al. 2004, Wear et al. 1999).

Using SII at either scale, 56 to 69 percent of Pennsylvania forest land is core forest and 7 to 9 percent is in unconnected fragments or has low spatial integrity. Statewide, core forest drops 12 to 20 percentage points by including WUI areas. Roads further reduce spatial integrity in some areas.

Fragmentation and urbanization continue to change how Pennsylvania's forests function, affecting forest health and sustainability, and their ability to supply forest products and ecosystem services. As housing development continues to sprawl into rural areas, fragmentation is a growing concern to land managers because forest stewardship becomes increasingly difficult on smaller ownerships. Conservation and planning activities that focus on preserving or creating connections between forest patches can maintain the benefits of high integrity and core forests. Road layout and design practices can help to enhance forest resilience. Effectively managing these concerns is crucial to the future sustainability of forests and forest-dwelling species.

Ownership

Background

As the major share of Pennsylvania forest land, private forests are essential to the character of the Commonwealth. The values they provide in terms of habitat, water quality, wood products, and recreation benefit not only the landowner, but society at large. Because landowners are the primary decisionmakers in land management, the availability and quality of forest resources are, to a large extent, determined by those owners. By understanding the priorities of forest landowners, the forest conservation community can better help them meet their needs, and in so doing, work to conserve the Commonwealth's forests for future generations. The National Woodland Owner Survey (NWOS; www.fia.fs.fed.us/nwos), conducted by FIA, studies private forest landowners' attitudes, management objectives, and concerns. It focuses on the diverse and dynamic group of owners that is least understood—families, individuals, trusts, estates, and family partnerships, collectively referred to as "family forest owners." The NWOS results reported here are based on responses from 214 of Pennsylvania's family forest owners who participated from 2011 and 2013 (Butler et al. 2016).

What we found

Family forest owners hold an estimated 8.9 million acres (52 percent) of forest land in Pennsylvania (Fig. 13). That total, combined with an estimated 2.3 million acres (13 percent) owned by corporations and an estimated 800,000 acres (5 percent) owned by other private owners (including conservation organizations and hunting clubs), places 70 percent of Pennsylvania forest land in private hands.

Public owners control 5.0 million acres of Pennsylvania's forest land, mostly in the North Central region (Fig. 14). The Federal government manages an estimated 600,000 acres of forest land, primarily on the Allegheny National Forest in the North Central region. State forests, parks, and gamelands make up 3.9 million acres of forest land. Municipal and county government agencies control an estimated 500,000 acres. Management of these lands is guided by more policies and procedures than the management of privately owned forest. Publicly owned timberland is professionally managed for a broad range of goods and services to allow for the sustainable use of natural resources.

According to the NWOS, there are an estimated 166,000 family forest owners across Pennsylvania who own 10 acres or more of forest land. This amounts to 7.6 million acres, with an average forest holding of 45 acres. About three-quarters of these family forest owners have less than 50 acres of forest land (Fig. 15). However, as a proportion of total family forest land, nearly two-thirds is in holdings of 50 acres or more. An estimated 393,000 family forest owners have between 1 and 9 acres of forest land, collectively holding the remaining 1.3 million acres.

The primary reasons reported for owning forest land include aesthetics, wildlife, nature, and privacy (Fig. 16). The most common activities on family forest land are personal recreation, such as hunting and hiking, and cutting trees for personal use, such as firewood (Fig. 17). A high percentage (39 percent) of family forest owners report having participated in a preferential property tax program, but few have participated in any other traditional forestry management and assistance programs in the past 5 years (Fig. 18). The most common "other" activity was receiving forest management advice, which was reported by fewer than 15 percent of the owners. Only an estimated 10 percent of owners have management plans. The average age of family forest owners in Pennsylvania was 61 years; 47 percent of the family forest land was owned by people who are 65 years of age or older (Fig. 19).

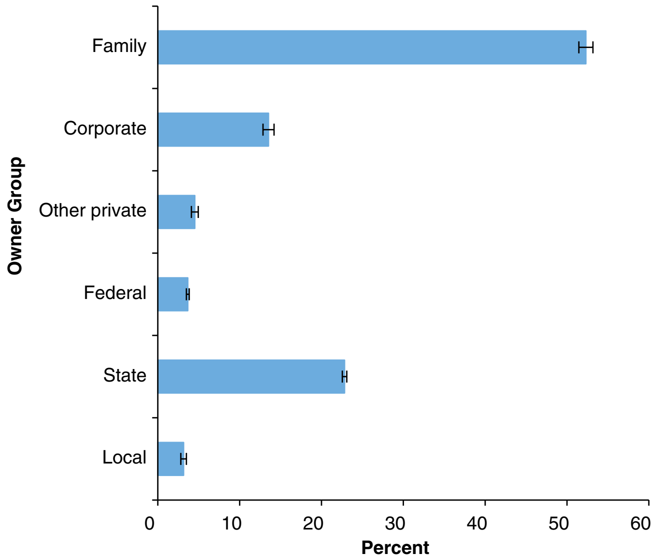

Figure 13.—Percentage of forest land by owner group, Pennsylvania, 2013. Error bars represent a 68 percent confidence interval around the estimated mean.

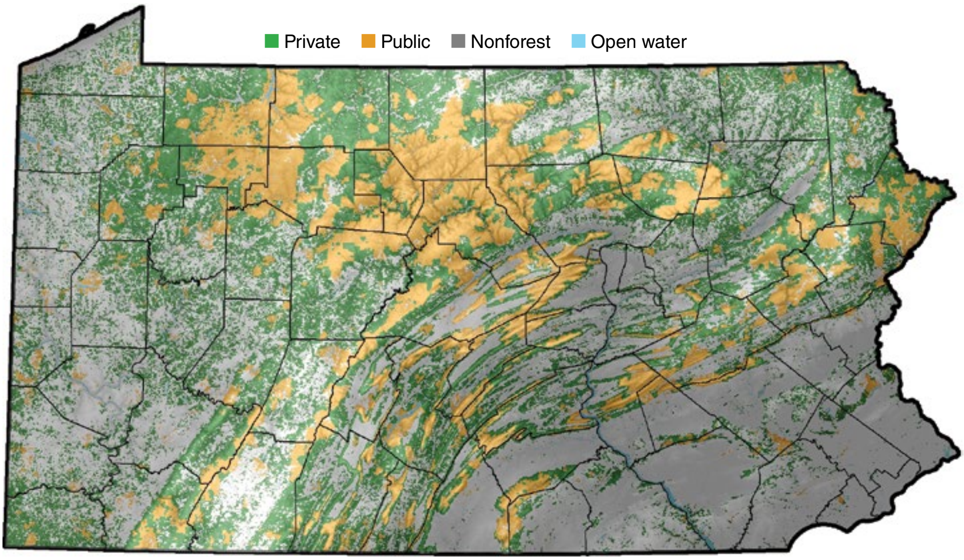

Figure 14.—Public and private ownership of forest land, Pennsylvania, 2012.

Projection: Pennsylvania State Plane North, NAD83. Source: U.S. Forest Service, Forest Inventory and Analysis program, 2009. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: T. Albright, U.S. Forest Service, March 2016.

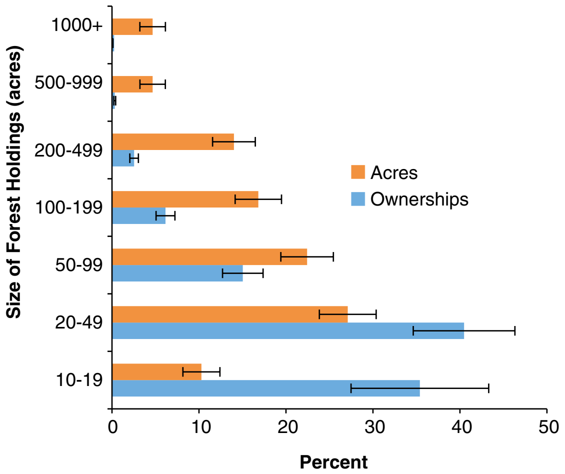

Figure 15.—Percentage of family forest owners and acres of forest land by size of forest landholdings, Pennsylvania, 2013. Error bars represent a 68 percent confidence interval around the estimated mean.

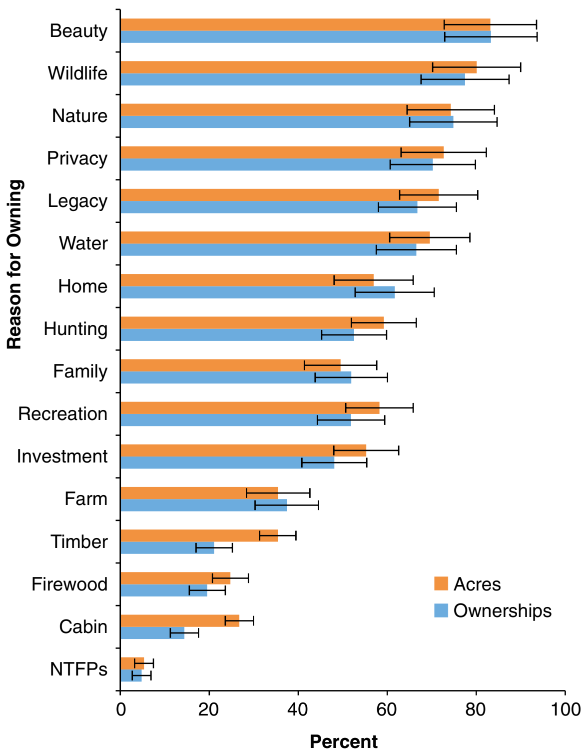

Figure 16.—Percentage of family forest owners and acres of forest land by reasons given for owning forest land ranked as very important or important, Pennsylvania, 2013. Categories are not exclusive. NTFPs indicates nontimber forest products. Error bars represent a 68 percent confidence interval around the estimated mean.

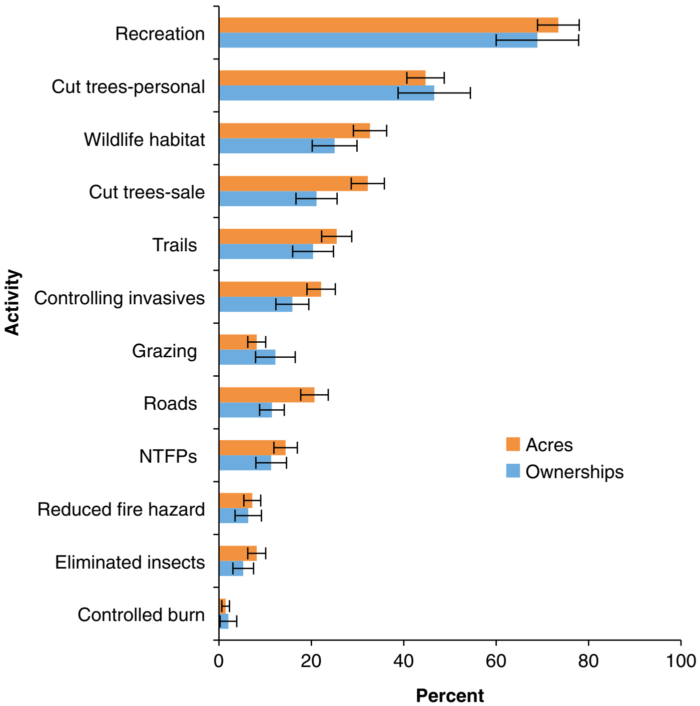

Figure 17.—Percentage of family forest owners and acres of forest land by activities in the past 5 years, Pennsylvania, 2013. Categories are not exclusive. NTFPs indicates nontimber forest products. Error bars represent a 68 percent confidence interval around the estimated mean.

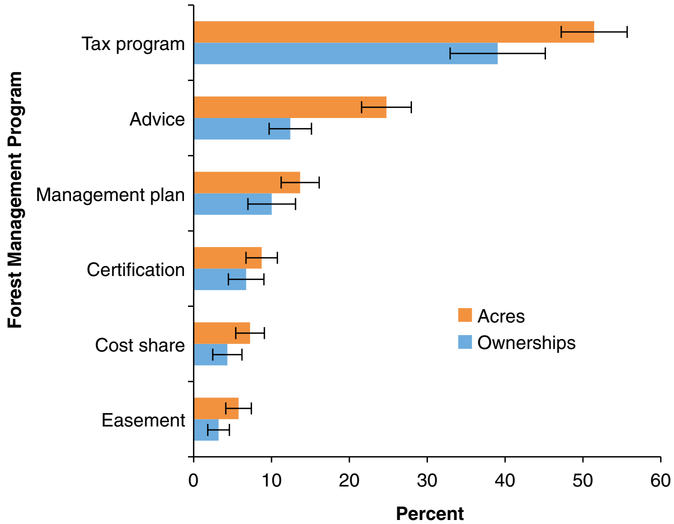

Figure 18.—Percentage of family forest owners and acres of forest land by participation in forest management programs, Pennsylvania, 2013. Categories are not exclusive. Error bars represent a 68 percent confidence interval around the estimated mean.

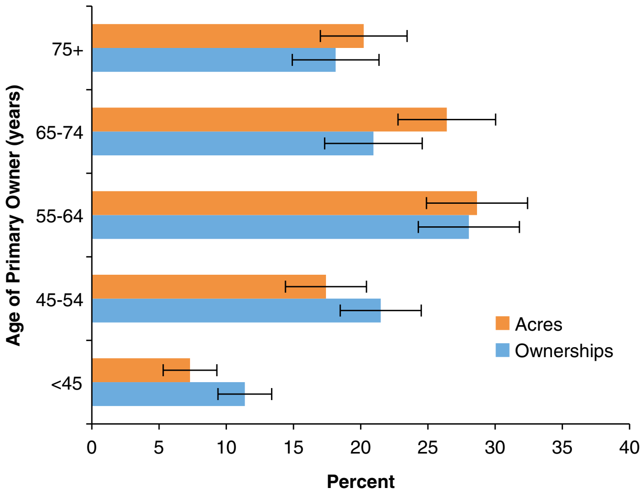

Figure 19.—Percentage of family forest owners and acres of forest land by age of primary owner, Pennsylvania, 2013. Error bars represent a 68 percent confidence interval around the estimated mean.

What this means

The future of the forests lies primarily in the hands of those who own and control the land as the primary decisionmakers. Additionally, foresters, educators, loggers, researchers, and others all have an interest in, and therefore responsibility for, implementing and promoting sound forest management practices. It is therefore critical to understand the different types of forest owners, their attitudes, and behaviors, and to identify the policies and programs that can help them conserve the forests for current and future generations. Generally, having both private and public ownerships enhances the benefits and ecological services provided by Pennsylvania's forests. These diverse ownerships create private market opportunities while protecting critical areas and providing for public recreation. Family forest owners are the least understood owner group and the future of their forest is arguably the most uncertain. They own their land primarily for amenity reasons, but many are actively doing things with their land. The vast majority does not have management plans and most have not participated in any other traditional forest management planning or assistance programs. There are significant opportunities to assist these owners with management and stewardship of their forests. Programs such as Tools for Engaging Landowners Effectively (http://www.engaginglandowners.org) can help the conservation community develop and implement programs more effectively and efficiently. Penn State Extension's Center for Private Forests also conducts applied research on private forests and provides education and outreach to landowners and industry. Another important factor to watch is the aging of the family forest owners. The relatively advanced age of many of the owners portends the transfer of land passing to the next generation in the not-too-distant future. To help owners meet their bequest goals, programs are available, such as Your Land Your Legacy (http://masswoods.net/monthly-update/your-land-your-legacy-deciding-future-your-land), Ties to the Land (http://tiestotheland.org), and the Pennsylvania Department of Conservation and Natural Resources' Bureau of Forestry Private Woodland Legacy Planning Partnership. But it is uncertain who the future forest owners will be and what they will do with their land.

Forest Resource Attributes

Young oak forest 8 years after harvest in Lycoming County. Photo by Thomas Albright, U.S. Forest Service.

Forest Composition

Background

Forest tree species composition is the result of the long-term interaction of climate, soils, disturbance, competition among plants, and other factors. Causes of forest disturbances in Pennsylvania include timber harvesting, insects and diseases, ice storms, wind, droughts, wildfires, and land clearing followed by abandonment. As forests recover from disturbance and mature, changes in growing conditions favor the growth of shade-tolerant species over shade-intolerant species in the understory unless forest management practices intervene to work toward the perpetuation of shade-intolerant species. White-tailed deer (*Odocoileus virginianus*) can affect species composition by heavily browsing some species while avoiding others. In many parts of the State, the prolonged abundance of deer continues to have a profound effect on forest community species composition. In addition, increases in competing vegetation, invasive species, past management practices, acid deposition, and climate change may also be contributing drivers of composition.

Forest attributes recorded by FIA that describe forest composition include forest type and numbers of trees by species and size. Forest types describe groups of species that frequently grow in association with one another and dominate the stand. Similar forest types are combined into forest-type groups. Changes in area by forest type are driven by changes in the species composition of large diameter trees, and while these large trees represent today's forest, the composition of the smaller diameter classes represents the future forest. Generally, trees in the larger diameter classes are those that currently dominate the overstory and those in the smaller diameter classes represent trees available for recruitment into the overstory as large trees either die or are removed by harvesting. Comparisons of species composition by size can provide insights into future changes in overstory species. In this discussion, "seedling size" refers to trees at least 1 foot tall but less than 1 inch in diameter. "Sapling size" refers to trees at least 1 inch but less than 5 inches in diameter at breast height. See Figure 1 for a map of Pennsylvania regions.

What we found

The 2014 inventory identified 101 tree species (appendix), and 58 forest types in Pennsylvania. These forest types are combined into 16 forest-type groups. Ninety-seven percent of the forest land in the State (16.3 million acres) is occupied by stands dominated by hardwood species, and 3 percent (586,000 acres) is predominantly occupied by softwood species. The largest hardwood forest-type groups are the oak/hickory group, which covers 9.1 million acres (54 percent), and the maple/beech/

birch group, which covers 5.5 million acres (33 percent). Nearly all of the stands in softwood groups are in the white pine/red pine/hemlock group, which covers 382,000 acres. The oak/hickory forest-type group is the dominant group in all but the North Central region of the State (Fig. 20), where nearly half the area is in the maple/beech/birch group (Fig. 21).

Many species are common to several forest-type groups, but there are generally substantial differences in composition between groups. For example, species such as red maple, ash, sweet birch, and northern red oak are common in both the oak/hickory and maple/beech/birch forest-type groups, but clear differences can be seen in the proportion of oak species by biomass between the two groups (Fig. 22A, B). In the oak/hickory forest-type group, oaks account for 47 percent of the biomass, whereas in the maple/beech/birch forest-type group oaks make up only 6 percent. These are two of the six forest-type groups that describe the current composition of overstory trees, and they have undergone little change in extent since 2004 (Fig. 23).

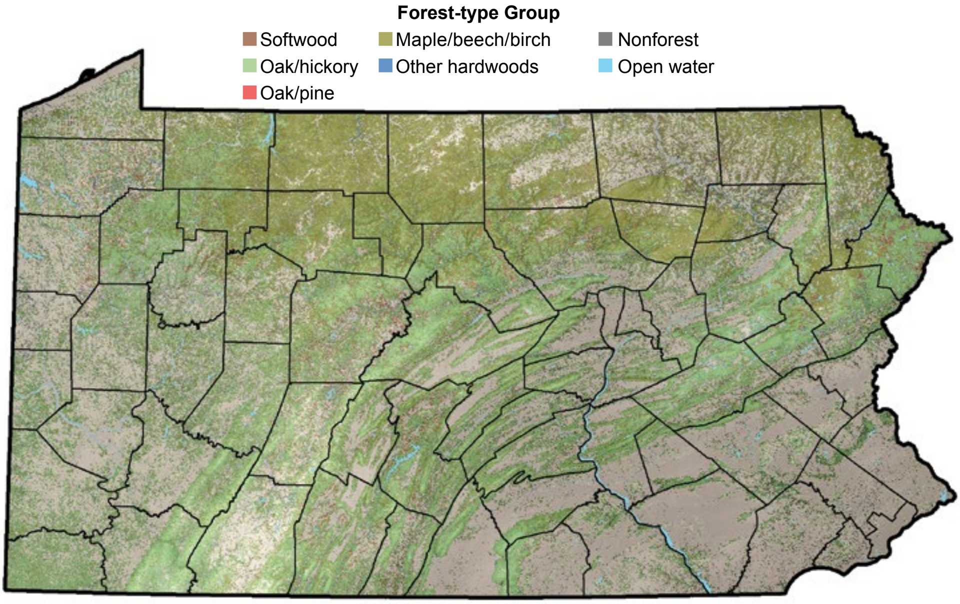

Figure 20.—Major forest-type groups, Pennsylvania, 2009.

Projection: Pennsylvania State Plane North, NAD83. Source: U.S. Forest Service, Forest Inventory and Analysis program, 2009. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: T. Albright, U.S. Forest Service, March 2016.

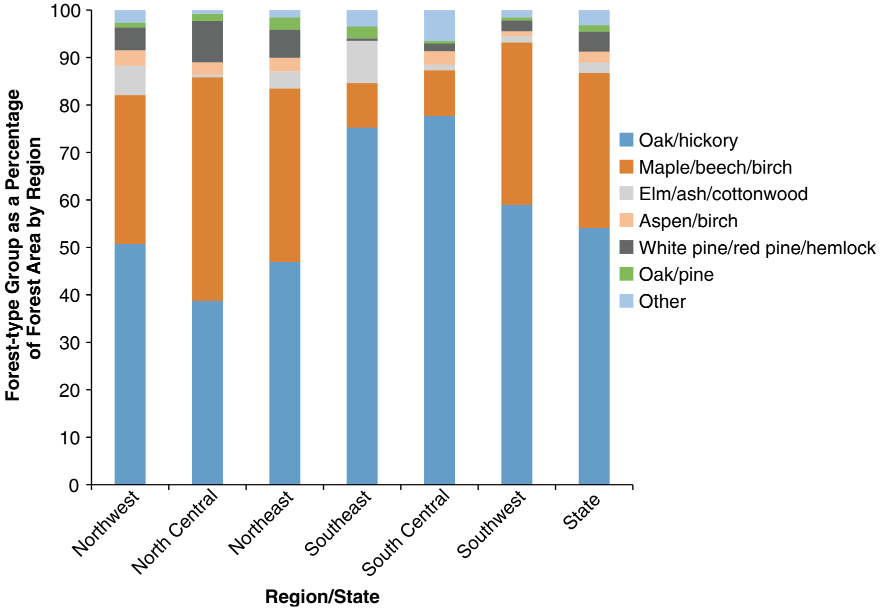

Figure 21.—Most abundant forest-type groups on forest land by region, Pennsylvania, 2014.

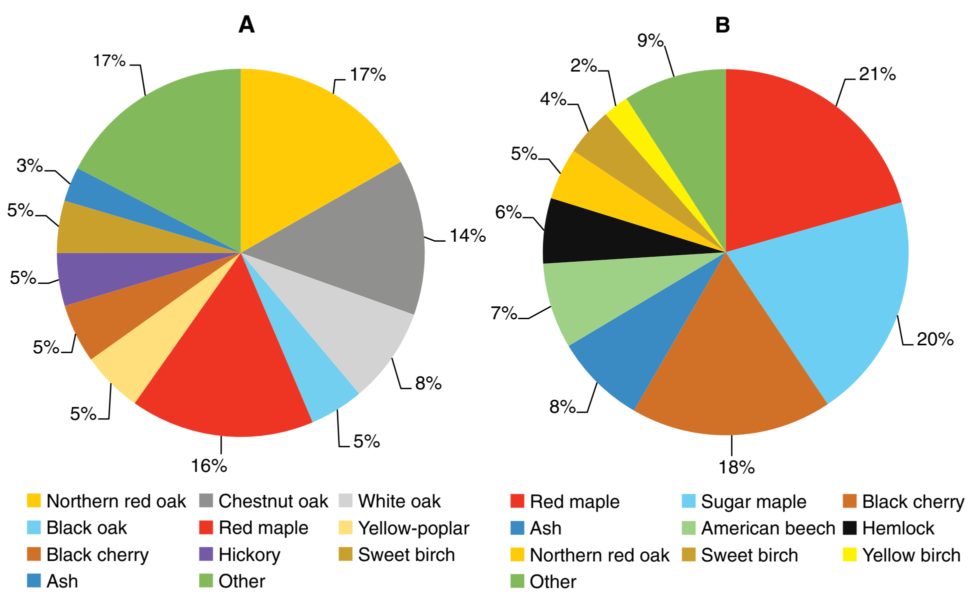

Figure 22.—Species composition within the oak/hickory forest-type group (A) and the maple/beech/birch forest-type group (B), by percentage of total biomass in the forest type, on forest land, Pennsylvania, 2014.

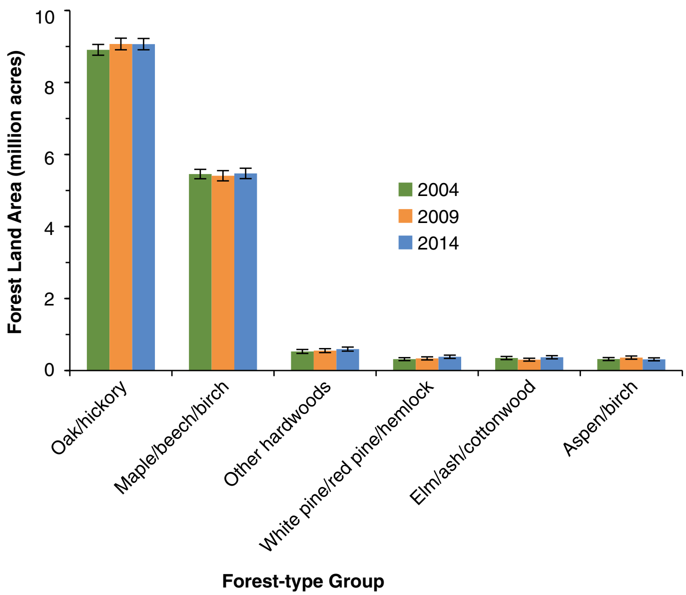

Figure 23.—Area of forest land by forest-type group and inventory year. Error bars represent a 68 percent confidence interval around the estimated mean.

American beech is the most numerous seedling size tree, followed by red maple, sweet birch, and ash (Fig. 24). Although these species are fairly common throughout the State, their distribution is uneven. In the North Central and Northeast regions beech accounts for 22 and 17 percent of seedlings (including root sprouts), respectively, whereas in other regions beech is much less prominent (Fig. 25). Ash has the largest percentage of seedlings in the Northwest and Southeast regions, 14 and 12 percent, respectively. Sweet birch has the largest percentage of seedlings in the South Central region at 15 percent, and is among the five most numerous species for seedlings in four other regions. Although red maple is not the leading seedling species in any of the regions, it is among the top three species in every region and is more numerous statewide than all the oaks combined.

The total number of sapling size trees in Pennsylvania decreased by 5 percent since 2004 (Fig. 26). Notable decreases in sapling numbers were recorded for red maple (-12 percent), black cherry (-28 percent), ash (-18 percent), and northern red oak (-23 percent). Increases were found for sweet birch (+11 percent), American beech (+28 percent), yellow-poplar (+42 percent), and white oak (+26 percent). Since 2004, two noncommercial species that typically grow in the understory, eastern hophornbeam and American hornbeam, had large increases, 35 and 44 percent, respectively.

Oak, red maple, black cherry, sugar maple, and hemlock currently dominate the larger diameter classes within the Commonwealth (Fig. 27). Oaks make up at least 25

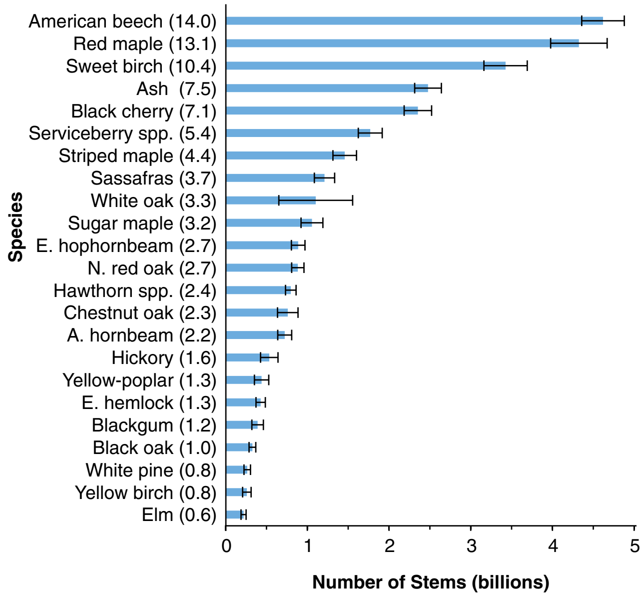

Figure 24.—Number of seedlings by species on timberland, Pennsylvania, 2014. Percentage of total seedlings is shown in parentheses. Error bars represent a 68 percent confidence interval around the estimated mean.

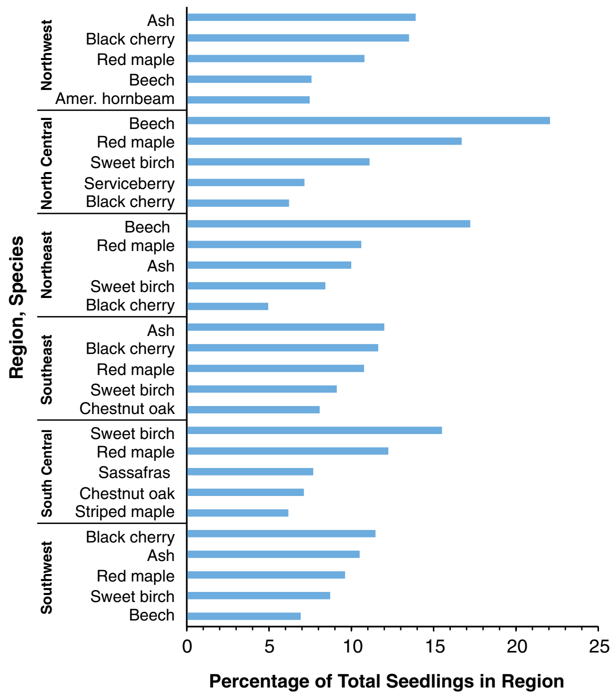

Figure 25.—Five seedling species with the most seedlings, by region, and by percentage of total seedlings in the region, Pennsylvania, 2014.

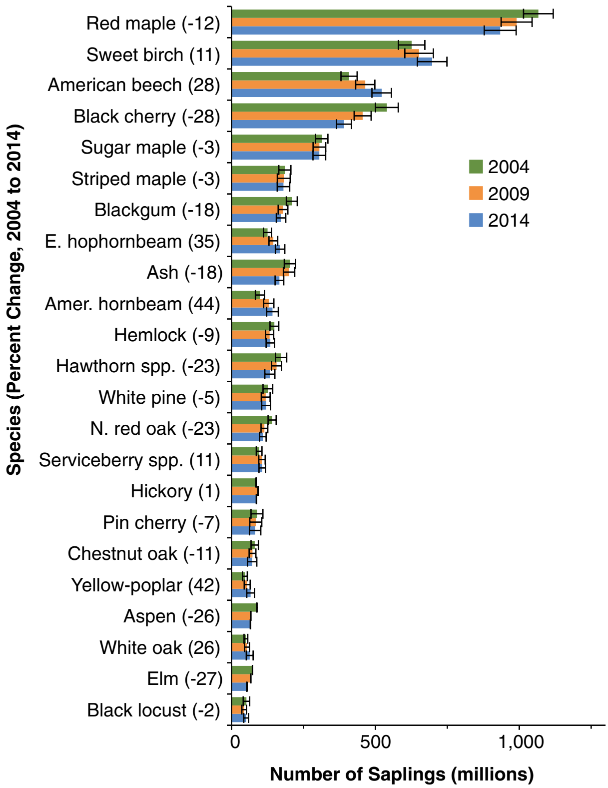

Figure 26.—Number of saplings by species on timberland, Pennsylvania, 2004, 2009, and 2014. Species are ranked by numbers of stems, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

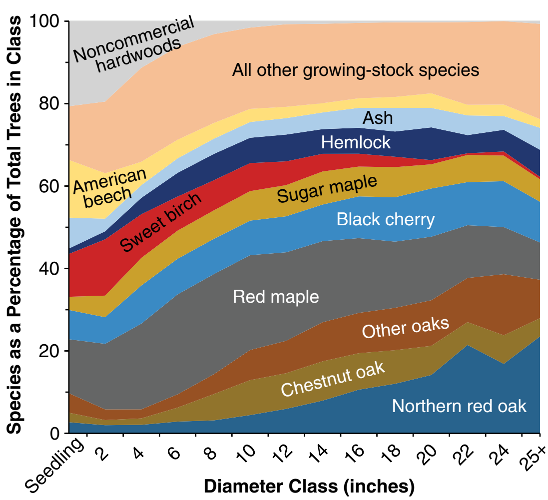

Figure 27.—Species composition by diameter class on timberland, Pennsylvania, 2014.

percent of trees in diameter classes 14 inches and larger, but are poorly represented in the sapling size classes. Less than 6 percent of trees in the 2- and 4-inch classes are oak species. Hemlock is similar to the oaks with small percentages in seedling size (1 percent of all stems) and 2-inch class (2 percent of trees), whereas 6 percent of trees in diameter classes 8 inches and larger are hemlock. Red maple is the most numerous species in all diameter classes 2 inches and larger. The largest proportion of red maple trees are in the 6-, 8-, and 10-inch classes, where they compose nearly a quarter of the trees in each of these classes. Red maple represents 22 percent of all trees in Pennsylvania that are greater than 5 inches diameter at breast height. Red maple, American beech, and sweet birch have the largest numbers of seedlings and saplings in the State. Beech and sweet birch are poorly represented in large-size trees.

What this means

The large numbers of tree species, forest types, and forest-type groups in the Commonwealth demonstrate the great diversity in Pennsylvania forests. This rich diversity enhances the forest's ability to provide a variety of goods and services, and fosters resilience to disturbances, such as insects and diseases. The stability of the oak/hickory and other major forest-type groups since 2004 does not depict the underlying shifts in species composition that are likely to occur, as species now in the understory grow into the canopy and replace large trees that currently dominate the overstory. These shifts will occur slowly as large trees are harvested or succumb to natural mortality, potentially changing the future species composition of Pennsylvania's forests.

The overall decrease in numbers of saplings since 2004 is likely the result of stand dynamics and the maturing of Pennsylvania's forests. The vast majority of saplings grow in the understory and many have poor live crown ratios; as a result, expected mortality of sapling size trees is high. Decreases in saplings can also be due to few seedlings growing into the sapling size class. Although many of the data for numbers of seedlings and saplings have high sampling errors, some general trends emerge from the sapling data. Less preferred white-tailed deer browse species fare better than favored species; shade-tolerant species are reproducing better than shade-intolerant species; and species that can take advantage of small canopy gaps created by disturbance, such as partial harvesting, are increasing in number. Sweet birch and American beech are not preferred browse for white-tailed deer, are tolerant of shaded conditions, and can respond well to gaps created by partial harvests and other disturbances. These species have large numbers of seedlings in the understory.

Throughout the State, a lack of oaks in the smaller diameter classes means that as large oaks are harvested or die, they are likely to be replaced by species such as red maple, sweet birch, and others that now represent large portions of sapling and seedling size trees. Red maple is ubiquitous, occurring prominently in all diameter classes across the State. Large numbers of red maple, sweet birch, and beech saplings and seedlings mean that these species are readily available to fill canopy gaps. Red maple is among the top three species ranked by sapling and seedling numbers in every region of the State, and sweet birch and beech are among the few species that showed increases in numbers of saplings.

Decreases in the oak portion of the resource have been attributed to inadequate oak regeneration, the subsequent lack of oaks growing into the larger diameter classes, and selective harvesting of oak over other species. Generally, current forest management practices do not promote the regeneration of oaks, and silvicultural tools (fencing to exclude deer, controlled fires to inhibit competing species, and seed tree retention) to promote oak regeneration are seldom used on private land. Contributing factors to poor oak regeneration are lack of fire, understory growing conditions that favor more shade-tolerant hardwoods, white-tailed deer preferentially browsing oak seedlings, acorn consumption by animals and insects, and the low intensity harvesting practices that leave only small gaps in the canopy.

Eastern hemlock is among the leading large canopy trees across the northern three regions of the State. This species is poorly represented in the sapling and seedling size classes and is likely to be replaced by other species because of a lack of regeneration. Hemlock is the most shade tolerant of all tree species in North America and can withstand suppression from overstory trees for as long as 400 years (Godman and Lancaster 1990). In a maturing forest resource such as Pennsylvania's, it would be expected that a very shade tolerant species such as hemlock would increase. But hemlock is readily browsed by white-tailed deer, affecting the numbers of hemlock seedlings and saplings. Hemlock woolly adelgid, a nonnative insect pest, may also be a contributing factor because it reduces the vigor and causes mortality of large hemlocks, thereby reducing seed production (see Hemlock Woolly Adelgid starting on p. 108).

Despite high numbers of small ash and beech trees, notably ash in the Northwest, Southeast, and Southwest regions and beech in the North Central region, the outlook for these species is difficult to assess given the impacts of insect and disease outbreaks. Emerald ash borer (EAB; see Emerald Ash Borer starting on p. 106) is a relatively new insect pest and to date, ash trees have exhibited little or no resistance to it, so the future of ash is bleak. It is expected that many of the beech trees now in the understory will succumb to beech bark disease as they mature (see Beech Bark Disease starting on p. 115), although beech is likely to persist in the understory because infected trees produce large numbers of root sprouts (i.e., beech brush). The future value of ash and beech for producing timber products and hard mast for wildlife will most likely decrease as beech bark disease and EAB continue to spread. Land managers may need to work to promote regeneration of other species to fill the ecological niche these species occupy. Practices to improve species composition in recently harvested stands could include enhancing deer management techniques, establishing tree regeneration prior to overstory removal, and treatments. Currently a large portion of seedlings and saplings comprises beech, ash, and noncommercial species such as eastern hophornbeam, hornbeam, and striped maple. These species thrive in the canopy gaps created by partial harvesting, a harvesting practice that is common in Pennsylvania. As beech and many noncommercial species can interfere with the regeneration of more valuable species, removing these species before or after harvests will allow more diverse species recruitment.

Long-term changes in forest composition can alter wildlife habitats and affect the value of the forest for timber products. The lack of an oak seedling and sapling base from which recruitment into the larger diameter classes can occur is changing the composition of the timber resource away from oaks toward more red maple, sweet birch, blackgum, and other non-oak species. To remain sustainable, the composition of the timber harvest in the State will need to shift to reflect changes in the resource.

Projected changes in species composition due to climate change suggest that by 2100 growing conditions in the northeastern United Sates will become more suitable for oaks and less suitable for maples (Iverson and Prasad 1998, Rustad et al. 2012, Vose et. al. 2012). Current trends in Pennsylvania do not reflect these projected changes indicating that to date, other factors, such as browse by white-tailed deer, successional stage, cutting practices, fire suppression, competing vegetation, invasive species, localized topographic and watershed features, soil conditions, and insects and diseases are driving changes in forest composition. Current trends may also suggest that Pennsylvania's forests are becoming less resilient to predicted changes in climate. To maintain forest productivity and ensure a sustainable supply of ecosystem goods and services, natural resource managers will need new management strategies and practices that promote adaptation to climate variability and change.

Forest Succession

Background

The amount and character of forest land in various stages of succession determine the values and services available for the public good. A balanced distribution of forest land by age, or stage of successional development, ensures long-term diversity and sustainability of resources. Healthy young forest provides unique wildlife habitat for early successional obligate and facultative wildlife species that are declining due to habitat loss (Goodrich et al. 2002). Mid- and late successional forests dominate the landscape and the resources and benefits available as they account for 95 percent of the State's timberland. Although very rare, old-growth remnant forests offer understanding and knowledge of forest conditions prior to European settlement, as well as a unique suite of ecosystem services.

The current distribution of forest land is the result of land-use changes that occurred about a century ago (Nowacki and Abrams 2014). From about 1880 to 1920, forests were cleared for agriculture and for supplying much needed wood resources. On the more productive sites in the southern portions of the Commonwealth, forests were cleared for agricultural production. On less productive mountainous sites, forest resources were used to build cities, provide heat, and meet other needs. Most of the timber harvesting occurred over a 20-year period from 1900 to 1920. This resulted in an agricultural land base and an extensive block of young forest of a similar age that stands today as a legacy of the clearing and timbering era.

The conversion of old forest to new forest was so extensive that by 1922, Joseph Illick, then Director of the Bureau of Forestry, concluded that only about 25,000 acres could be classified as "original forest" (1923). The new forest originated without active regeneration management and was composed of species that had ecological advantages, such as prolific stump sprouting, intolerance of shade, and habitat generalization. Oaks, black cherry, and red maple achieved canopy status quickly and remain as dominant species in the present forest. Species that were more prevalent in the original forest, such as American beech, white pine, and eastern hemlock, remain, but are of lesser status today.

This section discusses the distribution of timberland by stand-size and stand-age class, or successional stage. Timberland is used because it is an estimate that excludes forest land designated as wilderness, and so is not available for management. A dearth of young and old growth timberland mixed with mid- and late successional forest is described. The emphasis is on the imbalanced distribution of timberland by successional stage to better inform forest management and policy on this important forest sustainability topic.

What we found

Contemporary forest issues are rooted in the history of land use and forest growth since the end of the 19th century. The estimated area of forest land during the presettlement period is 28.6 million acres (Fig. 3). By 1860, just before the building of the timber economy, forest land had decreased by about one-third (to 18.8 million acres), primarily reflecting a diversion of land for agricultural use. As timber harvesting expanded, the area of forest further declined to a low of 12.0 million acres in 1900, or 42 percent of the original forest. As marginal agricultural land reverted to forest, the acreage had increased to 17.1 million acres by 1965. The forest land base has remained stable since then, reflecting a depletion of most of the agricultural land available for reversion.

Stand-size and stand-age class are two variables that describe forest succession, or the division of the forest into successional stages. Stand-size class is a broad measure of succession based on the plurality of relative stocking of sample trees (Stout and Nyland 1986) grouped into three classes: small, medium, and large (Arner et al. 2001). The advantage of stand size for describing forest succession is that it is available in digitized publications as far back as the first Pennsylvania FIA report for 1955 (Ferguson 1958).

The availability of FIA results as early as 1955 and the Illick report (1923) provide the opportunity to track the decline in the area of small-size stands since the beginning of the 20th century (Fig. 28). In 1900, small-size stands accounted for 93 percent of timberland due to the extensive removal of merchantable wood. This percentage decreased to about 20 percent in 1960 and fell to 9 percent by 2014.

The FIA stand-age estimates are based on increment cores of trees that represent the predominant canopy of the forest condition. Two or three trees are cored and a weighted average is computed by using the percentage of the canopy that each sample tree represents and the tree age measurement. To illustrate, if a white ash (72 years)

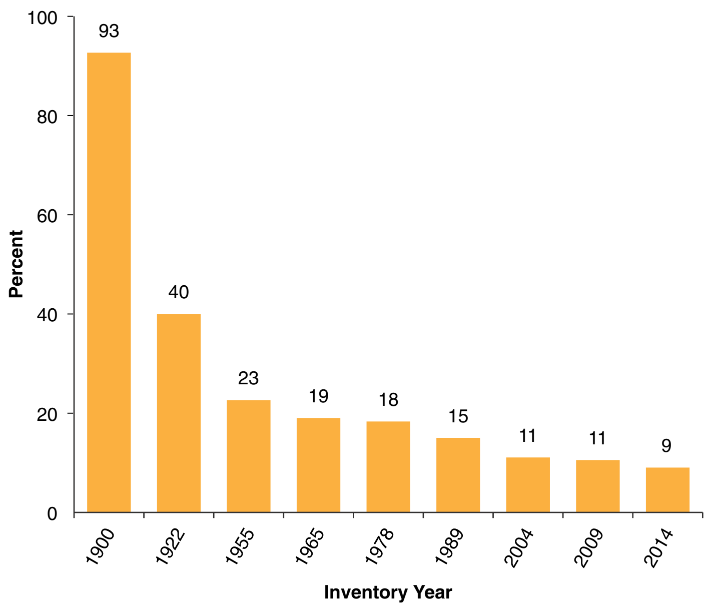

Figure 28.—Percentage of timberland classified as the small stand-size class (sapling-seedling), by year, Pennsylvania. Estimates for 1900 and 1922 are approximated from findings of Illick (1923).

and red oak (86 years) are cored and those species represent 30 and 70 percent of the stand, respectively, then the age assigned is 82 years [(72 × 0.30) + (86 × 0.70)].

The relationship between stand-size and stand-age classes shows how the two classifications interact (Fig. 29). For example, small saplings and seedlings may be sampled with larger trees that are given more weight in the classification based on diameter. If a few medium or large trees are included in a sample of seedlings and saplings, the classification may be a medium or large stand-size class rather than a small size class. This means that some young stands are assigned to the medium and large classes, as shown for the 0- to 20-year class.

The stand-age profile expressed both as a percentage of total timberland and as acres provides an interpretation of current age structure (Fig. 30). The maturing forest in the 41- to 120-year range makes up 84 percent of Pennsylvania's timberland. Young forests from 0 to 20 years are only 6 percent of timberland. Using a broad definition for old-growth forest of 141 years and older captures timberland with trees from the time prior to wide-scale timbering, but this component may still have been disturbed (Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry 2015). Using this definition, only 0.2 percent of the timberland would be old growth, or only 33,100 acres (subject to a sampling error of plus or minus 17,000 acres).

The stand-age profile for public and private owners reveals that 57 percent of public timberland is older than 80 years, compared to 33 percent of private holdings (Fig. 31). In terms of acres, private owners have the most acreage in mid- and late stages of succession that could be available to fill the gap in overall young forest acreage following stand-

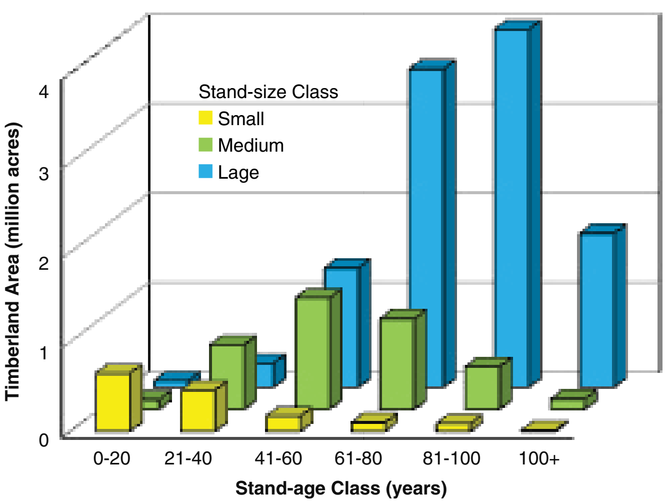

Figure 29.—Area of timberland by stand-age class and stand-size class, Pennsylvania, 2014.

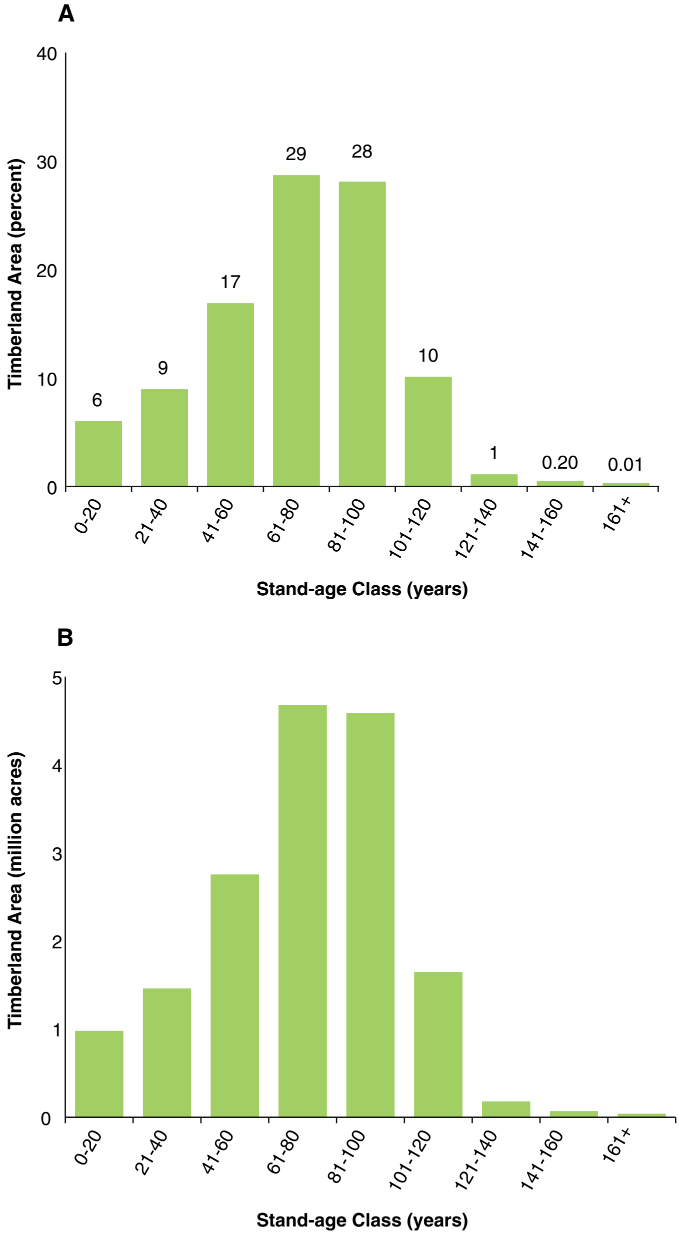

Figure 30.—Percentage of timberland (A) and area of timberland (B) by stand-age class, Pennsylvania, 2014.

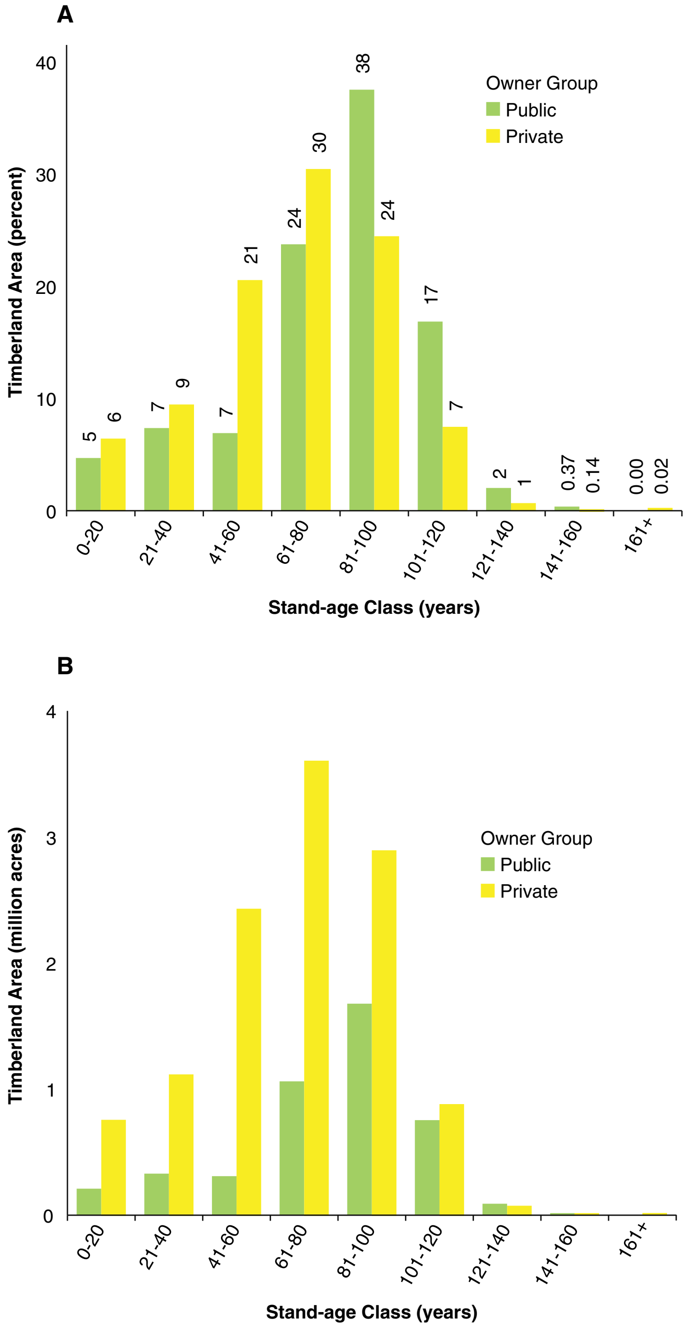

Figure 31.—Percentage of timberland (A) and area of timberland (B) by stand-age class and ownership, Pennsylvania, 2014.

initiation disturbance. The proportions of public and private timberland in the 0- to 20-year age class are 5 and 6 percent, respectively; however, more than three times the acreage of early-successional timberland is in private hands than in public ownership.

What this means

Extensive harvesting about a century ago created a widespread even-aged forest and nearly extirpated old-growth forest. The comparative lack of acreage in the youngest and oldest stand-age classes makes it timely to review approaches to achieving a better long-term balance of stand-age classes. Management of new young forests is needed to support the values and benefits of all stages of forest succession. The challenge for forest managers is to create young forests under conditions that are very different from those during the initiation of contemporary forests. They must now consider several interrelated factors that challenge prescriptive decisions for reestablishing forest ecosystems during stand initiation:

- Herbivory: white-tailed deer
- Lack of fire in oak management
- Competing native vegetation: mountain laurel (*Kalmia latifolia*), eastern hayscented fern (*Dennstaedtia punctilobula*), and New York fern (*Thelypteris noveboracensis*)
- Competing nonnative vegetation: bush honeysuckles (*Lonicera* spp.), multiflora rose (*Rosa multiflora*), and other species
- Gypsy moth and other nonnative pests/pathogens (see also Tree Pests and Diseases of Special Concern section starting on p. 106)
- Poor cutting practices and lack of planning on private timberland
- High cost of regeneration management (shelterwood, herbicide, fence)
- Fragmentation, parcelization, and urban influence
- Pollutant deposition
- Changing climate
- Interaction of all of the above impacts.

The findings for both public and private forests show a dearth of young timberland to replace older timberland. This has created a deficit in faunal diversity and abundance for early-successional species compared to conditions common 100 years ago. The character and abundance of native tree species are also threatened due to the challenges of regeneration management and particularly the interactions between species.

The lack of old-growth forest in Pennsylvania constitutes another acute forest health issue. The opportunity for today's late-successional forest to evolve as tomorrow's old growth is enormous but problematic. Forest management activities directed at fostering and stewarding future old growth are hampered by the same set of interrelated stress factors mentioned earlier.

Comparing management approaches of public and private owners elucidates key differences that will have an impact on future forests. Pennsylvania's primary public owners are the Allegheny National Forest, Bureau of Forestry, and the Game Commission, all of which have overarching forest management plans that consider the amount of old forest, special ecosystems, and rare habitat (Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry 2015, U.S. Forest Service 2007)[2]. Professionally managed stands have science-based plans that address regeneration management when stand replacement is called for. Private timberland owners are a diverse group with a wide range of reasons for owning forests, but most do not have a management plan or participate in planning or assistance programs. Furthermore, the cost of implementing silvicultural prescriptions to achieve successful regeneration is often a difficult obstacle to overcome. Hence, many private owners are unprepared when a regeneration harvest is warranted. Unfortunately, this lack of planning can result in the use of harvesting practices (e.g., "select" cutting or high-grading) that remove only the best trees and leave behind a degraded stand.

It is important to recognize that a long history of forest management research has produced methods for regenerating forests under stress, such as herbivory and undesired plant invasion. Managers need to consider existing methods and keep abreast of new research to make fully informed decisions. Most of the lessons learned for managing forests under stress are not new, but in Pennsylvania, the full suite of stressors and their complex interactions must be considered. Some prominent examples of management solutions are discussed next.

- Prescriptions that establish, recruit, and retain desirable seedlings from the mature stand prior to harvest through the stem exclusion phase after harvest will need to pay particular attention to contemporary drivers and stressors, such as invasive plants and climate change (Dey 2014).
- Herbivory by white-tailed deer needs to be considered before harvest in stands scheduled for stand initiation in medium- and high-pressure subregions.

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[2] Also: Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry. 2015. 2015 State forest resource management plan (Draft). On file at: Harrisburg, PA: Department of Conservation and Natural Resources, Bureau of Forestry. 193 p.

- The shelterwood system and related management prescriptions described by Brose et al. (2008) for oak/hickory and Marquis (1994) for maple/beech/birch can be highly successful at regenerating stands.
- Controlling composition and structure of understory vegetation in stands with entrenched competing vegetation typically require expensive treatments (Jackson and Finley 2011).
- Fencing is often needed to reduce deer impacts and facilitate application of herbicides and other controls (Jackson and Finley 2011).
- Fire is a useful and well-understood practice in Pennsylvania and restores a natural process (Brose et al. 2014).
- Developing adequate stocking of desired species requires vigilant stewardship through the sapling stage in many cases.
- Information available so far indicates a slow restorative process for understories with sparse regeneration and entrenched competing vegetation that requires long-term commitment (Latham et al. 2005).

Although the challenges of regenerating Pennsylvania's maturing forests are troublesome, they can be overcome by diligent planning and rigorous forest management activity. This is important because trends indicate less agricultural land will be reverting to forest and management of existing timberland will be the primary option for new stand development. Unlike other stages of succession, young forests are ephemeral and quickly grow to medium size. Establishment and maintenance of healthy young forests is likely to be one of the paramount issues facing Pennsylvania's environmental community in the 21st century.

Forest Structure

Background

Stand-size class and relative stocking are important descriptors of any forest. FIA categorizes the stand size based on the size of trees occupying a majority of the area within a condition and reports them as one of three classes: large diameter (minimum 11.0 inch d.b.h. for hardwoods and 9.0 inch d.b.h. for softwoods), medium diameter (5.0 inch to 10.9 inch d.b.h. for hardwoods and 5.0 to 8.9 inch d.b.h. for softwoods), and small diameter (less than 5.0 inch d.b.h.). These classes can be referred to as sawtimber, poletimber, and seedling/sapling, respectively and are also indicative of the forest developmental stage.

Relative stocking is a measure of the area occupancy of trees in a forested stand. Understanding stocking is critical to gaining a perspective on stand dynamics, especially competition between individuals, individual tree growth rates, and light distribution. FIA classifies stocking into five categories: overstocked (>100 percent), full (60-100 percent), moderate (35-59 percent), poor (10-34 percent), and nonstocked (0-9 percent). Overstocked stands are exceedingly dense, resulting in crowded trees fighting for limited resources at the expense of health and growth. Increased mortality and lack of regeneration, especially of shade-intolerant species, are characteristic of overstocked stands. Stands considered fully stocked are of sufficient density to effectively utilize the site resources, and moderately stocked stands have ample room for ingrowth with canopy gaps allowing light to reach the forest floor. Poorly stocked stands have sparse canopy cover and are open to colonization by invasive and undesirable species. Nonstocked stands are typically found after a severe disturbance, but have not been converted to a nonforest land use.

FIA evaluates stocking in two ways: using growing-stock trees only and using all live trees. Growing-stock trees are commercial species with less than two-thirds rough and rotten cull. Live-tree stocking includes trees of noncommercial species and cull trees. These trees do add value to a forest as food and habitat sources for wildlife and provide the diversity necessary for a healthy forest, but also occupy space that could grow trees of higher commercial value. Comparisons of growing-stock stocking and live-tree stocking provide some insight into the relative proportions of merchantable tree species and cull trees.

What we found

Pennsylvania's forests continue to grow in size class. In 2014, 11 million (67 percent) of the 16.3 million acres of timberland were classified as large diameter stands, up from 9.3 million acres (58 percent) in 2004 (Fig. 32). Conversely, over the same time period, the poletimber class decreased by 1.1 million acres to an estimated 3.7 million acres (23 percent). The small diameter class also decreased by roughly 300,000 acres resulting in a 2014 estimate of 1.5 million acres (9 percent). Eighty-three percent of all large diameter stands were in the fully stocked or moderately stocked classes (Fig. 33). Publicly owned timberland had a higher percentage of large diameter stands than privately owned timberland, 71 and 66 percent, respectively.

Eighty-five percent of Pennsylvania's timberland in 2014 was classified as fully (48 percent) or moderately (37 percent) stocked with all live trees. Nine percent was poorly stocked, 5 percent was overstocked, and about 1 percent of timberland was nonstocked. Removing noncommercial species and cull trees from consideration finds 3 percent overstocked, 38 percent fully stocked, 39 percent moderately stocked, 18 percent poorly stocked, and 3 percent nonstocked.

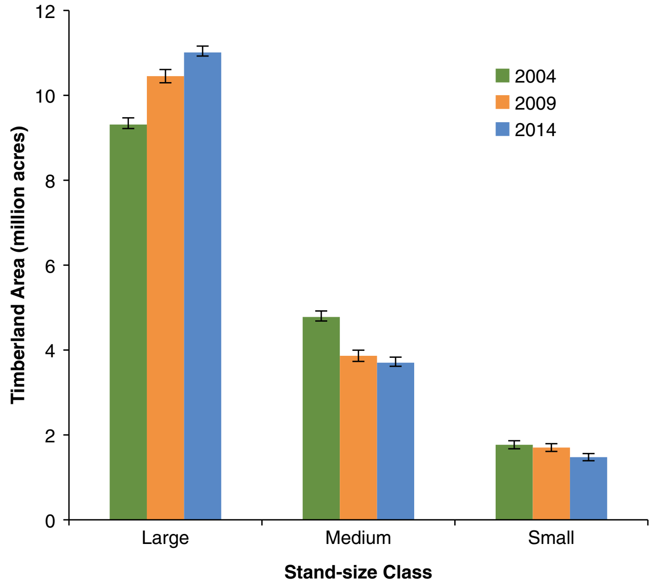

Figure 32.—Acres of timberland by stand-size class, Pennsylvania. Error bars represent a 68 percent confidence interval around the estimated mean.

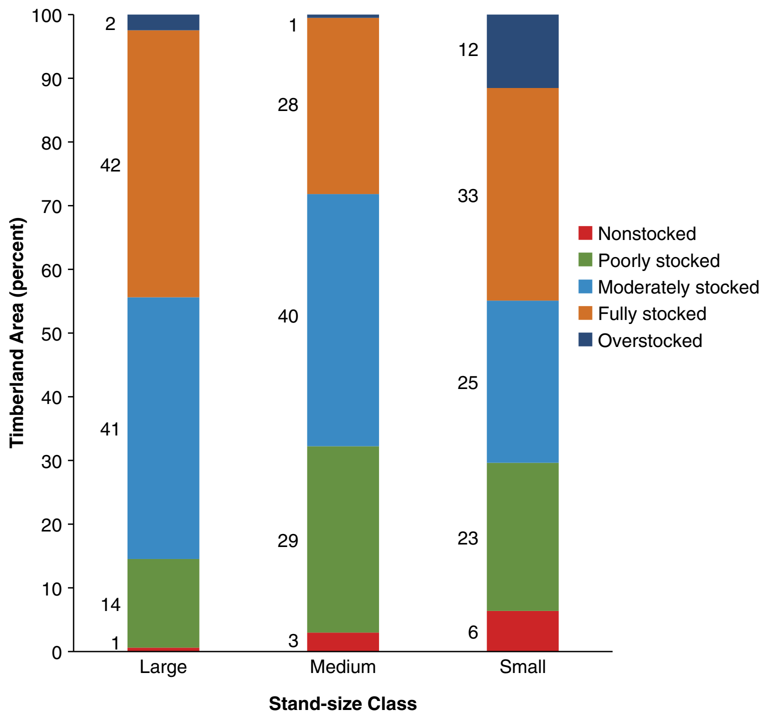

Figure 33.—Percentage of timberland area by stocking class and stand-size class, Pennsylvania, 2014.

Statewide, timberland area shifted to lower live-tree stocking classes with both upper classes losing acreage. The area of overstocked and fully stocked stands decreased 8 and 3 percent, respectively, between 2004 and 2014. The moderate and poor stocking classes both increased in area by 9 percent over the same time. When considering only growing stock, changes in area by stocking class were more pronounced. For growing stock, overstocked acreage decreased by 14 percent and fully stocked areas decreased by 10 percent. Stands moderately stocked with growing stock increased in area by 4 percent, and stands poorly stocked with growing-stock trees increased in area by 31 percent from 2004 to 2014.

On privately owned timberland, stocking of growing-stock trees differed substantially from all live trees (Fig. 34). Since 2004 the disparity in area poorly stocked with growing stock and poorly stocked with all live trees has grown substantially. The 2014 estimate of private timberland poorly stocked with growing stock was 2.4 million acres, double the estimated acreage poorly stocked with all live trees. In 2004, there was only 71 percent more area poorly stocked with growing stock compared to poorly stocked with all live trees. The proportion of private timberland classified as either fully or moderately stocked with growing-stock trees dropped from 79 percent in 2004 to 74 percent in 2014. Twenty-three percent of privately held timberland was classified as poorly stocked or nonstocked with growing stock trees, up from 18 percent in 2004. The widening disparity between growing stock and all live stocking indicates an increasing amount of timberland dominated by trees of little commercial value.

Publicly owned timberland showed similar trends from 2004 to 2014, but to a lesser extent (Fig. 35). Areas overstocked and fully stocked with commercial trees decreased 9 and 6 percent, respectively, while moderate and poorly stocked areas increased 12 and 30 percent, respectively. Eighty-three percent of the 4.5 million acres of public timberland in 2014 was either fully or moderately stocked with growing-stock trees and 14 percent was classified as poorly stocked or nonstocked, up from 11 percent in 2004.

What this means

A healthy mature forest has a diversity of species and tree forms and should have a greater stocking level for all live trees than just growing stock (because growing stock is a subset of all live trees). However, the increasing proportion of timberland moderately stocked to overstocked with live trees that is poorly stocked with growing stock suggests that some forces are at work selectively removing the growing stock from Pennsylvania's forests. Sustainable forest management becomes increasingly difficult and costly on land with poor growing-stock stocking. Although noncommercial species and cull trees have value, thinning them from fully stocked stands can increase resources available for the remaining growing-stock trees as

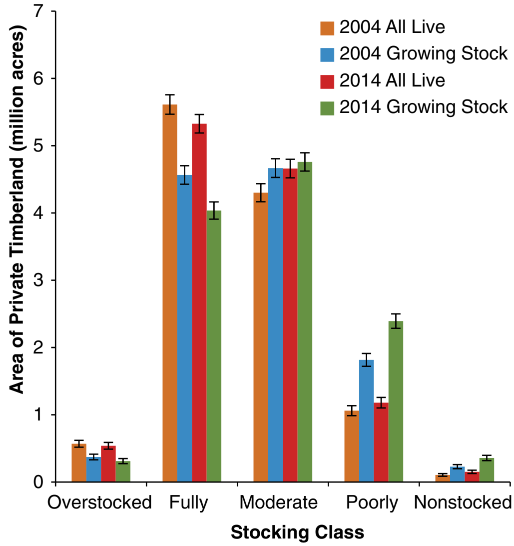

Figure 34.—Area of private timberland by stocking class, Pennsylvania, 2004 and 2014. Errors bars represent a 68 percent confidence interval around the estimated mean.

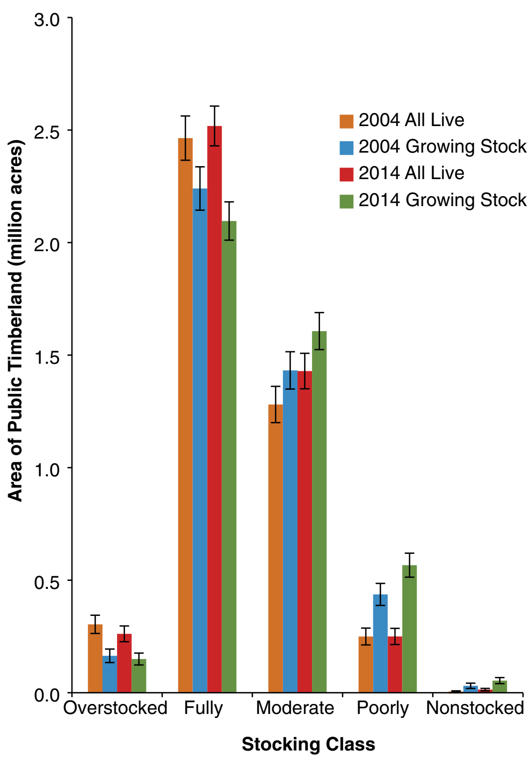

Figure 35.—Area of public timberland by stocking class, Pennsylvania, 2004 and 2014.

well as create canopy gaps for regeneration of less shade-tolerant species. The increasing amount of timberland acreage classified as poorly stocked with growing-stock trees may represent a legacy of poor management. Stands managed primarily for short-term economic gain disproportionately contain trees with poor form and low commercial value. This devalues the residual stand by removing the seed source for desirable species, allows the expansion of noncommercial tree species, and may provide opportunities for invasive plants to dominate the site. Private timberland with increased area of stands poorly stocked with commercially valuable trees is indicative of challenges facing individual landowners. Programs and education emphasizing the importance of sustainable forest management will be invaluable going forward to slow the proliferation of stands with high proportions of cull trees and noncommercial species. The National Woodland Owner Survey has found that less than 13 percent of family forest owners, with a total of 2.2 million acres, have received management advice for their timberland. Proper forest management techniques that balance the economic value of timber with the health of the residual stand are crucial for the long-term sustainability of the State's forest resources.

The continuing shift of acreage from small and medium diameter stands into large diameters indicates a lack of harvesting and disturbance sufficient to convert stands back to early successional stages. A diversity of forest successional stages supports a greater diversity of the wildlife species that depend on those forests to provide both food and cover. Additionally, forests that contain stands of multiple sizes may be more resilient to insect and disease outbreaks and other disturbances. Because the bulk of large diameter stands are either fully or moderately stocked, opportunities for management abound with stand improvement activities funded by the removal of a portion of the sawtimber. These opportunities are more available on timberland with high growing-stock stocking. Monitoring forest structure and identifying trends in the resource is crucial for Pennsylvania's forest sustainability.

Volume on Timberland

Background

Volume estimates provide the opportunity to evaluate trends in the wood resource, potential uses of that wood, and its economic value. FIA reports tree volume as sound and net volume of live trees and growing-stock trees (cubic feet), sawtimber trees (board feet, International ¼-inch rule), and biomass (dry tons). Each of these measures characterizes the wood resource in a different way and provides insight into its use and management. Cubic foot and board foot estimates quantify the volume of wood on timberland available for potential utilization. Biomass estimates help quantify carbon storage. Because of changes in procedures, comparisons to inventories prior to 2000 are less consistent for some measures.

FIA calculates a cubic foot volume for all trees 5 inches in diameter and larger. The sound volume of live trees makes deductions only for rotten and missing wood. Net sound-wood volume, also referred to as net volume, is sound volume with additional deductions for tree form, including sweep, crooks, and forks. It includes qualifying sections of cull trees (trees with more than two-thirds cull due to rot and form or those of a noncommercial species). Growing-stock trees must be of commercial species and contain less than two-thirds cull. The requirements to qualify as growing stock make it the most restrictive and subjective of the volume measures. Sawtimber is the volume in the saw-log portion of growing-stock trees. The minimum diameter at breast height for sawtimber trees is 11 inches for hardwood species and 9 inches for softwood species.

What we found

There is an estimated 41.7 billion cubic feet of sound wood volume on Pennsylvania timberland (Fig. 36). Eighty percent of this volume, 33.3 billion cubic feet, is contributed by growing-stock volume in growing-stock trees. Also contained within the boles of growing-stock trees is an additional 4.1 billion cubic feet of sound wood that is too defective to qualify as growing-stock volume. Trees not meeting growing-stock standards either because they have large amounts of defect or are noncommercial species are classified as rough or rotten "cull" trees. Rough and rotten cull trees account for a combined 4.2 billion cubic feet, or 10 percent of sound volume on timberland. In addition to the volume of trees growing on timberland, an estimated 1.8 billion cubic feet of sound volume is growing on reserved and other forest land, a 21.5 percent increase since 2004. Though the volume on reserved land is not available for harvesting, it provides habitat for wildlife and many ecosystem services, including carbon storage.

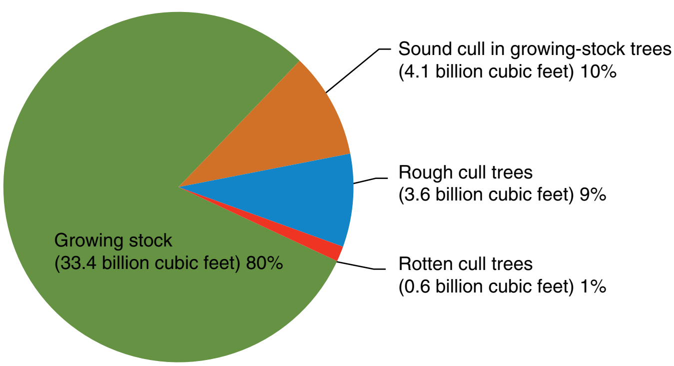

Figure 36.—Components of live sound wood volume on timberland, Pennsylvania, 2014.

Recent volume increases are a continuation of a 60-year trend. Since 2004, increases have been observed in sound wood volume (14.1 percent), net sound volume (12.9 percent), growing-stock volume (9.0 percent), and sawtimber volume (23.5 percent) on Pennsylvania timberland (Fig. 37). Net volume averages 2,244 cubic feet per acre of timberland across the State, two and a half times the volume estimated in 1955 (Fig. 38). Volume per acre is higher on public timberland than on private ownerships and greatest on the Allegheny National Forest; county and municipal ownerships had the largest percentage increase since 2004 (Fig. 39). Per-acre volumes are highest in the Southeast region and are lowest in the South Central region. (Fig. 40) These regions experienced the largest and smallest increases in per-acre volume since 2004, 20.3 percent in the Southeast region and 5.8 percent in the South Central region.

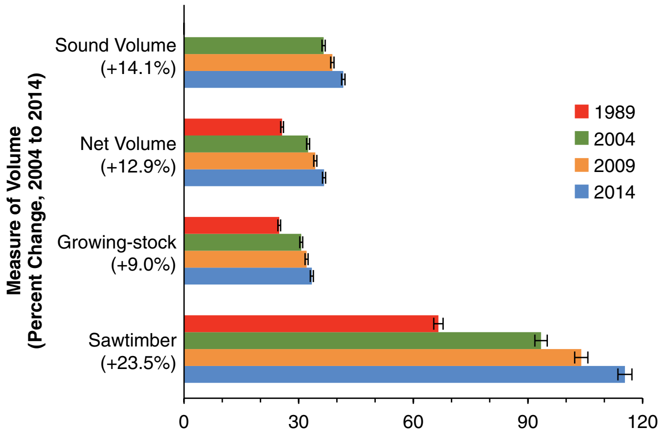

Figure 37.—Four measures of volume on timberland by inventory year, Pennsylvania. Volumes are expressed in billion cubic feet, except for sawtimber, which is in billion board feet (International ¼-inch rule). Note: 1989 sound volume not available due to procedural changes. Error bars represent a 68 percent confidence interval around the estimated mean.

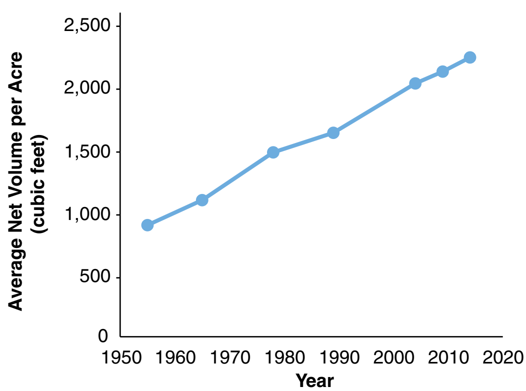

Figure 38.—Average net volume per acre on timberland, by inventory year, Pennsylvania.

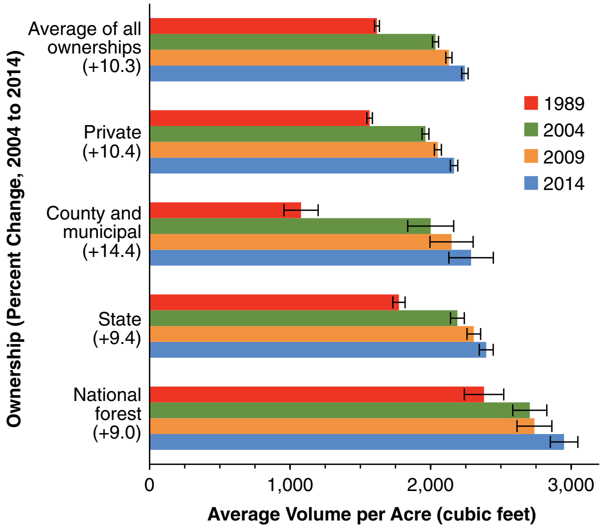

Figure 39.—Average net volume per acre of timberland, by major ownership and inventory year, Pennsylvania. Error bars represent a 68 percent confidence interval around the estimated mean.

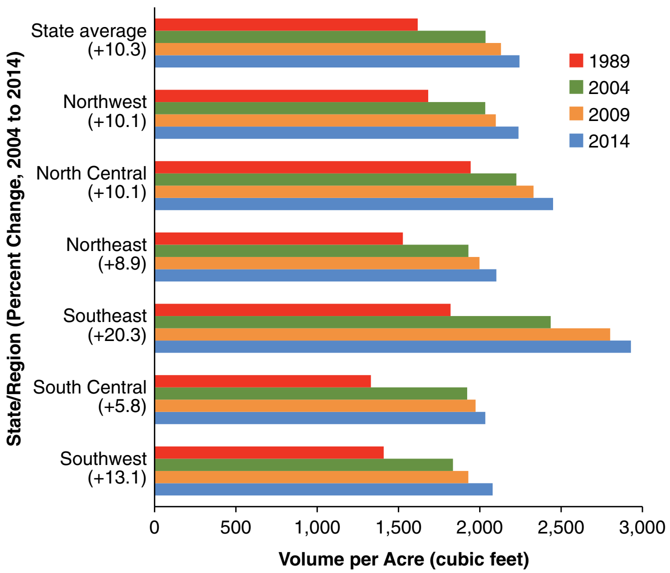

Figure 40.—Average net volume per acre of timberland, by region and inventory year, Pennsylvania.

Volumes have shifted toward the larger tree diameter classes, which is an indication of the aging forest age class distribution of Pennsylvania's forests. Between 2004 and 2014, net volume decreased by 6.7 percent in diameter classes less than 12 inches, while volume in classes 12 inches and larger increased by 21.9 percent (Fig. 41). All of the volume gains were in trees large enough to produce saw logs.

Red maple continues to be the most voluminous species followed by black cherry, northern red oak, sugar maple, and chestnut oak (Figs. 42, 43), but volume changes were inconsistent across species. Although most major species exhibited increases in volume, net volume decreases were observed for American beech, aspen, black locust, sassafras, and elm. Large percentage increases in volume were found in yellow-poplar, sweet birch, and white pine (Fig. 42).

Since 2004, sawtimber volume on timberland has increased by 23.5 percent and now totals 115.4 billion board feet. Ninety percent (104 billion board feet) of this volume is in hardwood species, making Pennsylvania the leading state in the Nation for growing hardwood sawtimber. Red maple is the leading sawtimber species by volume, followed by northern red oak, black cherry, sugar maple, and yellow-poplar (Fig. 44). Since 2004, all major species increased in board foot volume, although the increase for beech was significantly lower than for other species.

Across all ownerships, the distribution of hardwood sawtimber by tree grade changed very little between the 2004 and 2014 inventories. A little over 50 percent of hardwood sawtimber volume was contained in trees graded 1 and 2 (Fig. 45). In absolute terms, the volume in grades 1 and 2 increased by 26 percent to 54 billion board feet, while volume in the lowest grade (tie/local use) increased by 16 percent to 21 billion board feet. The distribution of grade by ownership shows that publicly owned lands have a higher proportion of sawtimber volume in the higher quality grades than privately held timberland. Public timberland has nearly 60 percent of its sawtimber volume classified as grade 1 or 2 (20.1 billion board feet) whereas private timberland has only 48 percent of its volume in the same grades (33.6 billion board feet; Fig. 46). Furthermore, most of the sawtimber volume gain on public timberland was in tree grade 1, whereas the bulk of the increase in private sawtimber volume was in both grade 1 and the lower quality grade 3.

Of the major species in the State, northern red oak and yellow-poplar have the largest percentage of their volume in grades 1 and 2, each with nearly 70 percent of their volume in these valuable grades (Fig. 47). Red maple is the leading species in board foot volume as well as other volume measures and generally grades more poorly than other major species. Beech has the lowest portion of volume in grades 1 and 2 (11 percent) and the highest portion in the low tie/local use grade (64 percent).

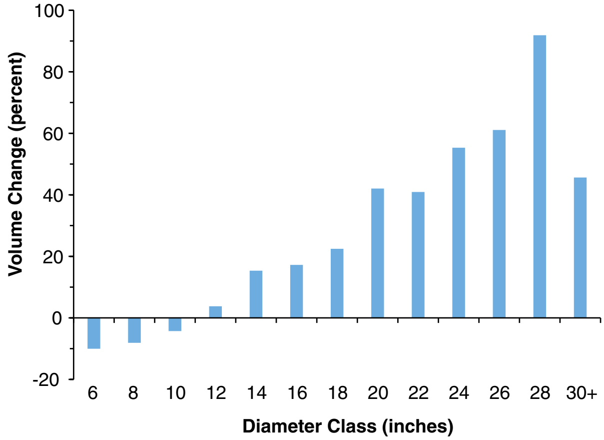

Figure 41.—Percent change in net volume, by diameter class on timberland, Pennsylvania, 2004 to 2014.

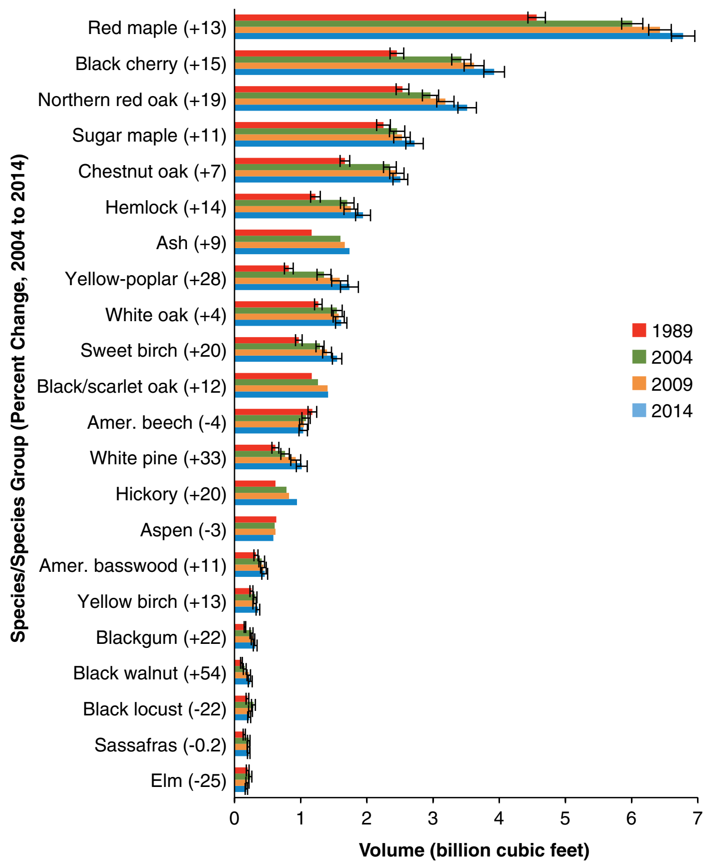

Figure 42.—Net volume for the 22 most voluminous species or species groups on timberland, by inventory year, Pennsylvania. Error bars represent a 68 percent confidence interval around the estimated mean and are not available for species groups.

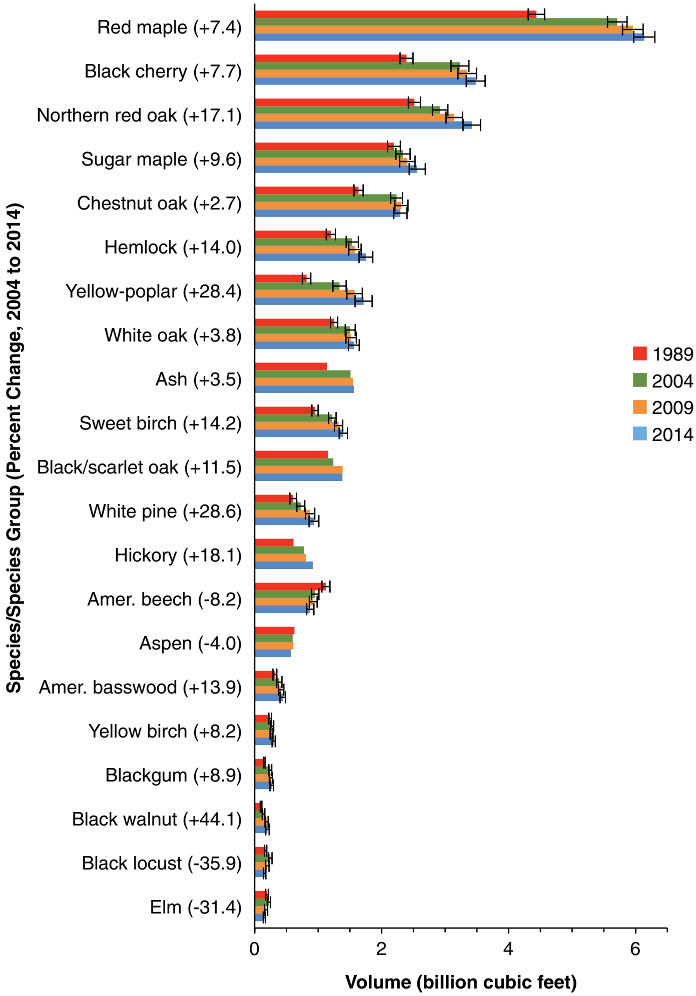

Figure 43.—Growing-stock volume by species or species group and inventory year, on timberland, Pennsylvania. Error bars represent a 68 percent confidence interval around the estimated mean and are not available for species groups.

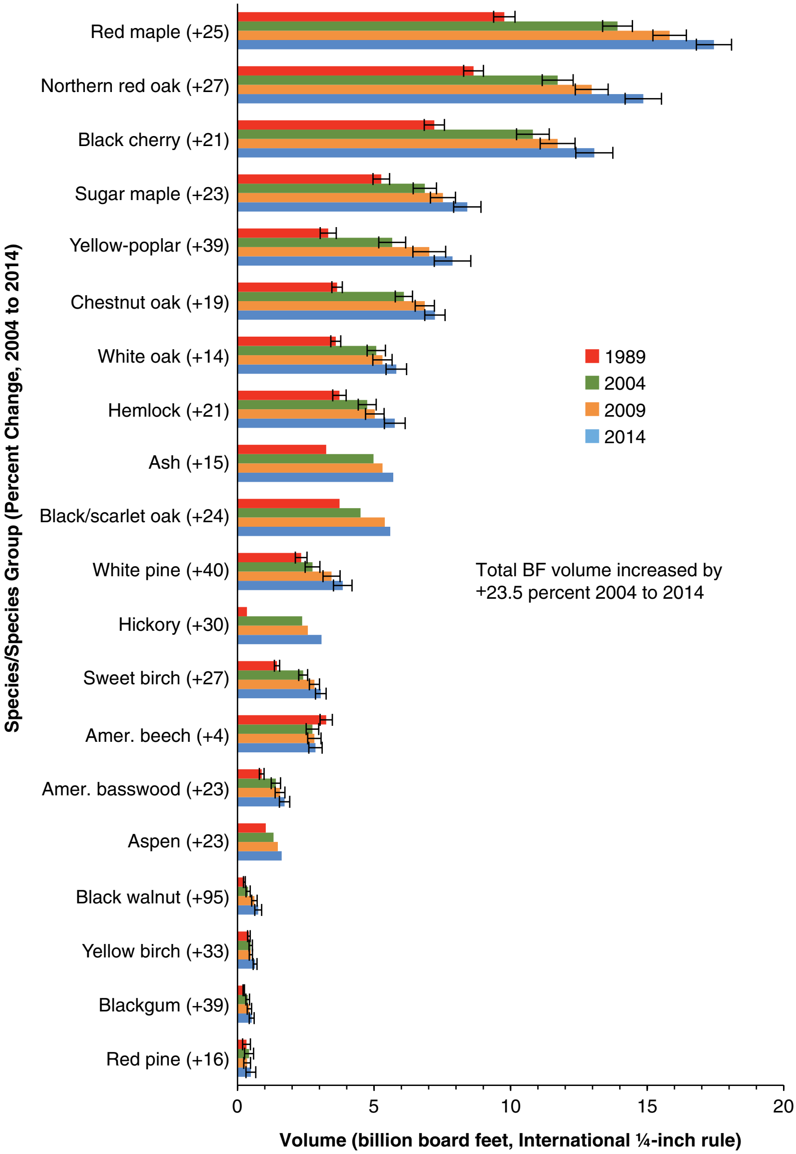

Figure 44.—Sawtimber volume on timberland by species or species group and inventory year, Pennsylvania. Error bars represent a 68 percent confidence interval around the estimated mean and are not available for species groups.

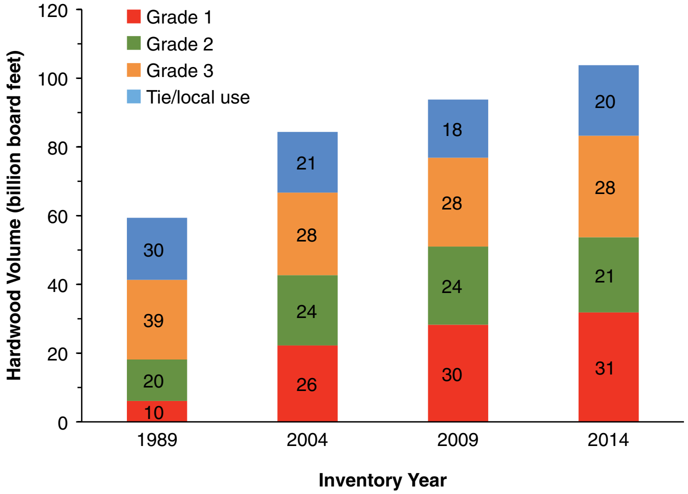

Figure 45.—Hardwood sawtimber volume by tree grade and inventory year with percentage of total volume by grade, Pennsylvania.

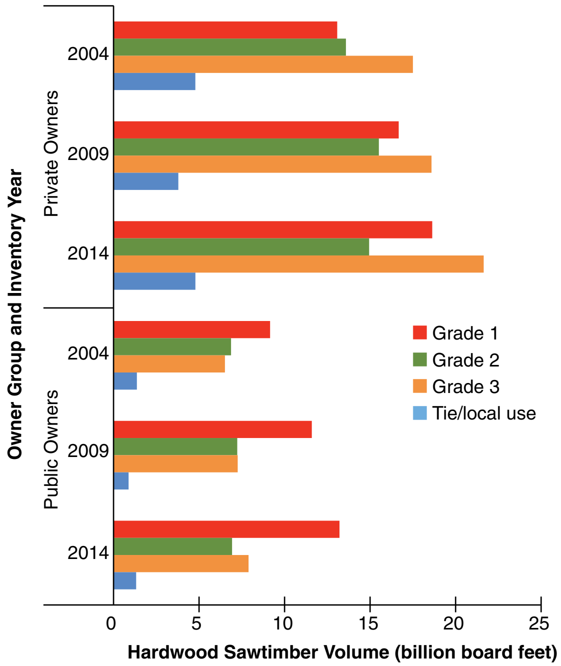

Figure 46.—Hardwood sawtimber volume by tree grade, ownership, and inventory year, Pennsylvania.

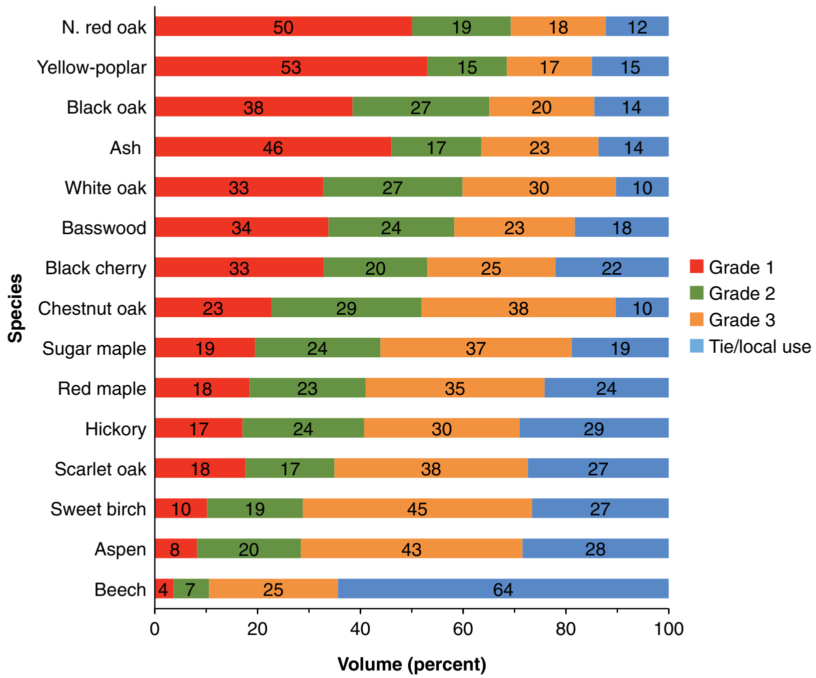

Figure 47.—Percentage of saw-log volume by tree grade for major species, Pennsylvania, 2014.

Among the regions, the species with the greatest net volume differ, but across all regions, the 10 most voluminous species represent about 80 percent of the total net volume in each region (Table 5). Red maple reaches its greatest proportion of net volume across the northern half of the State, where it represents at least one-fifth of the total volume in the Northwest (27 percent), North Central (23 percent), and Northeast (20 percent) regions. In the South Central region, oaks reach their highest proportion of total volume; chestnut oak, northern red oak, white oak, and black oak combined account for 42 percent of the total volume in the region. Across the State, species of ash represent between 3 (South Central region) and 10 (Southeast region) percent of total volume. Ash volume increased by 14.5 and 21.3 percent in the Northeast and Southeast regions, respectively, whereas changes in ash volume in other regions ranged from +6.2 percent in the North Central region to -2.5 percent in the South Central region. Yellow-poplar is the dominant species in the Southeast unit, where it increased in volume by 52.8 percent since 2004 and composes 22 percent of total net volume.

Table 5.—Ten most voluminous species by region, ranked by 2014 volume, and net volume by species, percentage of regional volume, and percent change in volume between 2004 and 2014, on timberland, Pennsylvania

Region		Volume in region, 2014 (million ft^3)	Volume as a percentage of unit volume	Volume percent change, 2004 to 2014
Northwest	Red maple	605	27	16.4
	Black cherry	287	13	-2.2
	Northern red oak	168	8	20.9
	Sugar maple	155	7	-0.4
	Ash	113	5	0.7
	Hickory	106	5	13.8
	Hemlock	106	5	47.1
	American beech	84	4	-11.8
	Yellow-poplar	77	3	2.3
	White oak	77	3	-24.2
	Regional total	**2,223**	**100**	**5.9**
North Central	Red maple	2,796	23	10.7
	Black cherry	1,630	13	11.9
	Sugar maple	1,277	10	7.7
	Northern red oak	1,065	9	14.7
	Hemlock	925	8	19.0
	Sweet birch	597	5	19.3
	Chestnut oak	550	4	16.1
	Ash	531	4	6.2
	American beech	486	4	-15.1
	White oak	467	4	6.0
	Regional total	**12,256**	**100**	**10.7**
Northeast	Red maple	1,443	20	11.8
	Chestnut oak	632	9	1.0
	Hemlock	631	9	14.2
	Northern red oak	536	8	13.1
	Sugar maple	532	8	7.0
	Ash	409	6	14.5
	Black cherry	397	6	19.0
	White oak	381	5	1.4
	Sweet birch	338	5	21.8
	American beech	269	4	6.3
	Regional total	**7,097**	**100**	**11.2**

(continued)

Table 5.—*(Continued)* Ten most voluminous species by region, ranked by 2014 volume, and net volume by species, percentage of regional volume, and percent change in volume between 2004 and 2014, on timberland, Pennsylvania

Region		Volume in region, 2014 (million ft^3)	Volume as a percentage of unit volume	Volume percent change, 2004 to 2014
Southeast	Yellow-poplar	552	22	52.8
	Ash	261	10	21.3
	Northern red oak	233	9	32.0
	Chestnut oak	204	8	36.8
	Red maple	179	7	14.6
	Black oak	174	7	10.4
	Hickory	153	6	30.8
	Black walnut	87	3	68.1
	Sweet birch	86	3	19.1
	Black cherry	83	3	24.0
	Regional total	**2,545**	**100**	**32.8**
South Central	Chestnut oak	960	15	-0.6
	Northern red oak	948	15	15.5
	Red maple	705	11	15.5
	White oak	396	6	1.2
	Sweet birch	382	6	18.3
	Black oak	293	5	9.8
	Black cherry	282	5	33.0
	Yellow-poplar	273	4	5.5
	Hickory	251	4	17.5
	Sugar maple	246	4	3.6
	Regional total	**6,217**	**100**	**8.3**
Southwest	Black cherry	1,244	20	16.8
	Red maple	1,051	17	15.8
	Northern red oak	564	9	33.5
	Yellow-poplar	556	9	39.4
	Sugar maple	481	8	34.0
	Ash	233	4	5.7
	White oak	230	4	22.5
	Hickory	170	3	36.9
	Black oak	150	2	33.7
	Chestnut oak	148	2	24.6
	Regional total	**6,304**	**100**	**20.0**

What this means

Pennsylvania is the heart of the Nation's hardwood resource. All measures of volume for the State's timber resources have continued to increase to levels unseen since the wide-scale harvesting of the early 20th century. Most of the inventory volume is in trees that meet minimum requirements to qualify as growing-stock trees. The concentration of volume increases in sawtimber-size trees explains why increases in board-foot volume (+23.5 percent) were higher than increases in growing-stock cubic-foot volume (+9.0 percent). As trees grow into sawtimber size, their economic value can increase markedly because they can yield higher value timber products. Despite the substantial increase in sawtimber volume, trends in tree quality and species composition raise concern for the sustainability of some high-value species. Furthermore, the shift of volume out of the poletimber size class into sawtimber is one more indication that Pennsylvania's smaller diameter trees are not being replaced.

Since 2004, sound wood volume increased by 14.9 percent, or 57 percent more than the increase of growing-stock volume, even though these two measures refer to bole volume between a 1-foot stump and a 4-inch top diameter. The difference is that measurements of sound wood exclude only rotten and missing wood, whereas measures of growing-stock volume also take deductions for rough cull (i.e., sweep, crook, and forks) and exclude trees classified as cull or noncommercial species. These measures indicate that low-value wood is increasing faster than the higher quality timber.

Overall forest quality is affected by changes in species composition, though other factors are also involved. Since 2004, yellow-poplar and northern red oak, which typically grade higher than other species, had large increases in board-foot volume. The low numbers of red oak seedlings and saplings indicate a lack of regeneration that will affect the abundance of this species in the future. The numbers of yellow-poplar seedlings and saplings appear adequate to sustain this species. Red maple continues to be the leading species by growing-stock and sawtimber volume and has had a large increase in volume since 2004. It makes up a large portion of both seedlings and saplings, suggesting that large amounts of red maple volume will continue to grow to sawtimber size. Because tree grades for red maple are typically poorer than other major species, the yield of clear high-value lumber from red maple logs is less than that of other species such as yellow-poplar and red and white oak. Currently, however, there is high demand for high-quality red maple lumber.

There is a large amount of sound volume in the cull sections of growing-stock trees and trees classified as rough and rotten cull. This wood could present opportunities for increased utilization of low-value wood, much of which is now left in the woods during harvest operations either in standing live trees or as logging residue. Although cull trees have low value for wood products, they are often of high value for wildlife habitat. Many of the same features that decrease the value for wood products increase these species' value for wildlife, such as bole cavities, large amounts of rot, and broken tops. Cull trees and portions of growing-stock trees left in the woods as logging residues provide habitat for wildlife and provide for nutrient recycling.

In Pennsylvania, 60 percent of sawtimber-size hardwood trees are less than 15.0 inches in diameter. These trees are too small for grade 1 and are given a lower grade solely on d.b.h. Forest landowners can receive better financial returns by practicing sustainable forestry and thinning around trees with potential to grow into quality grade 1 and 2 trees. By using silvicultural tools that promote high-value species and increase tree quality, landowners can improve the financial return from their harvest and improve residual forest health. Having markets for small trees and lower grade wood products, such as pallets, pulpwood, wood pellets, and biomass energy gives landowners opportunities to apply best management practices and improve overall stand quality. Without markets for low-value wood, landowners have little incentive to remove low-value trees during harvesting operations and many are left in the residual stand.

The diversity of tree species ensures that no single species represents more than about one-quarter of the total volume in any region. There are few areas in Pennsylvania where any species dominates by volume. This diverse mix reduces the impact of insects and diseases that affect a single species; however, this diversity may be in jeopardy. Statewide, red maple is the most numerous species, representing 22 percent of all trees over 5 inches. Because it has the second most seedlings—more seedlings than all oaks combined—red maple is likely to increase in dominance.

Changes in ash volume by region indicate that mortality and slowed growth caused by the emerald ash borer (EAB) has most likely affected ash in the four regions that represent the western two-thirds of the State. The impact of EAB has not yet shown up in the data for the two eastern regions. Currently ash species represent between 3 (South Central region) and 10 percent (Southeast region) of total volume. The impact of EAB will be proportional to the ash volume, so future impacts are likely to be greatest in the Southeast region as it continues to move east, although EAB is likely to cause decreases in ash volume throughout the State.

The high volumes are further evidence that Pennsylvania's forests are maturing and trees continue to increase in size. The lack of management to replace some portion of this older forest with younger stands that will grow the sawtimber of the future is a concern. This maturing is occurring over the broad landscape. Larger and older trees may be more susceptible than younger trees to windstorms, ice storms, drought, and exotic insects and diseases, all of which may increase. Furthermore, because the majority of growth is now occurring on large trees, there are fewer trees growing into the sawtimber size class. Declining ingrowth into the sawtimber size class places increasing importance on practicing good forest management to maintain a high-quality resource. Because of the large portion of Pennsylvania's wood resource contained in large sawtimber-size trees of desirable species, the production of high-quality lumber is the likely use for the bulk of its hardwood resource and the main goal of most forest management. Pulpwood, biomass, and wood for low-value uses such as pallet lumber are typically by-products of managing for high-quality timber in the State.

Components of Annual Volume Change: Growth, Removals, and Mortality

Background

Well-tended forests supply a continuous flow of products and services without impairing long-term productivity or the ecological integrity of the forest. One way to judge the sustainability of a forest is to examine components of annual change in inventory volume from the perspectives of growth, removals, and mortality. Net growth includes growth (accretion) on trees measured previously, ingrowth[3] of trees reaching the 5-inch threshold for volume measurement, deductions for mortality due to natural causes, and tree volume on land reverting to forest. Removals include trees harvested and trees removed from the inventory because the forest land was converted to a nonforest use. On timberland, removals also include trees on land reclassified as reserved or other forest land. Analysis of these individual components can help us better understand causes for net change in volume.

What we found

Tree growth in Pennsylvania has greatly outpaced mortality and removals during the past 50 years. The most recent inventory revealed that since 2009, gross growth in the net volume of live trees on timberland is more than 1.1 billion cubic feet annually (Fig. 48). Annual mortality averages 322 million cubic feet, resulting in a net growth of 807 million cubic feet per year. Annual removals averaged 340 million cubic feet and result from harvest (87 percent), land-use change to nonforest (12 percent), and land-use change to other forest land (1 percent), leaving an annual net increase of 467 million cubic feet on Pennsylvania's timberland (Fig. 48). As a percentage of the current inventory, gross growth was 3.1 percent, mortality was 0.9 percent, net growth

[3] Ingrowth on timberland refers to the estimated net volume of trees that became 5.0 inches d.b.h. or larger during the period between inventories as well as the estimated net volume of trees 5.0 inches d.b.h. and larger growing on land that was reclassified from nonforest to timberland.

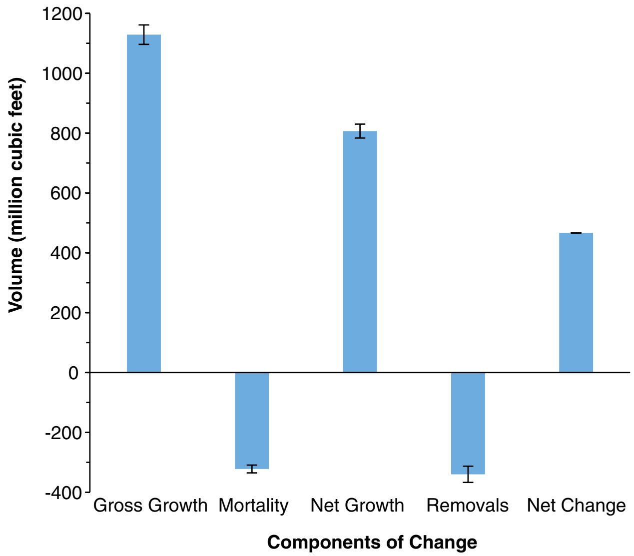

Figure 48.—Average annual components of change in net volume on timberland, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

was 2.2 percent, and removals were 0.9 percent. These result in an average annual net increase in total volume of 1.3 percent (Table 6).

On land classified as timberland in both 2009 and 2014, 77 percent of net growth was on trees previously in the 6-inch diameter class and larger (accretion) and the remaining 23 percent was from trees that were less than the 5-inch threshold in 2009 and are now 5 inches in diameter or larger (ingrowth). Fifty-eight percent of the accretion was on trees that previously were in diameter classes 12 inches and larger (sawtimber size) (Fig. 49).

Statewide, 87 percent of the removals were attributable to harvesting on land that remained in timberland, 12 percent was on timberland diverted to a nonforest land use, and 1 percent was from timberland reclassified to other forest land. The regions with the highest percentage of removals due to land-use change were the Northeast (27 percent) and the Southwest (17 percent). On land classified as timberland in both 2009 and 2014, removals were concentrated on trees in the 14- to 18-inch diameter classes in the 2009 inventory (Fig. 50). These classes account for 45 percent of these harvest removals by volume.

Harvests were primarily from highly stocked stands. Sixty-one percent of harvest removals came from stands that previously had a live-tree basal area greater than 120 square feet per acre and 30 percent from stands with previous basal areas of 81 to 120 square feet per acre. The 2014 inventory found evidence of harvest on 1.2 million

Table 6.—Average annual components of change in net volume as a percentage of current volume on timberland, by region, Pennsylvania, 2014

Pennsylvania region	Gross growth	Mortality	Net growth	Removals	Net change
	percent				
Northwest	3.7	0.8	2.9	1.4	1.6
North Central	2.4	0.7	1.8	1.0	0.8
Northeast	3.1	1.0	2.1	1.0	1.1
Southeast	4.0	0.9	3.1	0.8	2.3
South Central	3.2	1.3	1.9	0.9	1.0
Southwest	3.7	0.8	2.8	0.7	2.2
State	**3.1**	**0.9**	**2.2**	**0.9**	**1.3**

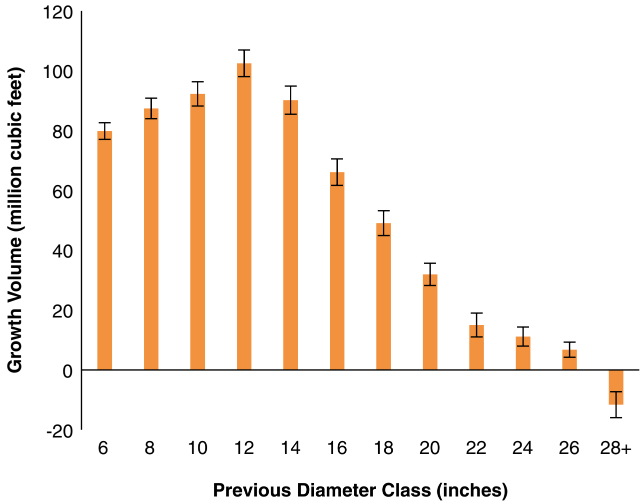

Figure 49.—Average annual net growth (volume) on live trees (i.e., accretion) by 2009 diameter class on timberland, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

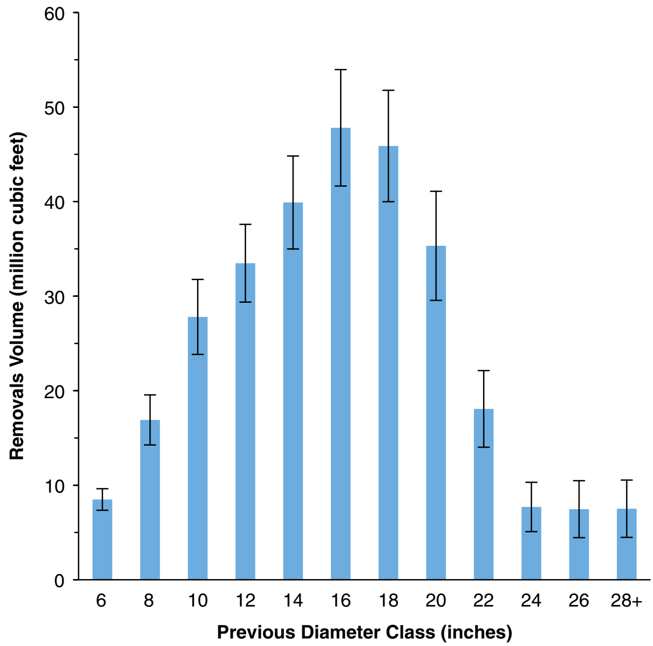

Figure 50.—Average annual removals (volume) by 2009 diameter class on timberland, Pennsylvania, 2014. Data exclude removals due to forest land being diverted to nonforest uses. Error bars represent a 68 percent confidence interval around the estimated mean.

acres during the 5 years between plot measurements. A fairly high density of trees was retained on most of these harvested acres. Thirty-one percent of the harvested area currently has a basal area per acre between 81 and 120 square feet per acre, and 22 percent currently has a basal area of at least 120 square feet. Only 16 percent of the harvested area currently has a basal area of less than 40 square feet. On timberland with evidence of harvesting over the 5-year remeasurement period, volume currently averages 1,837 cubic feet of sound wood per acre. This is equivalent to 81 percent of the average volume on timberland with no evidence of harvesting over the same time period. Trees previously classified as growing stock had a higher rate of removal, 0.9 percent per year, than trees that were classified as cull, 0.4 percent per year.

On timberland, the ratio of total net growth to removals (G/R) averaged 2.4:1 over the 5-year period between plot measurements. This compares to an average G/R ratio of 2.0:1 during the 2009 inventory. Most of the increase in the G/R ratio is due to a 21 percent decrease in removals since the 2009 inventory. If growth and removals due to land-use change are excluded, the current G/R ratio is 2.3:1. The G/R ratio was lowest in the North Central region (1.8:1), where removals were 37 percent of the statewide removals and growth accounted for 27 percent of the State's net growth. The G/R ratio was highest in the Southwest and Southeast regions, where growth outpaced removals by ratios of 4.3:1 and 3.9:1, respectively (Fig. 51). Growth-to-removals ratios were 2.3:1 on privately owned timberland and 2.9:1 on publicly owned timberland.

In terms of growth and removals by species, red maple had the largest volume of both growth and removals, accounting for 18 percent of total growth and 16 percent of removals; and together oak species account for 19 percent of growth and 21 percent of removals (Fig. 52). Growth-to-removals ratios varied considerably among major species in the State, with various reasons for individual species having high and low ratios. Blackgum and sweet birch have relatively high G/R ratios, 5.8:1 and 3.9:1, respectively, because of large numbers of small trees crossing the 5-inch threshold for measurement (ingrowth) and low removals. Additionally, blackgum has very low mortality. Conversely, yellow-poplar has a high G/R ratio of 4.2:1 because of growth on large trees (accretion) with low recruitment into the 6-inch class and low mortality. Despite large amounts of ingrowth for American beech, this species had low net growth because of high mortality. Generally net growth for the oaks when compared to other species was lower because only small amounts of growth were attributed to ingrowth and large amounts of removals occurred in large trees. In contrast, the growth observed in red maple and black cherry was balanced across diameter classes. Statewide net growth exceeded removals for all major species, with the exceptions of American beech and aspen (quaking and bigtooth aspen combined), where removals outpace growth by ratios of 0.9:1 and 0.7:1, respectively.

What this means

Today's well-stocked forests are a product of growth consistently outpacing removals during the last 60 years and the surplus of timber accumulating in the forest. Since 2009, net growth has occurred at more than twice the rate of removals, with the net change amounting to an annual increase of 1.3 percent in inventory volume. This implies that the current level of removals is sustainable and that increases in volume will continue at the State level and in all regions. Where harvesting took place, the cuts were light and retained a relatively high volume of residual trees. These light harvests influence the future growth and species composition of Pennsylvania's forests. Future growth will tend to occur on residual trees rather than ingrowth in response to gaps in the canopy. The reproduction that does occur will favor more shade-tolerant species at the expense of shade-intolerant species. The growth occurring on trees previously measured and especially on trees 11 inches in diameter and larger means there are few new trees growing into the sawtimber size classes and in many cases stands are composed of residual trees left after harvest. This puts increased importance on practicing good forest management, where high-quality crop trees are retained and tended toward future harvests.

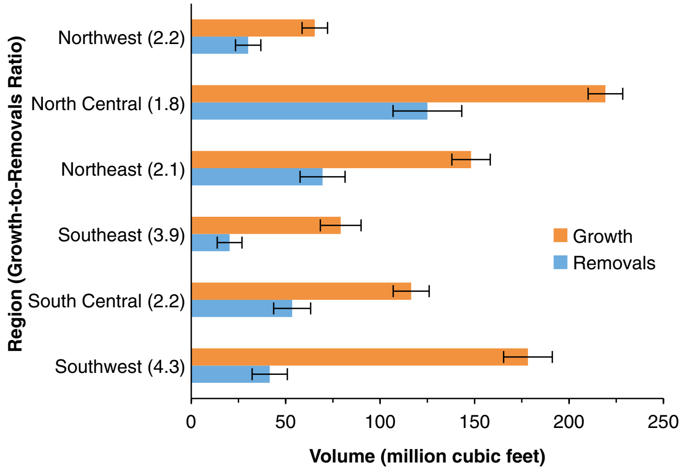

Figure 51.—Average annual growth and removals of net volume on timberland by region, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

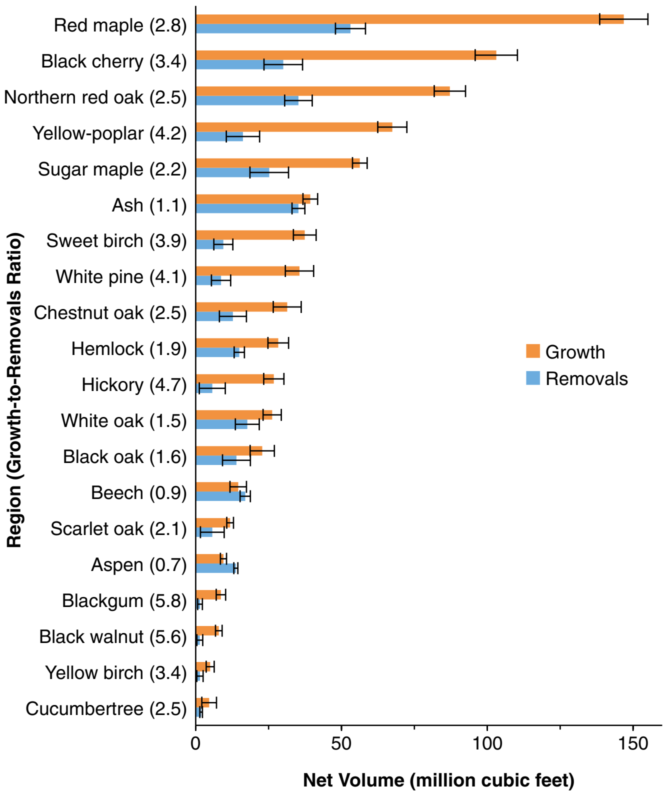

Figure 52.—Average annual growth and removals of net volume on timberland by species, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

Over half the removals in the State occurred in the North Central and Northeast regions. These regions contributed a disproportionate share of the Commonwealth's total removals, although they experienced lower growth rates than other regions of Pennsylvania. The Southwest and Southeast regions had the highest growth rates and low harvest rates; as a result, these regions had the highest annual volume increase. The concentration of large urban areas and fragmented, small ownerships most likely impedes harvesting in these regions.

Comparing the G/R ratios of individual species to the average ratio for all species (2.4:1) reveals which species are increasing in importance and which are decreasing. The high G/R ratios for red maple, hickory, sweet birch, and blackgum indicate these species will increase in importance in Pennsylvania's forests. Yellow-poplar also has a high G/R ratio, but because much of its growth is on large diameter trees with little ingrowth, the ratio is likely to decrease. Similarly, for oak species, most growth is attributed to accretion on large trees; because of low ingrowth into the 5-inch diameter class, the rate of future growth in oaks is likely to decrease. The G/R ratio for ash indicates a positive annual change in volume. However, future growth is being threatened by the exotic insect pest emerald ash borer (EAB). Currently, ash species account for 5 percent of net growth in Pennsylvania. This is unlikely to continue as the EAB spreads across the State, slowing ash growth and increasing mortality.

Tree Mortality

Background

The volume of trees that die from natural causes, such as insects, diseases, fire, wind, and competition from other trees, is reported as mortality; harvested trees are not included in mortality estimates. Tree mortality is a natural process that occurs in a functioning ecosystem. Dramatic increases in mortality can indicate forest health problems, such as invasions by exotic insects and diseases.

What we found

In Pennsylvania, the average annual rate of mortality for live trees on timberland was 0.9 percent over the 5-year remeasurement period. This is the same rate found in the 2009 inventory. If only growing-stock trees are considered, the mortality rate for this period is 0.7 percent, again the same as the 2009 inventory. The mortality rate of live trees in Pennsylvania was lower than in the neighboring states of Ohio (1.2 percent), New York (1.1 percent), New Jersey (1.1 percent), Maryland (1.0), and West Virginia (1.0). Rates were highest in the South Central region (1.3 percent), and lowest in the North Central region (0.7 percent) (Fig. 53).

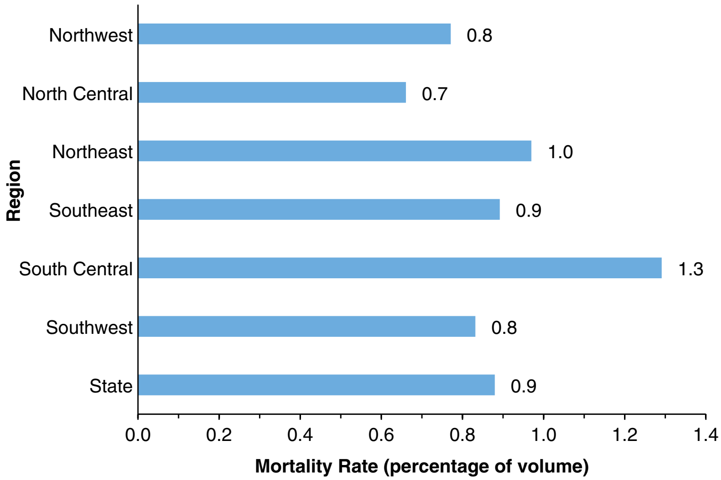

Figure 53.—Average annual mortality as a percentage of current live tree volume on timberland by region, Pennsylvania, 2014.

Mortality rates were generally higher for smaller diameter trees than for larger ones, although rates were highest for trees in the 30-inch diameter class and larger (Fig. 54). The mortality rate in the 6-inch class was 1.6 percent per year, nearly double the average rate across all diameter classes. The 20-inch diameter class had the lowest mortality rate at 0.5 percent. Trees less than 11.0 inches in diameter accounted for 37 percent of the total mortality by volume even though they represent only 26 percent of total tree volume.

Red maple, the leading species by volume in the State, had an annual mortality rate of 0.5 percent—nearly 50 percent less than the State average for all species. Other species with low mortality were blackgum, yellow-poplar, and white pine: 0.2, 0.3, and 0.4 percent, respectively. Species with highest annual mortality rates were elm (8.3 percent), black locust (4.9 percent), aspen (2.6 percent) and sassafras (1.9 percent) (Fig. 55).

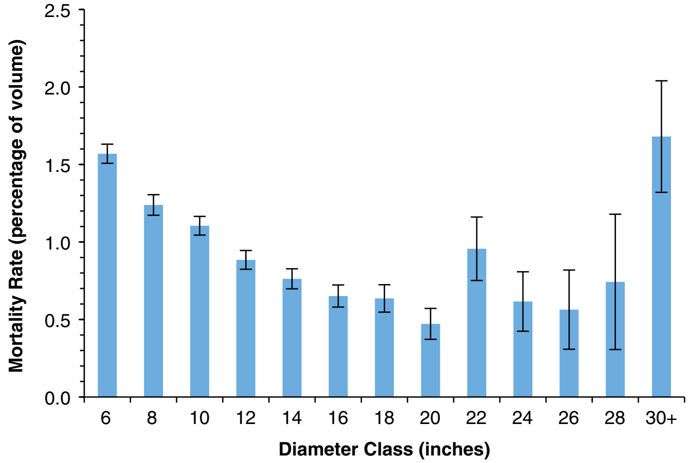

Figure 54.—Average annual mortality as a percentage of current live tree volume on timberland by previous diameter class, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

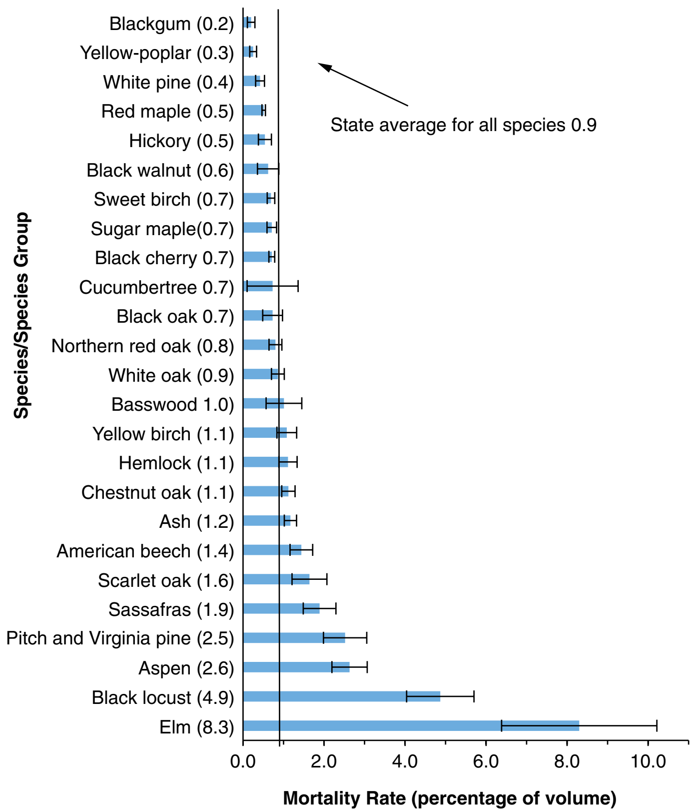

Figure 55.—Average annual mortality as a percentage of current live tree volume for major species on timberland, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

What this means

Mortality rates in Pennsylvania are lower than surrounding states. Pennsylvania's lower rates, although difficult to explain, could be the result of a currently greater impact of insects and diseases, such as beech bark disease, Dutch elm disease, elm yellows, and emerald ash borer in surrounding states (see also Tree Pests and Diseases of Special Concern section starting on p. 106). Further, a greater portion of stands in other states may be in the stem exclusion stage of development, where small tree mortality is expectedly high. Much of the mortality in Pennsylvania is attributable to insects and diseases that target specific species, or stand dynamics. Currently beech, elm, hemlock, and ash species are under attack by exotic insects and diseases and have mortality rates higher than the State average for all species.

Stocking and age-class data for Pennsylvania describe a maturing forest and crowded conditions. As trees compete for light and growing space, some fall behind their neighbors, lose vigor, and succumb to insects, diseases, and their inability to compete for resources. This is evident in the higher mortality rates in small diameter classes, where trees are in the understory and have live crown ratios of 20 percent or less. Species classified as early successional and intolerant of shaded conditions, such as aspen, black locust, pitch and Virginia pine, and sassafras, all have high mortality rates and should be expected to decline in importance as stands age.

Mortality rates vary between species, with many species deviating substantially from the State average. Having a large diversity of species contributes to the overall resilience of Pennsylvania's forests, as the impacts of insects and diseases that attack individual species is confined to a smaller portion of the resource.

Forest Carbon

Background

Forests sequester carbon from the atmosphere, thus playing a critical role in global climate change. Because the dry biomass of trees is about 50 percent carbon, forests contain the largest reserves of sequestered carbon among terrestrial ecosystems. Regional and national greenhouse gas reporting forums include forest carbon stocks because increases in these carbon stocks represent quantifiable partial offsets to other greenhouse gas emissions. For example, carbon sequestered by U.S. forests represented an offset of more than 11 percent of total U.S. greenhouse gas emissions in 2013 (U.S. Environmental Protection Agency [EPA] 2015). The continuing increase in Pennsylvania forest carbon stocks contributes to this offset.

Carbon accumulates in growing trees via the photosynthetic process and is stored as wood. Over time, this stored carbon also accumulates in dead trees, woody debris, litter, and forest soils. Roots are the belowground portion of trees and are reported as part of live biomass, not in the soils estimates. For most forests, understory grasses, forbs, and non-vascular plants represent minor pools of carbon stocks. Carbon loss from a forest stand includes mechanisms such as respiration (including live trees and decomposers), combustion from wildland fires, runoff or leaching of dissolved or particulate organic particles, or direct removal such as the harvest and use of wood. Regarding greenhouse gas reporting, it is important to note that not all losses result in release of carbon dioxide to the atmosphere; many wood products not used as a fuel source represent continued long-term carbon sequestration.

The carbon pools discussed or depicted here are:

- Living plant biomass (live trees ≥1 inch d.b.h. and understory vegetation)
- Dead wood (standing dead trees, down dead wood, and forest floor litter)
- Soil organic matter exclusive of coarse roots and estimated to a depth of 1 meter (3.3 feet).

Carbon estimates for ecosystem pools are based on sampling and modeling. Because of the variability in information available for each pool, greater interpretive results can be derived for certain carbon estimates than for others. For example, due to the level of sampling and availability of allometric relationships applied to the tree data, the greatest confidence is in the estimate of live tree carbon. Limited data and high variability mean lower confidence in the soil organic carbon estimates and hence, limited interpretation. Additional information on current approaches for determining forest carbon stocks are described in U.S. EPA (2015), U.S. Forest Service, Forest Inventory and Analysis (2014), and O'Connell et al. (2014). The carbon estimates provided here are consistent with the methods used to develop the forest carbon reported in the U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013 (published April 2015); however, this 2014 inventory summary includes some newer data relative to the Pennsylvania forest contribution (U.S. EPA 2015).

What we found

Total forest ecosystem carbon stocks in Pennsylvania are estimated to be 1,298 million tons of carbon, a 4 percent increase from 5 years ago. Live trees and soil organic carbon are the largest pools and account for 87 percent of forest carbon stocks (Fig. 56). Thirty-one percent of carbon is in the wood and bark of boles of trees at least 5 inches d.b.h.

Average aboveground carbon per acre (Fig. 57) and net accumulation increase with stand age; as such, total carbon stocks are the product of carbon per acre and total acres of forest

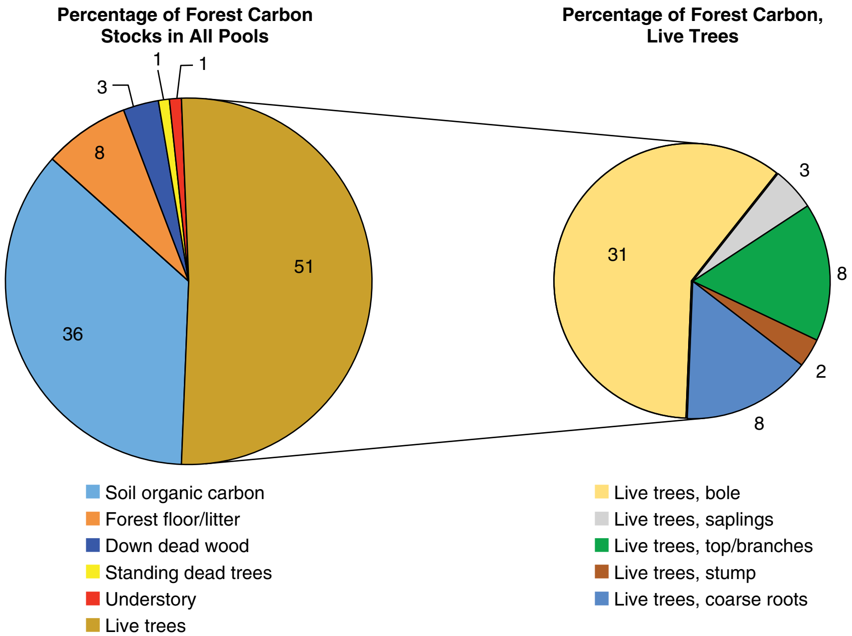

Figure 56.—Percentage of total forest carbon stocks by detailed pool, Pennsylvania, 2014. Percentages may not sum to totals due to rounding.

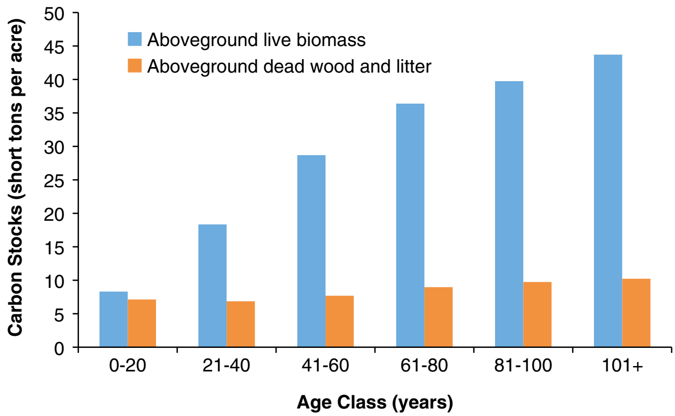

Figure 57.—Aboveground carbon stocks per acre for live and dead components on forest land by stand-age class, Pennsylvania, 2014.

within each age class. The majority of carbon stocks are in the mid- to older-age classes. Sixty-three percent of total aboveground carbon stocks are in the two age classes from 61 to 100 years old (57 percent of forest land); in contrast, the two youngest age classes together account for only 7 percent of forest carbon stocks (14 percent of forest land).

Species composition also affects the amount of carbon sequestered. Note that the variability in average carbon per acre (shorts tons) for the major forest-type groups identified in Pennsylvania (Fig. 58) is most closely associated with variability in live-tree biomass. Statewide, 87 percent of total carbon was in the two forest-type groups that make up 86 percent of forest land area: oak/hickory (52 percent) and maple/beech/birch (34 percent).

The current carbon estimation methods and data were also applied to the 2004 and 2009 Pennsylvania forest inventories (Fig. 59) to produce summaries consistent with those provided here for the 2014 inventory. Overall forest carbon per acre increased by 3 percent relative to 5 years ago, and live tree carbon per acre values increased by 5 percent. Total estimated forest land increased by 1 percent over the same period; total carbon stocks in 2014 are therefore 4 percent greater than the equivalent values calculated for 2009, surpassing the 3 percent increase between 2004 and 2009.

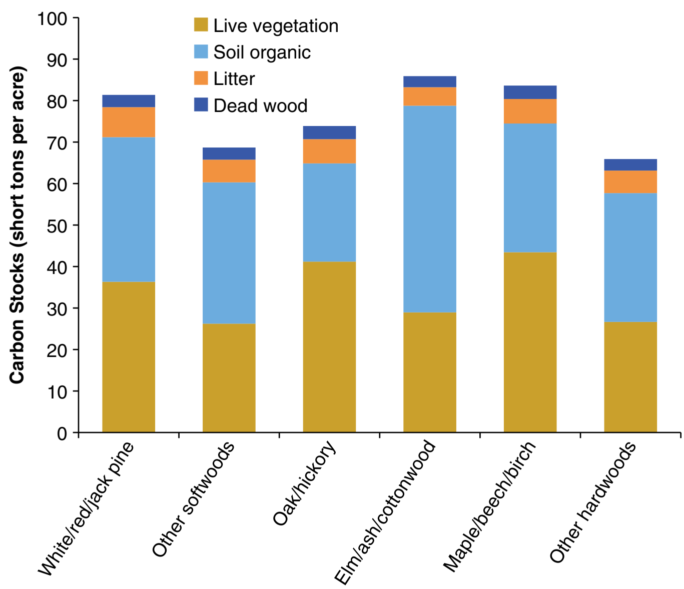

Figure 58.—Average carbon stocks per acre on forest land by forest-type group and carbon pool, Pennsylvania, 2014.

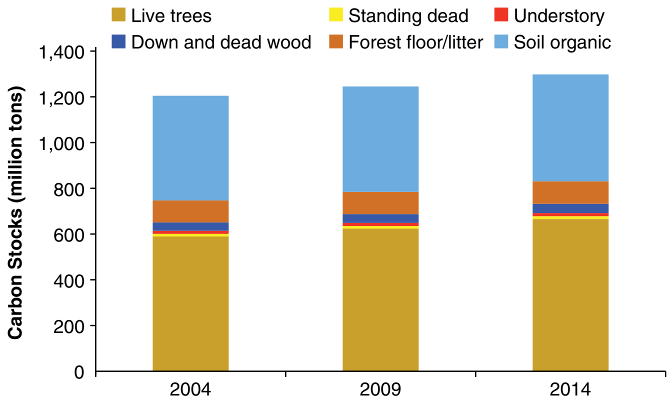

Figure 59.—Total carbon stocks on forest land by carbon pool and inventory year, Pennsylvania.

What this means

In general, forest carbon stocks and changes broadly reflect other measures of forest resources such as stand age, volume, or stocking. Carbon summaries are useful to compare Pennsylvania's carbon trends to those of other states, regions, and the Nation. In brief, the carbon summaries show:

- Just over half of total carbon is in live trees
- The majority of carbon is in stands of 61 to 100 years
- Specific stand-level carbon varies
- Overall forest carbon in Pennsylvania has increased over the past 5 years.

For any stand, carbon stocks depend on site history, management, stand age, and tree composition and size, much of which can be heavily influenced by forest management practices. Removal of wood products used in construction and furniture manufacturing results in long-term carbon storage and makes room for new, younger stands to capture and store new carbon. Although older forests store more carbon, younger age classes show greater rates of increase in carbon sequestration. Stands show the greatest rate of carbon accumulation moving from the 0-20 year class to the 21-40 year class and 41-60 year class. This storage is equivalent to an additional 10 tons of carbon per acre for each increase of one age class. Subsequently, more-mature stands gain only 3 to 4 tons of carbon per acre with each increase in age class (from 61-80 years to 81-100 years old and then to the 101+ age class). Thus, managing forests for a more balanced age-class distribution could result in greater rates of increase in carbon stocks in the future. Continued monitoring of forest carbon is prudent as we look for ways to mitigate the effects of increasing atmospheric carbon dioxide levels.

Forest Indicators of Health and Sustainability

Hayscented fern bed in sugar maple forest in Potter County. Photo by Thomas Albright, U.S. Forest Service.

Regeneration Status

Background

Pennsylvania's forest ecosystems face numerous regeneration stressors (e.g., herbivory, competing understory vegetation, invasive plants, insects, diseases, and climate change). As stands that make up these systems mature and undergo stand replacement disturbances, it is imperative to know the condition of the regeneration. Abundance and composition of tree seedlings drive the sustainability of forest ecosystems in the early years of stand development and set the stage for future composition and structure. The vitality of timber and invaluable ecosystem services, such as soil conservation, watershed protection, scenic beauty, and opportunities for personal enjoyment are other important reasons that forest regeneration bears careful monitoring.

To fill the need for more detailed information on regeneration in Pennsylvania, the Northern Research Station (NRS), Forest Inventory and Analysis (FIA) program added regeneration indicator protocols to a subset of NRS-FIA sample plots measured in the growing season during the periodic inventory in 1989 (McWilliams et al. 1995). This marked the beginning of the Pennsylvania Regeneration Study (PRS). The PRS protocols continued with the annual inventory system that was initiated in 2000. The procedures measure all established trees seedlings (less than 1-inch d.b.h.) at least 2 inches tall by height class and include an herbivory impact assessment for the area surrounding the sample location. In addition to core results used in standard reports, the data were analyzed for regeneration adequacy using metrics developed for the PRS (McWilliams et al. 2015). The PRS was implemented to provide empirical results on the quality and quantity of advance regeneration because of concern that herbivory and other factors were impeding regeneration success across the State. The PRS approach compares the number of seedlings and saplings encountered on NRS-FIA samples to accepted regeneration management guidelines to classify each sample as having adequate regeneration or not. Only samples from plots 40- to 75-percent stocked with live trees are used so that findings are limited to samples with adequate light for establishing advance regeneration. The metrics are adjusted using the browse impact code because forests under higher herbivory pressure require more seedlings for adequate regeneration than those under less pressure.

The regeneration indicator findings are used by forest managers and policy makers making decisions to improve landscape-scale regeneration. This section delivers an update of regeneration status since the previous report.

What we found

As Pennsylvania's forest stands continue to age, young forest has become rare as older, more mature stands dominate the forested landscape. Statewide, the area of small (sapling-seedling) stands decreased from 15 to 9 percent of the forest land, a loss of about 1 million acres. The oak/hickory and maple/beech/birch forest-type groups dominate Pennsylvania's woods with nearly 9 out of 10 acres of the forest land. In terms of age, only 4 percent of this forest land in these two groups is in the 0- to 20-year-old age class. This compares to 72 percent of the acreage in these groups that is 60 years and older.

Results of the browse impact assessment show that about 83 percent had medium or high levels of browse impact on understory plants (Fig. 60). Only 17 percent of the samples had low browse levels.

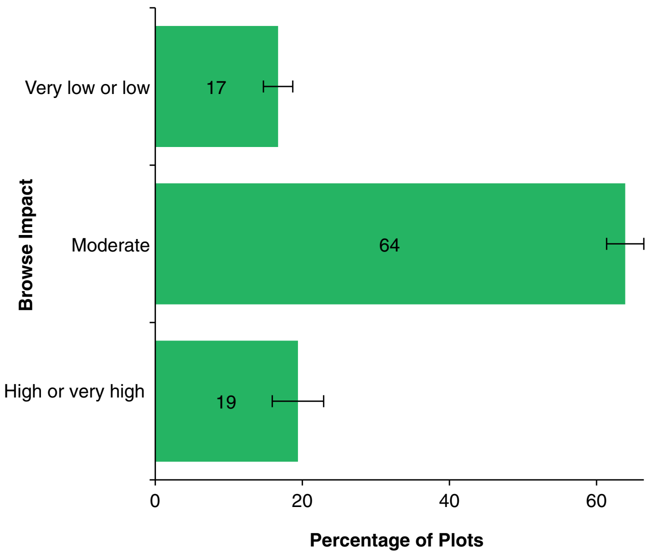

Figure 60.—Distribution of forested P2+ samples on forest land by browse impact, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

The total number of seedlings was estimated at 135.9 billion, or a statewide average of 7,115 seedlings per acre. Sixty-five percent of the seedlings were less than 1 foot tall, 29 percent were 1.0 to 4.9 feet, and 6 percent were 5.0 feet and taller (Fig. 61). No apparent pattern was found in the distribution of the number of seedlings per acre other than a greater frequency of samples in the highest class (more than 10,000 seedlings per acre) across the northern tier (Fig. 62).

Fifty-two species/species groups were encountered by the regeneration indicator samples. Maple was the most common genus with roughly half of the seedlings (Fig. 63). Ash ranked second with 10 percent. All the other genera had less than 10 percent of the population. The five species with the largest number of seedlings were red maple (31 percent of the seedlings), white ash (9 percent), black cherry (7 percent), sugar maple (6 percent), and American beech (6 percent). There was also an abundance of species that are not capable of achieving high canopy, such as serviceberry and hawthorn species.

Comparing species abundance by using the percentage of the total number of trees by size class highlights potential pathways for future canopy dominants (Fig. 64). Prospective "gainers" are those species with relatively high percentages of stems in the regeneration pool of seedlings and saplings compared to larger trees. Red maple, birch species, American beech, and the "other" group are the most apparent gainers. The situation for ash species appears favorable; however, expectations for the ashes should be tempered with information on the prospective demise of ash due to impacts of the emerald ash borer. Most species in the "other" group occupy low- to mid-canopy position, such as striped maple and sassafras. Prospective "losers" in the process of developing future canopy dominants are species with lower percentages in the regeneration pool than the adult pool. The list of potential losers includes sugar maple, black cherry, red oak, white oak, hickory/walnut, yellow-poplar, and eastern hemlock. The distribution of stem abundance by size class is out of balance for these species with seedlings, saplings, and young adults rare compared to older adults. Many of the species in the overstory of Pennsylvania's forests (e.g., the oaks and yellow-poplar) are either intolerant or intermediate in shade tolerance and typically require significant disturbance for a successful regeneration process.

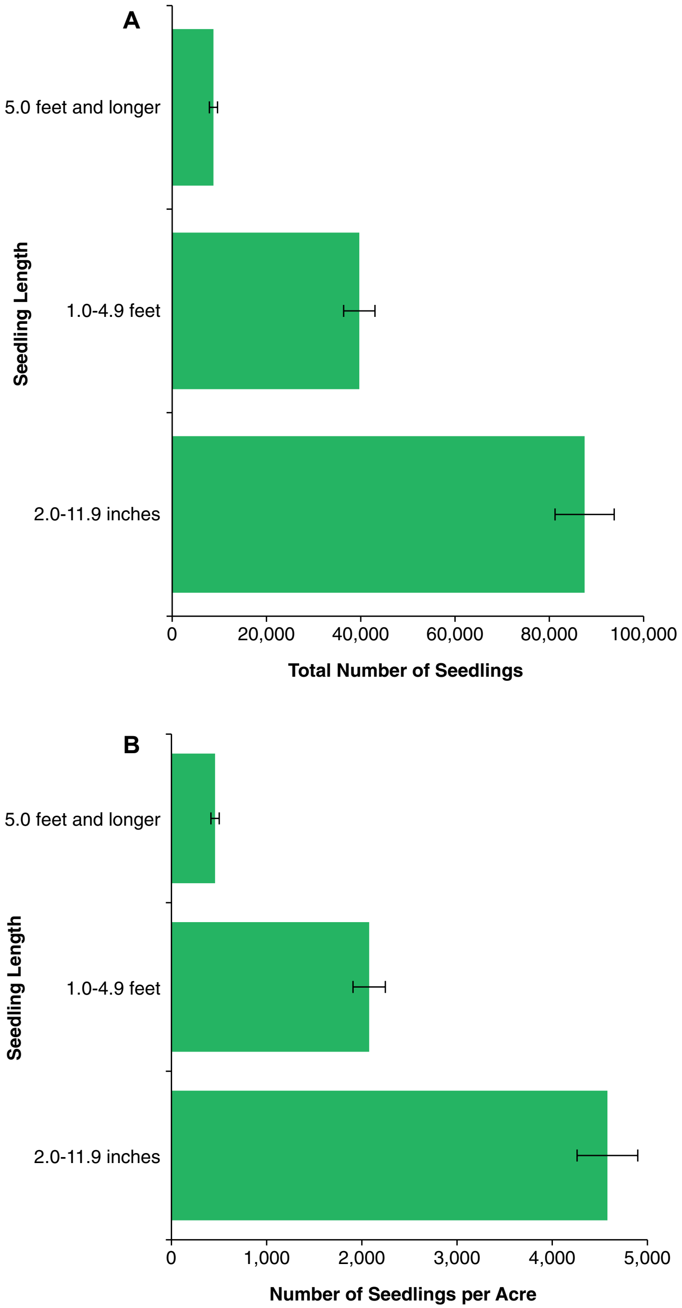

Figure 61.—Total and average number of seedlings per acre on forest land by height class, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

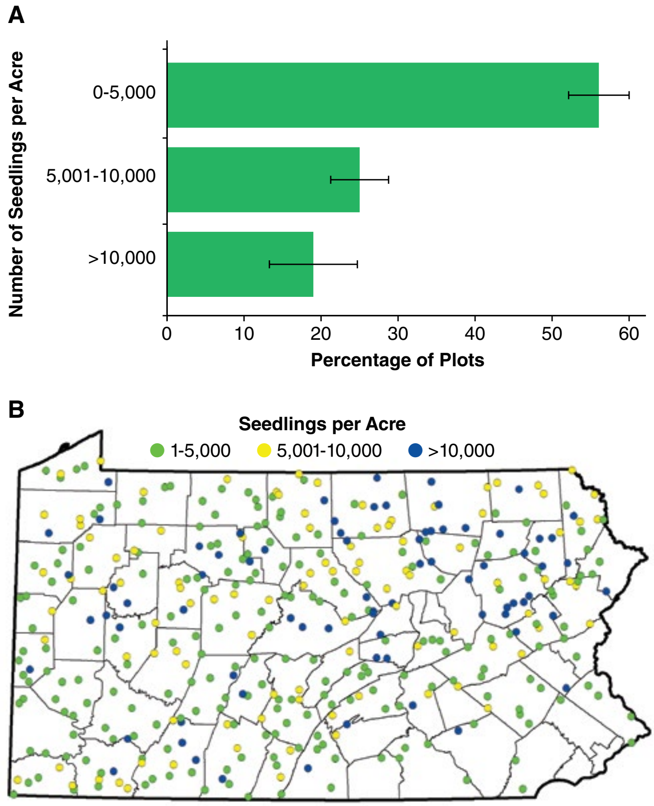

Figure 62.—Percentage of forested P2+ samples on forest land by class of number of seedlings per acre (A) and distribution of seedling classes (B), Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean. Depicted plot locations are approximate.

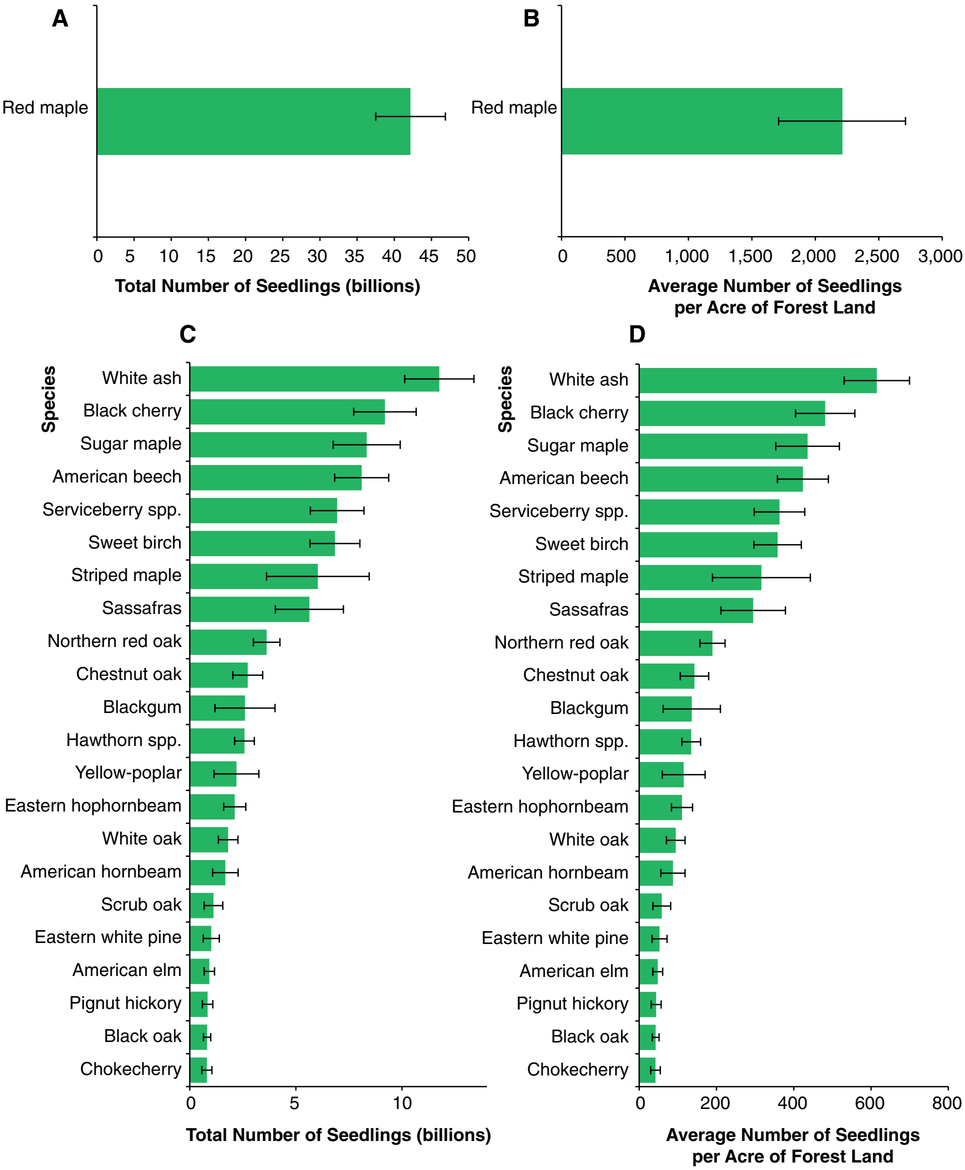

Figure 63.—Number of seedlings (A and C) and average number of seedlings per acre (B and D) on forest land by species for species with at least 1 percent of the total number of seedlings, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

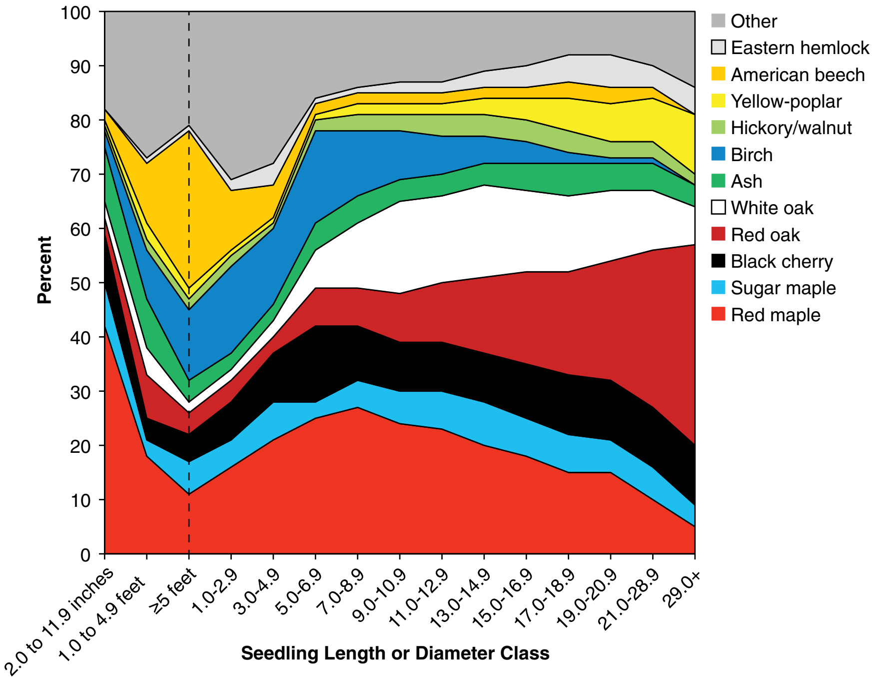

Figure 64.—Percentage of total number of seedlings, live saplings, and dominant and codominant growing-stock trees (adults; larger than 5.0 inches in diameter) on forest land for select species by seedling height or diameter class, Pennsylvania, 2012–2014 (seedlings) and 2010–2014 (adults). Species were selected based on total aboveground biomass. Size classes are height classes for seedlings, and 2-inch diameter classes for saplings and adults.

The PRS has provided an array of metrics designed to address objectives that range from replacing timber species to replacing any tree species at all. The metrics vary depending on the list of species used for evaluating existing tree seedlings and saplings found in the samples. Five species groups were used:

- Commercially desirable species preferred for timber management
- All commercial species
- High-canopy dominant species that make up at least 1 percent of the State's tree biomass
- All high-canopy species
- All tree species including undesirable and low-canopy species.

The findings are expressed as a population estimate of the percentage of samples deemed to have adequate stocking of tree seedling and sapling regeneration.

Findings of the first PRS analysis conducted using the 1989 periodic inventory data are not directly comparable to these results because the impact of herbivory was not included in the assessment in the same manner (McWilliams et al. 1995). However, the analysis did examine a range of findings from low to high deer impact to offer a range for consideration by decisionmakers. The most conservative estimates based on low herbivory impact showed that only 21, 28, and 41 percent were adequately stocked with desirable, commercial, or any tree species, respectively. These findings provide a benchmark for comparison to the more recent results of the annual inventory.

The results for the two commercial species groups follow a similar pattern of slight decreases from 2004 to 2009 and then an increase in 2014 with the highest percentages reported so far. Currently, the percentage of samples in the desirable and commercial groups was 41 and 59 percent, respectively (Fig. 65). The difference between these two groups was that the commercial group included American beech and birch; the desirable group did not. The results for the all-tree species group have shown improvement throughout the study period. For the two canopy replacement groups, the trends were similar to the commercial groups, but the percentages with adequate regeneration were slightly higher (Fig. 66). For three of the six regions (the Southwest, South Central, and Northwest), the percentage of samples in the desirable species group exceeded the statewide percentage in 2014 (Fig. 67). All regions except the South Central and Southeast equaled or exceeded the 2014 statewide average for percentage of plots adequately stocked with regeneration for high canopy dominant species (Fig. 68). The statewide average for percentage of plots adequately stocked with regeneration for all high-canopy species in 2014 was exceeded only in the Northeast, Southwest, and South Central regions. See the appendix for a list of tree species recorded in Pennsylvania with commercial and canopy status groups.

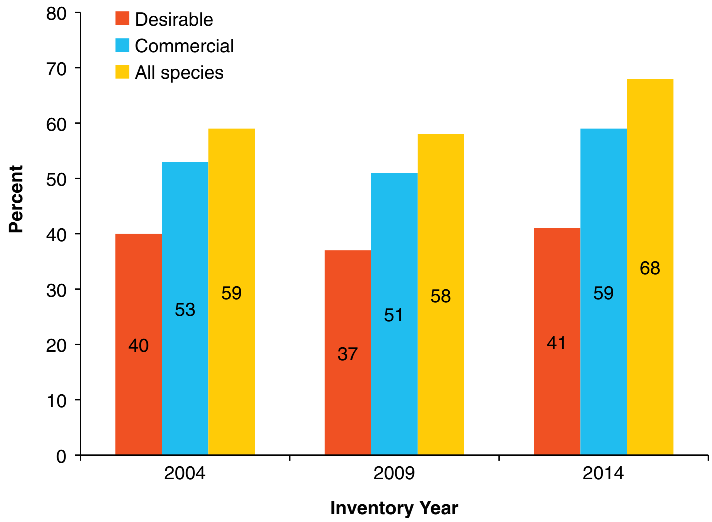

Figure 65.—Percentage of regeneration samples adequately stocked with advance regeneration for stands from 40- to 75-percent stocked with live trees for the commercial and all-species groups, Pennsylvania.

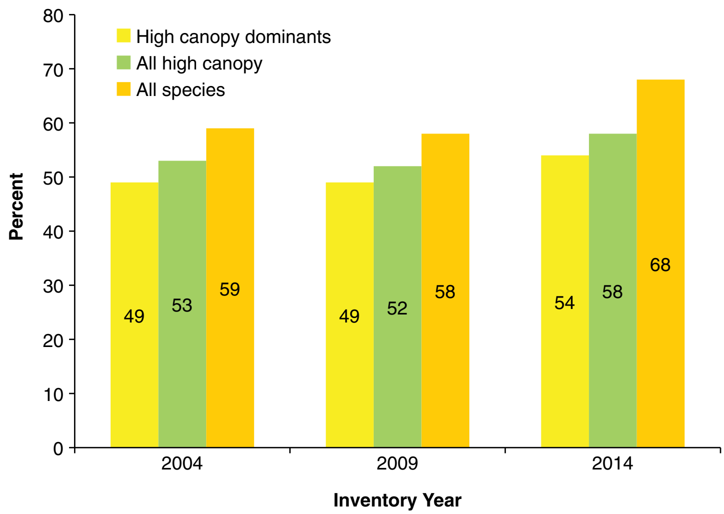

Figure 66.—Percentage of regeneration samples adequately stocked with advance regeneration for stands from 40- to 75-percent stocked with live trees for the high-canopy and all-species groups, by inventory year, Pennsylvania.

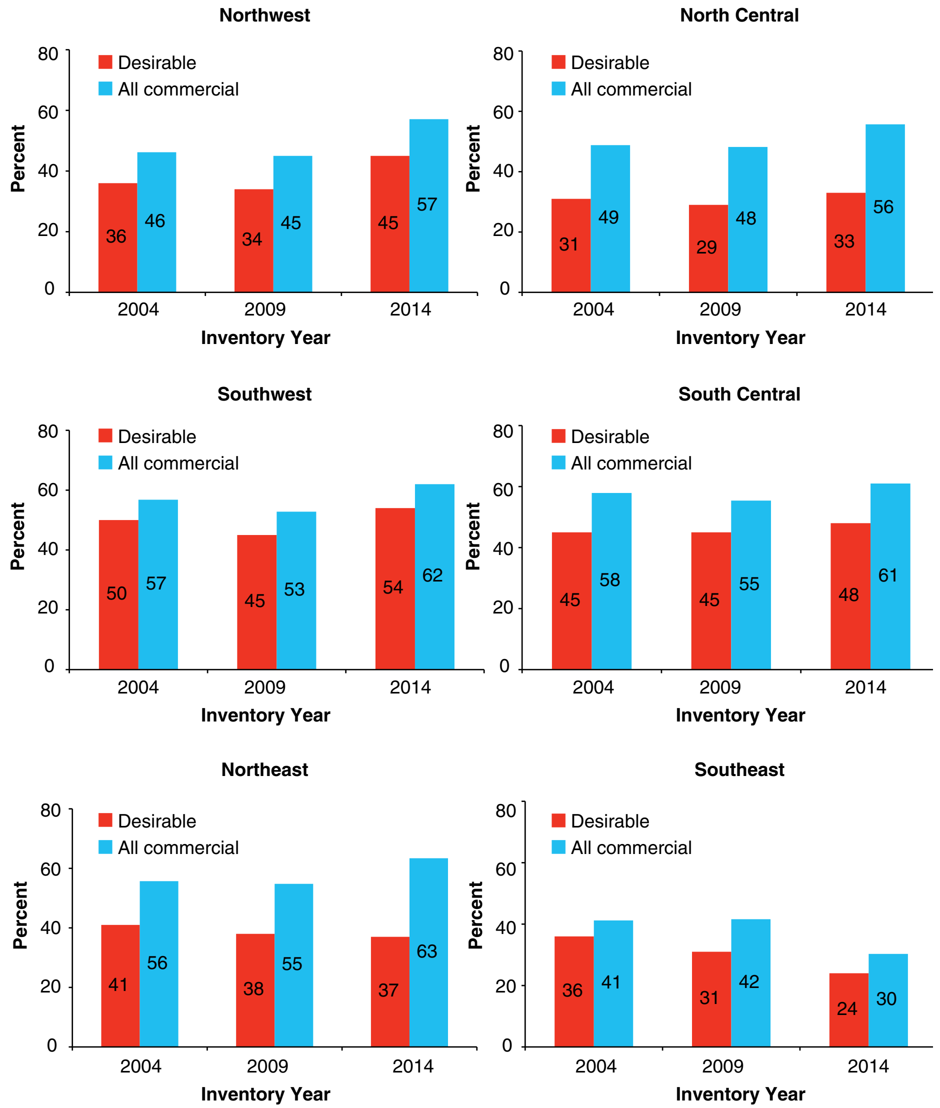

Figure 67.—Percentage of regeneration samples adequately stocked with advance regeneration for stands from 40- to 75-percent stocked with live trees for the commercial species groups by eco-political region and inventory year, Pennsylvania.

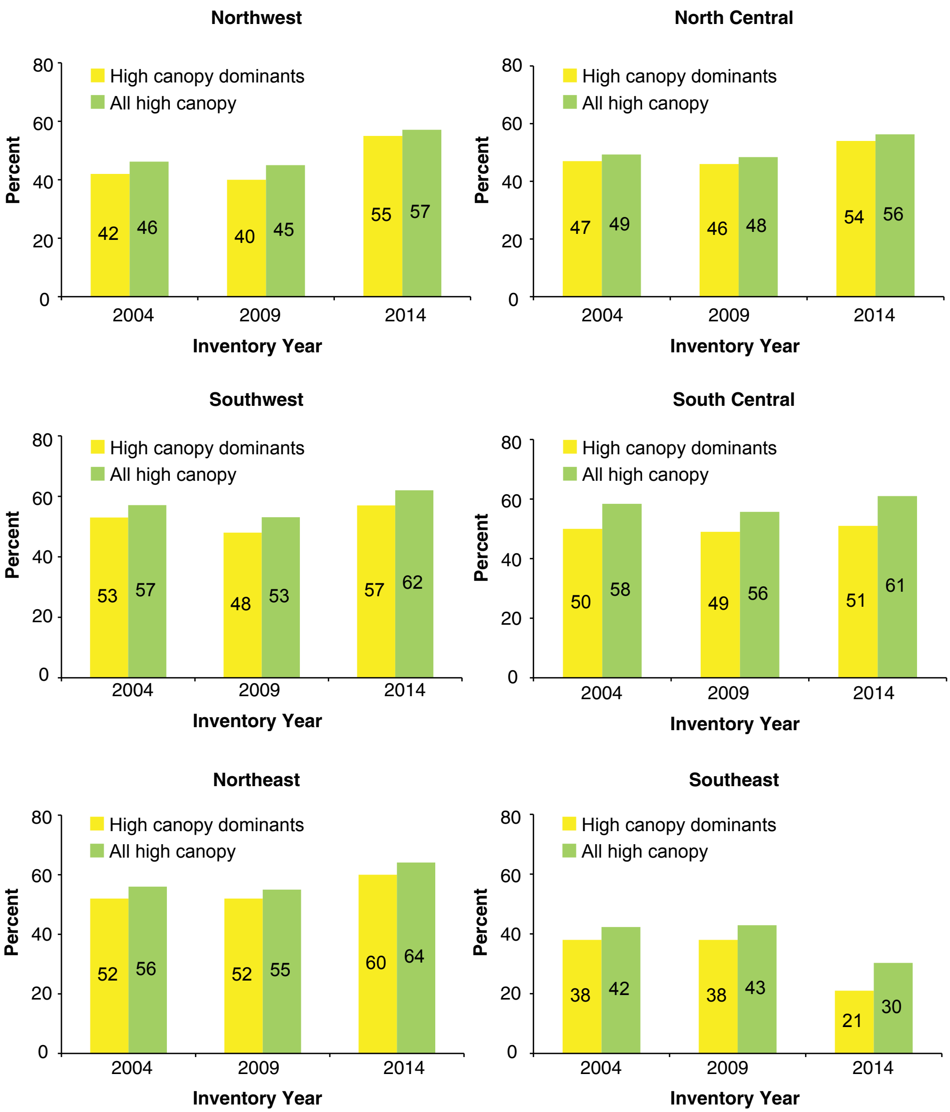

Figure 68.—Percentage of regeneration samples adequately stocked with advance regeneration for stands from 40- to 75-percent stocked with live trees for the high-canopy species groups by ecopolitical region and inventory year, Pennsylvania.

What this means

Pennsylvania's forest ecosystems adapted following large-scale forest clearing of the late 19th and early 20th centuries (Nowacki and Abrams 2014). This process resulted in a largely even-aged forest. After a century of growth and wildfire suppression, the forests continue to age and have withstood many catastrophic stressors such as the chestnut blight (*Cryphonectria parasitica*) and gypsy moth (see Gypsy Moth starting on p. 111). A lack of management and fire means that the mix of species that make up the future forest will be different from today as red maple and other mesophytic and shade-tolerant species expand their distribution (Fei and Steiner 2007, Nowacki and Abrams 2008).

The Commonwealth's forests face a variety of contemporary health risks. Some prominent examples are herbivory, invasive plants, insects and diseases, and forest fragmentation and parcelization. Regeneration is an integral process in ameliorating risks and managing composition and structure during the early phases of forest development following a stand initiation disturbance.

Deer browsing is a major factor affecting regeneration in the eastern United States (Russell et al. 2001, White 2012). The finding that nearly 9 out of 10 of the regeneration indicator samples had at least medium browse is an indication that browsing is having an impact. In general, forest managers need to consider regeneration management methods that limit the effects of deer browsing during the stand initiation phase when browse impact is medium or high. Lacking intervention, areas with high deer populations will have limited reproduction of desirable seedlings. Impacts of deer browsing are especially problematic in combination with habitat fragmentation, which occurs more commonly in heavily populated areas of the State (Augustine and Decalesta 2003).

The results suggest a continuing shift toward red maple and other mesophytic and shade-tolerant species (i.e., birches, and American beech). The most noteworthy issue is a proliferation of red maple seedlings and saplings. Red maple is mesophytic and shade-tolerant, which has given it an advantage during the regeneration phase in stands with low light on a wide variety of sites, from very wet to very dry. This has created an imbalance in the distribution of trees by size class with red maple seedlings dominating the seedling, sapling, and young adult size classes at the expense of other species that are intermediate or shade-intolerant, and more site-specific (e.g., oaks and hickories).

Regenerating oak/hickory forests is often difficult in the eastern United States and management challenges, such as lack of fire and overbrowsing, are recurrent across the forested landscape (Holt and Fischer 1979). The size-class imbalance just described is especially problematic for oak/hickory forests, which are the most common forest-type group in the State, occupying more than half of the forest land.

This means that forest policy makers and managers need to consider these trends when planning for the future of oak/hickory. The long-term future of oak-dominated forests will depend on management strategies that establish oak seedlings and foster development of saplings and adults along with associate species (hickories and yellow-poplar); these strategies require stand-tending prescriptions that forestall development of shade-tolerant species (Abrams 1992, Dey 2014).

Maple/beech/birch is the second most important forest-type group in Pennsylvania, with about one-third of the forest land. The future of this forest-type group appears to be positive because of the large population of red maple, birch, and American beech seedlings and saplings that could lead to eventual canopy dominance. It should be noted that many of the American beech seedlings in the samples are suppressed root sprouts commonly referred to as "beech brush," which do not develop into mature canopy trees. Beech brush represents an obstacle to establishing preferred species and often needs to be weeded out by using mechanical or herbicide prescriptions.

Regeneration has improved over the last 25 years as indicated by both the commercial and high-canopy metrics in the PRS analysis. The metric for all tree species highlighted improvements that were about 10 percent higher than the other metrics. This difference is due to the inclusion of undesirable and low-canopy species, which means managers need to consider this issue in making management prescriptions in stands where such species compete with preferred species.

In 1989, regeneration was described as "impoverished" across all ownerships, forest-type groups, and regions of the Commonwealth. The results presented here represent very important trends in the history of Pennsylvania's forests. It is well known that deer browsing is the major driver that has limited regeneration quality and abundance. Ongoing deer management policies and programs implemented by the Pennsylvania Game Commission have resulted in monumental improvements in the delicate balance between healthy forest and wildlife habitat (Rosenberry et al. 2009).

There is still considerable room for improving regeneration as stands are prepared for harvest, particularly in the case of providing a better mix of preferred species. Weed species and other competing vegetation need to be controlled to ensure that the composition, structure, and function of the future forests meet managers' goals and objectives. Managers need to consider strategies that take into account prospective conversion of critical forest types, such as oak/hickory forests, where advance regeneration is dominated by red maple and shade-intolerant species. The dearth of young forest habitat means there are tremendous opportunities for creating new young forests by actively managing stands prior to harvest. An increase in the area of young stands would also expand food sources in areas with low availability, thus reducing browsing pressure.

Eventually, most forest stands will undergo either anthropogenic or natural stand replacement events, such as harvest or mortality, and will require regeneration to establish new young forest. Successful establishment of healthy young forests depends on forest regeneration. The oak/hickory and maple/beech/birch forest-type groups require advance regeneration to secure a component of desirable species. Management options for establishing regeneration of preferred species will also be driven by the amount of browse present. The key to successful regeneration will be diligent stewardship and continued monitoring to ensure a bright future for Pennsylvania's forest ecosystems.

Tree Crown Health and Damage

Background

The crown condition of trees is influenced by various biotic and abiotic stressors. Biotic stressors include native or introduced insects, diseases, invasive plant species, and animals. Abiotic stressors include drought, flooding, cold temperatures or freeze injury, nutrient deficiencies, the physical properties of soils that affect moisture and aeration, and toxic pollutants.

Invasions by exotic diseases and insects are one of the most important threats to the productivity and stability of forest ecosystems around the world (Liebhold et al. 1995, Pimentel et al. 2000, Vitousek et al. 1996). Over the last century, Pennsylvania's forests have suffered the effects of well-known exotic and invasive agents such as chestnut blight, Dutch elm disease, gypsy moth, hemlock woolly adelgid, and the beech bark disease complex. More-recent invaders include the emerald ash borer and thousand cankers disease (a complex involving the beetle *Pityophthorus juglandis* and the fungus *Geosmithia morbida*).

Tree-crown dieback has been shown to be the best crown variable to use for predicting tree survival (Morin et al. 2015). Crown dieback was collected on 294 P2+ plots (a subset of FIA Phase 2 plots, on which additional measurements are taken) and is defined as recent mortality of branches with fine twigs, reflecting the severity of recent stresses on a tree. A crown was labeled as "poor" if crown dieback was greater than 20 percent. This threshold is based on findings by Steinman (2000) that associated crown ratings with tree mortality.

Tree damage is assessed on trees at least 5.0 inches d.b.h. on all plots. Up to three of the following types of damage can be recorded: insect damage, cankers, decay, fire, animal damage, weather, and logging damage. If more than three types of damage are observed, decisions about which three to record are based on the relative impact on tree health (U.S. Forest Service 2012).

What we found

The incidence of poor crown condition is rare in Pennsylvania. Very few plots had greater than 20 percent of tree basal area with poor crowns (Fig. 69). The species with the highest proportion of live basal area containing poor crowns is white ash (10 percent; Table 7), but plots with higher relative proportion of white ash with poor crowns have a random spatial pattern across the State. Conversely, all other species had a very low occurrence of poor crowns. The proportion of eastern hemlock basal area with poor crowns dropped substantially since 2009, from 5 to 2 percent.

Average crown dieback ranged from less than 1 percent for sweet birch and yellow-poplar to 3 percent for white ash (Table 8). An analysis of trees from the 2009 inventory remeasured in the 2014 inventory confirmed that the proportion of trees that die increases with increasing crown dieback (Fig. 70). Nearly 50 percent of trees with crown dieback above 20 percent in the 2009 inventory were dead when visited in the 2014 inventory.

Damage was recorded on about 27 percent of the Pennsylvania trees, but there was considerable variation between species. The most frequent damage on all species was decay (19 percent of trees), but this ranged from 4 percent of eastern hemlock to 30 percent of sugar maple. Notably, insect damage was present on 10 percent of eastern hemlock trees and 8 percent of sugar maple trees. The occurrence of all other injury types was very low (Fig. 71).

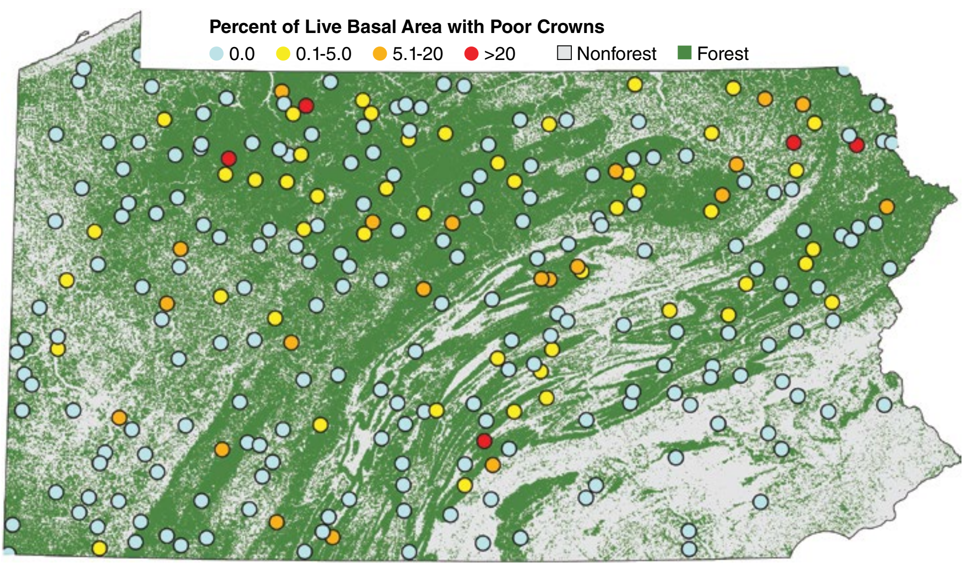

Figure 69.—Percentage of live basal area with poor crowns, Pennsylvania, 2014. Depicted plot locations are approximate.

Projection: Pennsylvania State Plane North, NAD83. Sources: U.S. Forest Service, Forest Inventory and Analysis program, 2009, 2014. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: R.S. Morin, U.S. Forest Service, October 2015.

Table 7.—Percentage of live-tree basal area with poor crowns, Pennsylvania, by inventory year

Species	Percentage of basal area with poor crowns	
	2009	2014
White ash	6.1	10.3
Eastern hemlock	4.9	1.7
Red maple	2.2	1.7
Chestnut oak	0.6	1.6
Sugar maple	1.3	1.3
Black cherry	4.1	1.3
Sweet birch	0.4	0.8
Yellow-poplar	0.0	0.0
White oak	0.1	0.0
Northern red oak	1.3	0.0

Table 8.—Mean crown dieback expressed as a percentage and other statistics for live trees (>5 inches d.b.h.) on forest land by species, Pennsylvania, 2014

Species	Trees sampled	Mean	SE	Minimum	Median	Maximum
		- - - - - - - - - - - - - - -	- - - - -	*percent*	- - - - - - - - - - - - - - -	
White ash	222	3.1	0.80	0	0	99
Black cherry	613	2.2	0.27	0	0	99
Red maple	1,310	2.0	0.20	0	0	99
Chestnut oak	351	1.7	0.34	0	0	80
Sugar maple	410	1.6	0.35	0	0	99
Eastern hemlock	444	1.4	0.30	0	0	80
White oak	129	1.2	0.23	0	0	15
Northern red oak	278	1.0	0.14	0	0	15
Sweet birch	449	0.9	0.25	0	0	99
Yellow-poplar	145	0.3	0.09	0	0	5

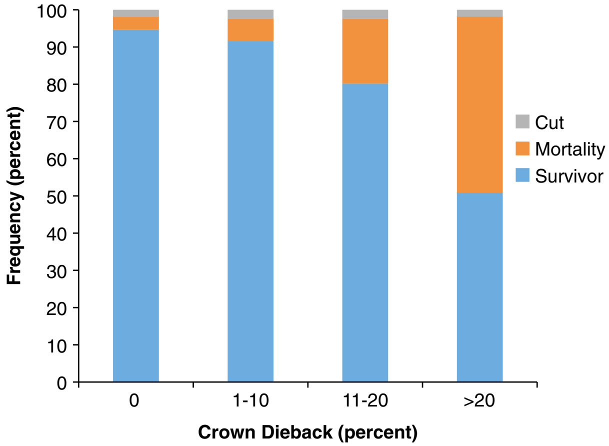

Figure 70.—Crown dieback distribution by tree survivorship for remeasured trees, Pennsylvania, 2009 to 2014.

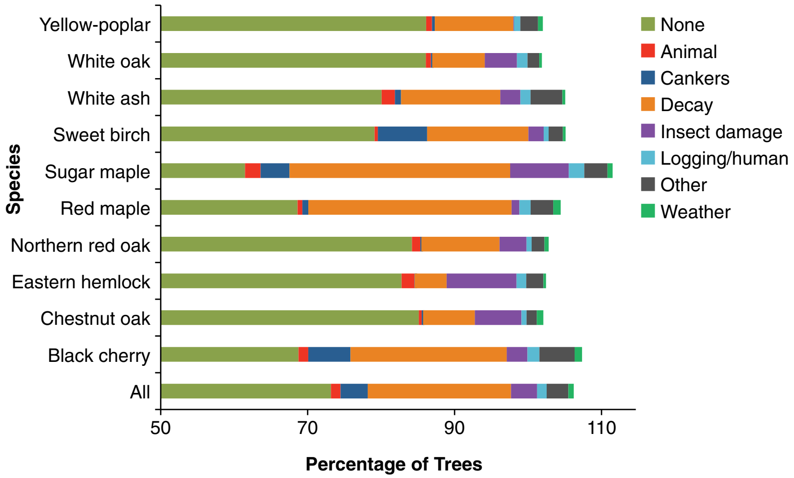

Figure 71.—Percentage of trees with damage, Pennsylvania, 2014. Note that bars do not sum to 100 because multiple damages can be recorded on trees.

What this means

The majority of tree species in Pennsylvania were generally in good health. As in most eastern U.S. forests, decay was the most commonly observed damage. This is not unusual because nearly 70 percent of Pennsylvania's forests are large diameter stands composed of mature trees. The high occurrence of insect damage for sugar maple is most likely due to the sugar maple borer (*Glycobius speciosus*), which can cause lumber defects, but rarely causes mortality (Hoffard and Marshall 1978, Morin et al. 2016). The high occurrence of insect damage for eastern hemlock is due to hemlock woolly adelgid. The health of tree crowns in American beech, eastern hemlock, and ash species should be monitored closely because of the expected impacts of beech bark disease, hemlock woolly adelgid, and emerald ash borer, respectively (see Tree Pests and Diseases of Special Concern section starting on p. 106).

Invasive Plants

Background

Invasive plant species (IPS) are both native and nonnative and have negative ecological impacts. Several characteristics contribute to their success, such as prolific seed production, rapid growth, vegetative propagation, and endurance of harsh conditions. IPS can quickly invade forests, changing the availability of light, water, and nutrients (Kuebbing et al. 2014). IPS can form dense understories that inhibit regeneration and reduce wildlife diversity and abundance by altering forest structure and forage availability (Pimentel et al. 2005). Invasive species monitored in forest ecosystems also affect agricultural systems (Kurtz 2013). An example is common barberry, an alternate host for wheat stem rust (*Puccinia graminis*), which can cause the complete loss of grain fields. Common buckthorn is another troublesome IPS as it is an alternate host for the soybean aphid (*Aphis glycines*). Although there are some beneficial uses for these invaders (e.g., culinary and medicinal use, and soil contaminant extraction) (Kurtz 2013), the negative effects outweigh these benefits. Two examples of past uses overshadowed by current problems are: multiflora rose, once promoted for planting as a living pasture fence, and autumn-olive, widely planted to restore degraded land by fixing soil nitrogen and as wildlife habitat with its abundant fruit production. Now, each year, inspection, management, and mitigation of IPS cost billions of dollars (Kurtz 2013, Pimentel et al. 2005).

To monitor IPS, FIA assessed the presence of 40 IPS (39 species and one undifferentiated genus[4]; Table 9) on 688 forested P2+ plots during the 2014 inventory. To maintain regional consistency, the species list is not customized for Pennsylvania,

[4] Hereafter these 39 species and one undifferentiated genus (nonnative bush honeysuckles, *Lonicera* spp.) are referred to as "invasive species," "invasive plants," or "IPS."

Table 9.—Common and scientific names of invasive plants monitored and recorded on Phase 2 invasive plots, Pennsylvania, 2014

Tree Species	
*Ailanthus	*Ailanthus altissima*
*Black locust	*Robinia pseudoacacia*
Chinaberry	*Melia azedarach*
Chinese tallow	*Triadica sebifera*
*Norway maple	*Acer platanoides*
*Paulownia	*Paulownia tomentosa*
Punktree	*Melaleuca quinquenervia*
*Russian-olive	*Elaeagnus angustifolia*
Saltcedar	*Tamarix ramosissima*
Siberian elm	*Ulmus pumila*
Silktree	*Albizia julibrissin*
Shrub Species	
*Autumn-olive	*Elaeagnus umbellata*
*Common barberry	*Berberis vulgaris*
*Common buckthorn	*Rhamnus cathartica*
European cranberrybush	*Viburnum opulus*
*European privet	*Ligustrum vulgare*
*Glossy buckthorn	*Frangula alnus*
*Japanese barberry	*Berberis thunbergii*
*Japanese meadowsweet	*Spiraea japonica*
*Multiflora rose	*Rosa multiflora*
*Nonnative bush honeysuckle	*Lonicera* spp.
Vine Species	
*English ivy	*Hedera helix*
*Japanese honeysuckle	*Lonicera japonica*
*Oriental bittersweet	*Celastrus orbiculatus*
Herbaceous Species	
Bohemian knotweed	*Polygonum xbohemicum*
*Bull thistle	*Cirsium vulgare*
*Canada thistle	*Cirsium arvense*
*Creeping jenny	*Lysimachia nummularia*
*Dames rocket	*Hesperis matronalis*
European swallow-wort	*Cynanchum rossicum*
*Garlic mustard	*Alliaria petiolata*
*Giant knotweed	*Polygonum sachalinense*
*Japanese knotweed	*Polygonum cuspidatum*
*Leafy spurge	*Euphorbia esula*
Louise's swallow-wort	*Cynanchum louiseae*
*Purple loosestrife	*Lythrum salicaria*
*Spotted knapweed	*Centaurea stoebe* ssp. *micranthos*
Grass Species	
*Common reed	*Phragmites australis*
*Nepalese browntop	*Microstegium vimineum*
*Reed canarygrass	*Phalaris arundinacea*

*Found on P2 invasive plots, Pennsylvania, 2014.

but represents native and nonnative species of regional concern. When reviewing these data, remember that the inventory takes place only on forested land so areas with less forest have fewer plots.

What we found

Of the 40 invasive plants monitored, 30 were observed (Table 10). Multiflora rose (Fig. 72) was the most commonly observed species (326 plots; 47 percent) and was found throughout the State. Nonnative bush honeysuckles were the second most common IPS; they occurred on 25 percent of the plots and were also found throughout Pennsylvania. Garlic mustard and Japanese barberry were found on 23 and 20 percent of plots, respectively. One or more of the monitored invasive species were present on 421 plots, with the number of invasive species per plot ranging from 0 to 11 (Fig. 73). Plots in the southern half of the State had the greatest number of IPS per plot (Fig. 74).

Comparing the 2014 inventory to the 2009 inventory, there was a similar percentage of multiflora rose, garlic mustard, and Japanese barberry, but it is important to note that there were only about half as many plots measured in the 2009 inventory (337 forested plots sampled; McCaskill et al. 2013). Regionally, Pennsylvania's forests have a higher percentage of plots invaded (61 percent) than neighboring New York (51 percent; Widmann et al. 2015) but a lower percentage than Ohio (93 percent; Widmann et al. 2014). The number of IPS observed was similar across these states with 29 species in New York and 28 in Ohio.

Table 10.—Invasive plants recorded on Phase 2 invasive plots, Pennsylvania, 2014

Species	Number of plots	Percentage of plots
Multiflora rose	326	47.4
Nonnative bush honeysuckles	173	25.1
Garlic mustard	161	23.4
Japanese barberry	140	20.3
Nepalese browntop	120	17.4
Black locust	90	13.1
Autumn-olive	76	11
Oriental bittersweet	71	10.3
Japanese honeysuckle	59	8.6
European privet	51	7.4
Ailanthus	40	5.8
Norway maple	21	3.1
Creeping jenny	14	2
Dames rocket	14	2
Canada thistle	11	1.6
Glossy buckthorn	11	1.6
Common barberry	7	1
Common buckthorn	7	1
Bull thistle	6	0.9
Japanese knotweed	5	0.7
Reed canarygrass	4	0.6
Giant knotweed	3	0.4
Spotted knapweed	3	0.4
English ivy	2	0.3
Japanese meadowsweet	2	0.3
Paulownia	2	0.3
Russian-olive	2	0.3
Common reed	1	0.1
Leafy spurge	1	0.1
Purple loosestrife	1	0.1

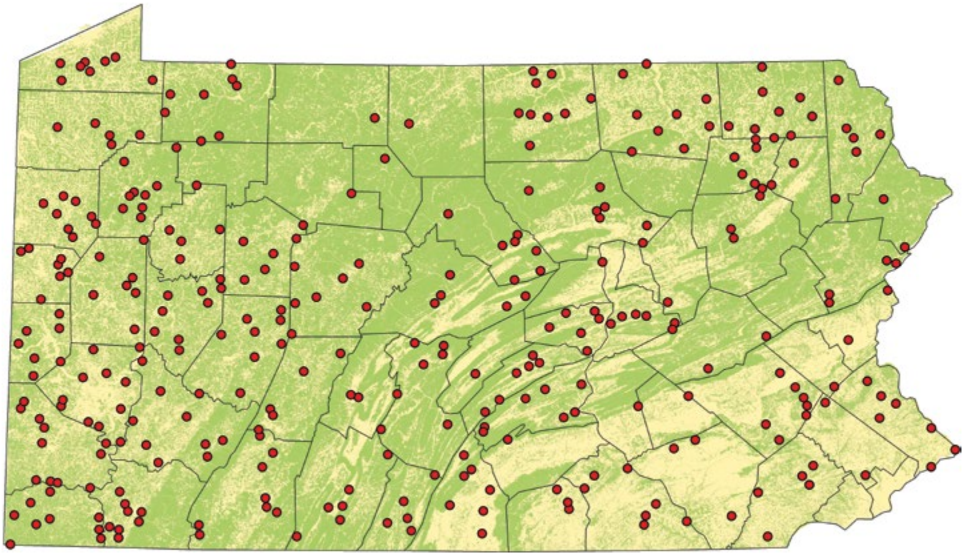

Figure 72.—Distribution of multiflora rose on forest land, Pennsylvania, 2014. Depicted plot locations are approximate.

Projection: Pennsylvania State Plane North, NAD83. Data source: U.S. Forest Service, Forest Inventory and Analysis program, 2010–2014 Phase 2 invasive data. Source for state and county layers: ESRI Data and Maps 10.1. Source for forest/nonforest: NLCD 2006.
Cartography: C.M. Kurtz, U.S. Forest Service, December 2015.

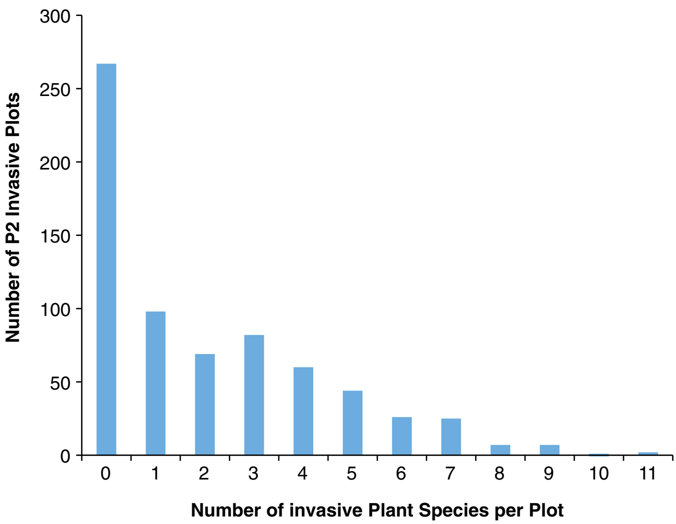

Figure 73.—Number of P2 invasive plots, by number of invasive plant species reported, Pennsylvania, 2014.

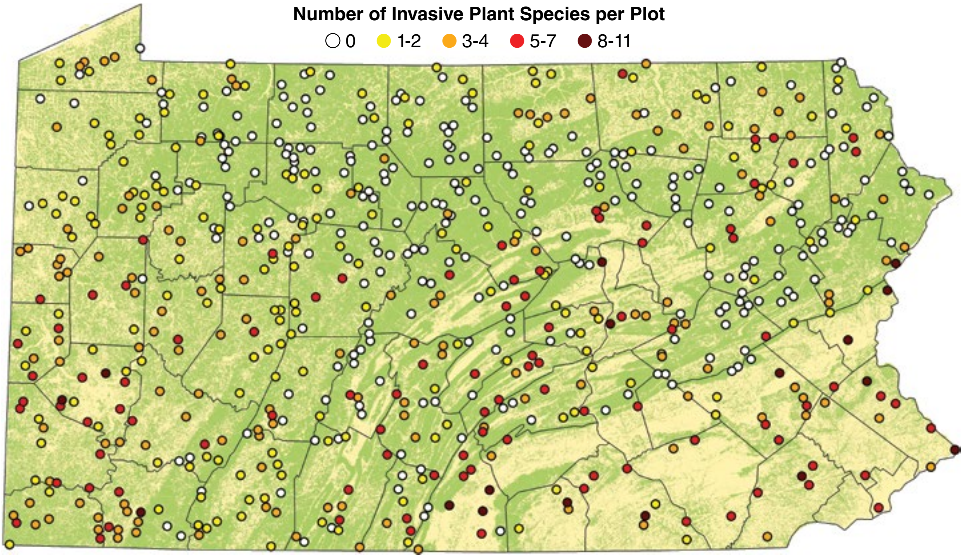

Figure 74.—Distribution and abundance of invasive plant species on forest land, Pennsylvania, 2014. Depicted plot locations are approximate.

Projection: Pennsylvania State Plane North, NAD83. Data source: U.S. Forest Service, Forest Inventory and Analysis program, 2010–2014 Phase 2 invasive data. Source for state and county layers: ESRI Data and Maps 10.1. Source for forest/nonforest: NLCD 2006.
Cartography: C.M. Kurtz, U.S. Forest Service, December 2015.

What this means

Invasive species are a concern throughout the Commonwealth because many IPS are effective competitors and can change forested ecosystems by inhibiting tree regeneration, displacing native species, and altering forage. Furthermore, IPS can cause negative economic impacts by reducing timber yield and aesthetic beauty as well as making it more difficult to regenerate stands without implementing measures to control invasive species. Although some invasive plants become established with little to no disturbance, development (residential and industrial) of adjacent areas contributes to forest invasion as does preferential browsing of non-invasive species by white-tailed deer. Additional investigation may reveal correlations between IPS and influential site and regional features as well as IPS factors associated with forest dynamics. Continual monitoring and reporting of IPS is necessary to inform managers and the public of their occurrence and spread.

Tree Pests and Diseases of Special Concern

EMERALD ASH BORER

Background

A wood-boring beetle native to Asia, emerald ash borer (EAB; *Agrilus planipennis*) is a pest of all North American ash (*Fraxinus* spp.) and has recently been found to attack white fringetree (*Chionanthus virginicus*), an understory shrub native to southern Pennsylvania but not tallied by FIA (Cipollini 2015, Herms and McCullough 2014, Natural Resources Conservation Service 2015). Although EAB shows some preference for stressed trees, all trees greater than 1 inch in diameter are susceptible regardless of vigor (Herms and McCullough 2014). Since its 2002 discovery in southeastern Michigan, EAB has been identified in 25 states (as of December 2015). EAB has been present in Pennsylvania since 2007 and was confirmed in 62 counties as of September 2016 (Pennsylvania State University 2016b).

What we found

Pennsylvania forest land contains an estimated 270.9 million ash trees (≥1-inch d.b.h.), about 3 percent of total species composition, which represents a 12 percent decrease since 2004. White ash is the most numerous ash species in the State, making up 94 percent of total ash abundance; green ash and black ash make up 4 and 2 percent, respectively. Ash is distributed across Pennsylvania; however, the majority of ash is concentrated in the northern half of the State (Fig. 75). Ash mortality has increased substantially since 1989, more than doubling from 6.3 million cubic feet to 14.4 million cubic feet. The mortality rate for ash statewide was 1.16 percent of net volume per year, higher than all species (0.9 percent). In counties containing EAB, the rate of ash mortality increases with increasing length of infestation (Fig. 76); however, as a group, counties where EAB has not been detected had the highest rate of ash mortality. Ash volume continued to increase, reaching an estimated net live tree volume of 1.8 billion cubic feet on forest land, 9 percent higher than the 2004 estimate.

What this means

Even though ash is a relatively small component of overall forest land, its prominence in rural, riparian, and urban forests makes EAB a significant threat to the health and composition of Pennsylvania's forests. The loss of ash in forested ecosystems will affect species composition and alter community dynamics while urban areas face significant costs for hazard mitigation, tree removal, and replacement. The increase in

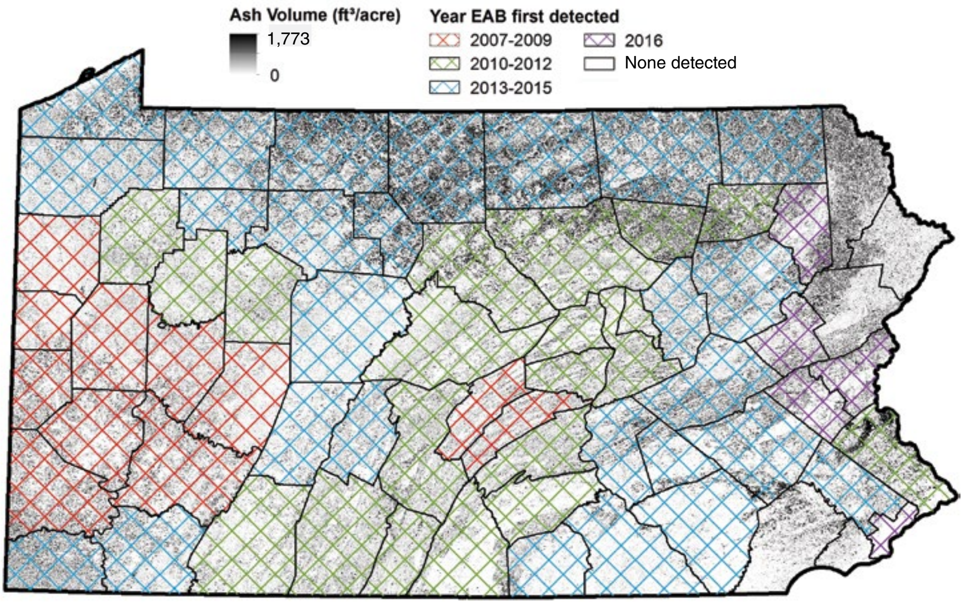

Figure 75.—Ash volume (trees at least 5 inches d.b.h.) on forest land, with year of first EAB detection, by county, Pennsylvania, 2014.

Projection: Pennsylvania State Plane North, NAD83. Sources: U.S. Forest Service, Forest Inventory and Analysis program, 2009; Pennsylvania Department of Conservation and Natural Resources, 2016. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: T. Albright, U.S. Forest Service, March 2016.

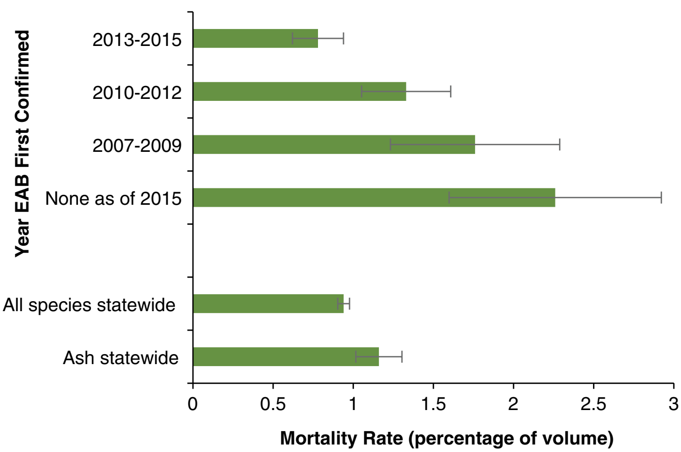

Figure 76.—Ash mortality rates by year EAB detected, ash mortality rate statewide, and mortality rate for all tree species, Pennsylvania, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

the ash mortality rate since first detection suggests that the northern tier counties will experience more ash mortality in the coming years. Furthermore, EAB can exist at low densities before detection (Herms and McCullough 2014) and this may partially explain the elevated mortality rate in areas with no confirmed EAB infestation. Ash also faces more challenges; for example, ash yellows, a disease that causes decline of ash species, is known to exist in Pennsylvania but data on its extent are lacking. Continued monitoring of ash resources will help identify long-term impacts of EAB in forested settings as well as the extent of other causes of elevated mortality.

HEMLOCK WOOLLY ADELGID

Background

Eastern hemlock is the Pennsylvania state tree and a major component of the State's forests. It ranks as the sixth most important species in terms of cubic-foot volume, but its value goes far beyond timber. The wildlife habitat and food it provides, and the unique niche it fills in riparian areas by shading streams and lowering water temperatures, make it ecologically very important. Forests with the highest proportion of hemlock volume are generally located throughout the northern tier, specifically in the North Central and Northeast regions (Fig. 77). Hemlock woolly adelgid (HWA; *Adelges tsugae*) is an insect pest native to East Asia and was first found in the eastern United States in the 1950s (Ward et al. 2004). Since then, it has slowly expanded its range, often reaching high densities and causing widespread defoliation and eventually mortality (McClure et al. 2001, Orwig et al. 2002). Mortality generally begins to increase dramatically after about 15 years of infestation (Morin and Liebhold 2015).

What we found

HWA was first discovered in southeastern Pennsylvania in 1979 and it has since spread to 59 of the 67 counties (Fig. 77). Over 94 percent of the estimated 1.96 billion cubic feet of hemlock in the State was in counties that had an HWA population as of 2014. Thirty-one percent of hemlock volume was in areas infested for 15 years or more. An additional 23 percent of the State's hemlock volume was in counties infested for 10 to 15 years.

Hemlock volume continued to increase, though at varying levels as the length of infestation correlates to slower rates of increase. Areas infested with HWA for 5 years or less saw a 25 percent increase in hemlock volume from 2004 to 2014 (Fig. 78). Similarly, areas infested between 5 and 10 years increased hemlock volume by 28 percent over the same period. Infestations 10 to 15 years old held volume increases to 12 percent, while areas infested for 15 years or more had a minimal increase in volume of 1 percent from 2004 to 2014.

Counties infested with HWA show substantial increases in the hemlock mortality rate around 15 years after HWA appears. Hemlock in counties infested with HWA in 2000 had an average mortality rate of 2.1 percent of net volume per year in 2014 (Fig. 79). The mortality rate in counties infested for 10 to 15 years was 0.7 percent and the rate in counties infested for 10 years or less was 0.6 percent.

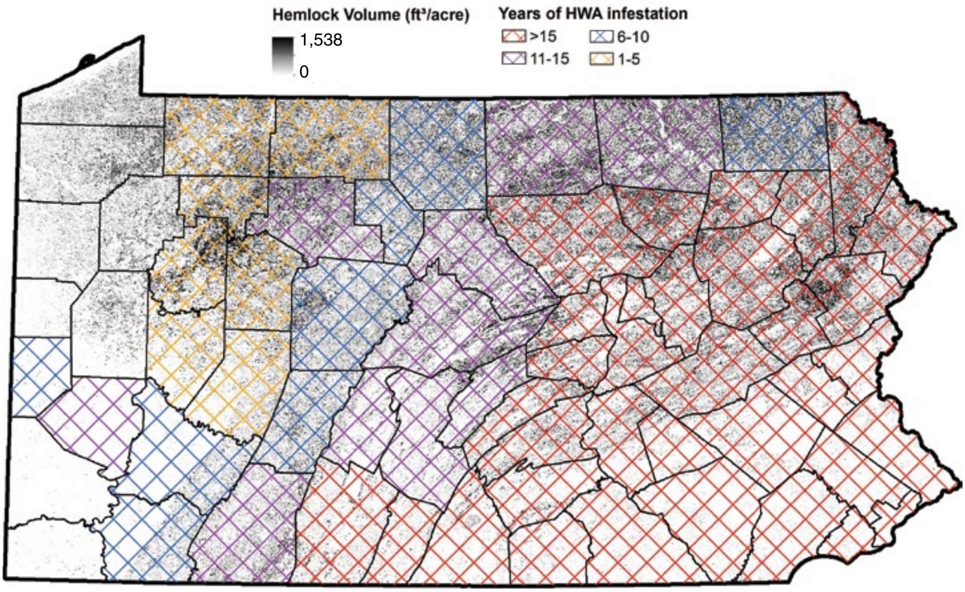

Figure 77.—Eastern hemlock volume (trees at least 5 inches d.b.h.) on forest land, with counties infested by HWA, by number of years of infestation, Pennsylvania, 2014.

Projection: Pennsylvania State Plane North, NAD83. Sources: U.S. Forest Service, Forest Inventory and Analysis program, 2009, and Forest Health Protection, 2016. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/. Cartography: T. Albright, U.S. Forest Service, March 2016.

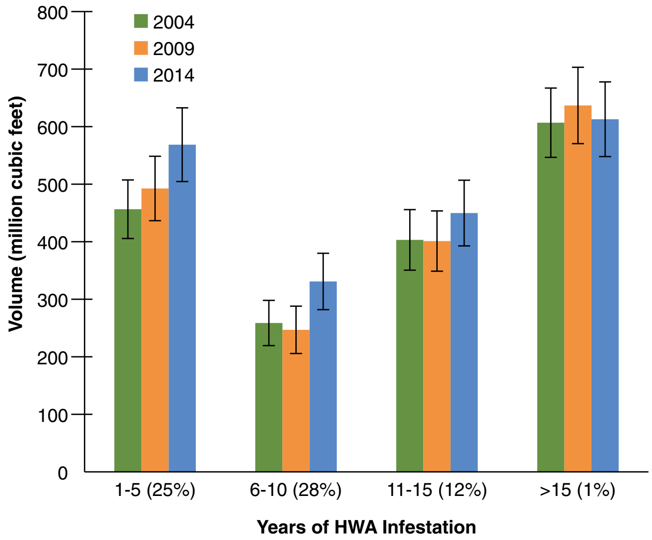

Figure 78.—Eastern hemlock volume (trees at least 5 inches d.b.h.) on forest land, by inventory year and years of HWA infestation as of 2014, Pennsylvania. The percent volume increase between 2004 and 2014 is shown in parentheses. Error bars represent a 68 percent confidence interval around the estimated mean.

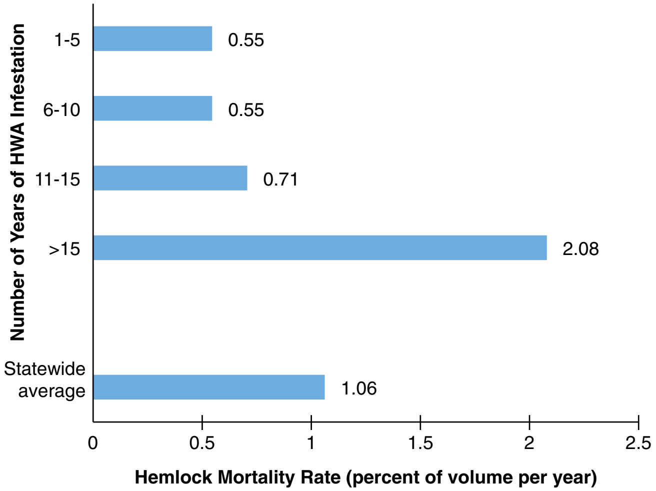

Figure 79.—Average annual mortality of eastern hemlock expressed as a percentage of hemlock volume by number of years of HWA infestation, and the statewide average, Pennsylvania, 2014.

What this means

HWA has already spread across most of Pennsylvania. In areas where it has been present for 15 years or more, hemlock mortality has increased substantially and volume growth has leveled off. Some of the areas with the highest densities of hemlock have not been infested long enough to have suffered major impacts, but hemlock mortality is likely to increase in the near future as an additional 450 million cubic feet of hemlock will move into the 15 year infestation category by 2019. If current trends continue, that will mean the majority of hemlock volume will have minimal increases in volume and mortality rates in excess of 2 percent of volume per year.

In an effort to forestall these effects, the Bureau of Forestry has developed the Eastern Hemlock Conservation Plan and has been treating high-value hemlocks in state parks and state forests since 2004. Predatory beetle releases have been conducted since 1999. The purpose of treating high-value hemlocks with insecticides is to keep hemlock habitat and trees protected until predatory beetles become established and contribute to hemlock woolly adelgid control.

The importance of hemlock in the forest ecosystem is hard to overstate. It is a late successional, highly shade tolerant species that is very long-lived and would be expected to be on the rise as forests age. The loss of hemlock as a result of HWA invasion has impacts on ecosystem properties such as stream temperatures and soil chemistry (Orwig et al. 2008, Stadler et al. 2005) so the status of this important species needs continued monitoring. With no effective landscape-level controls yet available, hemlock woolly adelgid will have a very significant lasting impact on the character of Penn's Woods.

GYPSY MOTH

Background

Gypsy moth (*Lymantria dispar*) first caused damage in Pennsylvania in the 1920s, but extensive damage began in about 1970. Since then, periodic outbreaks have occurred, making it the most destructive forest pest in the State. The largest outbreaks took place during the 1980s and early 1990s. Aerial surveys in 2006–2008 determined that gypsy moth populations were again on the rise; more than 2 million acres of defoliation were detected over that 3-year period.

Quantifying gypsy moth defoliation can help land managers plan for suppression activities. Tree species were split into preferred and nonpreferred suitability classes based on previously published field and laboratory tests (Liebhold et al. 1995). Species from suitability class 1 were considered preferred and all others were considered nonpreferred. Annual mortality rates were calculated for preferred and nonpreferred species. Mortality was computed by using remeasured plots (originally surveyed 2004–2008 and remeasured 2009–2013) as proportions of live volume at the time of the initial survey (i.e., annual mortality volume divided by live volume at time 1). Plots were assigned years of defoliation based on the 10 years before measurement; for example, a plot that was measured in 2010 was assigned the number of defoliations that occurred between 2000 and 2009. Historical defoliation records were recorded by U.S. Forest Service, Northeastern Area State and Private Forestry and assembled at the Northern Research Station, Morgantown, WV, and are available online (http://www.fs.fed.us/ne/morgantown/4557/gmoth/atlas/#defoliation). These data were not based upon systematic surveys and therefore slight inconsistencies may exist among years and states in how gypsy moth defoliation was surveyed and recorded.

What we found

About 31 percent of the live tree volume in Pennsylvania's forests is preferred by gypsy moth. Oaks and aspens are the most abundant preferred species in Pennsylvania. The density of preferred gypsy moth host species is highest in the mountainous region of central and northeastern Pennsylvania (Fig. 80). The largest gypsy moth defoliation events were concentrated in the Allegheny and Pocono Mountain regions of the State (Fig. 81). According to aerial surveys reported by U.S. Forest Service Forest Health Protection, between 2000 and 2014 nearly 3.3 million acres were defoliated at least one time (Fig. 82). More than 610,000 of those acres had two defoliations and nearly 120,000 acres were defoliated three or more times. Most of the defoliated area occurred in forest land classified as the oak/hickory forest-type group. The annual mortality rate in species preferred by gypsy moth is more than double in areas defoliated two or more times in the 10-year period prior to plot remeasurement compared to areas with no defoliations over the same period (Fig. 83).

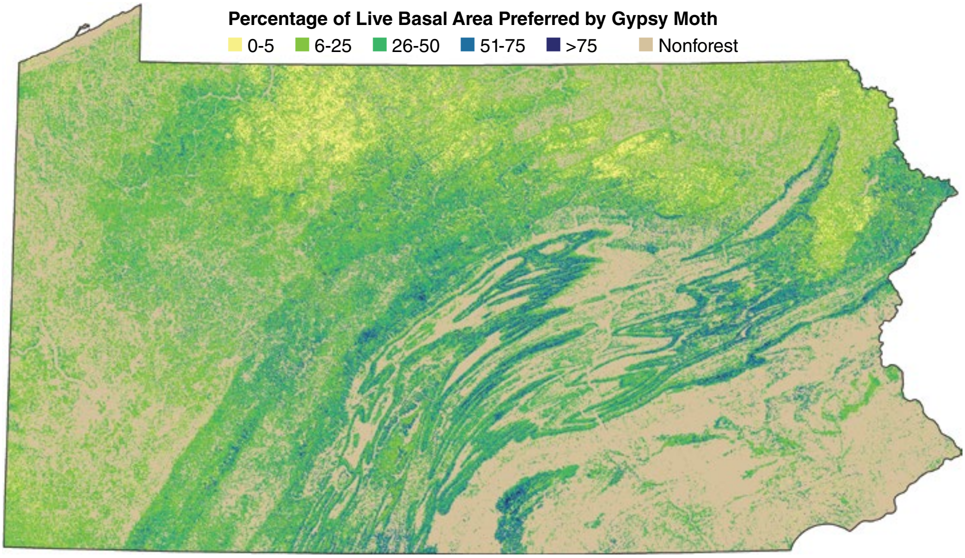

Figure 80.—Percentage of live basal area in host tree species that are preferred by gypsy moth, Pennsylvania, 2009.

Projection: Pennsylvania State Plane North, NAD83. Sources: U.S. Forest Service, Forest Inventory and Analysis program, 2009. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: R.S. Morin, U.S. Forest Service, November 2015.

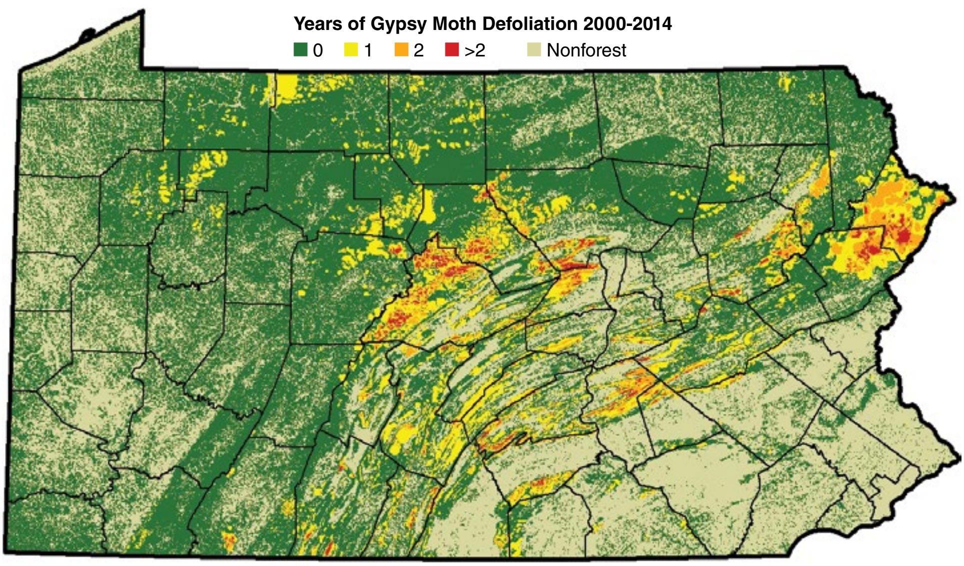

Figure 81.—Number of gypsy moth defoliations, Pennsylvania, 2000 to 2014.

Projection: Pennsylvania State Plane North, NAD83. Sources: U.S. Forest Service, Forest Inventory and Analysis program, 2009; U.S. Forest Service, Forest Health Protection and its partners, 2016. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: T. Albright, U.S. Forest Service, March 2016.

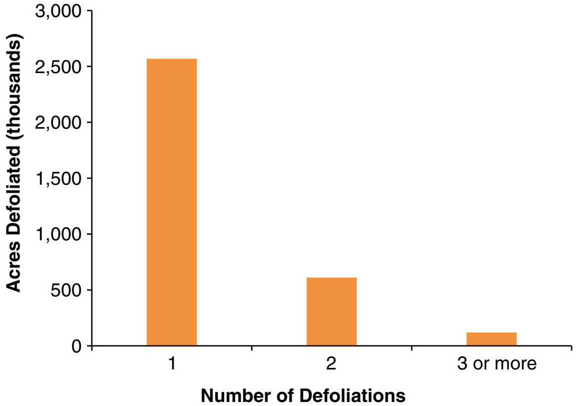

Figure 82.—Acres of gypsy moth defoliation by number of defoliations, Pennsylvania, 2000 through 2014.

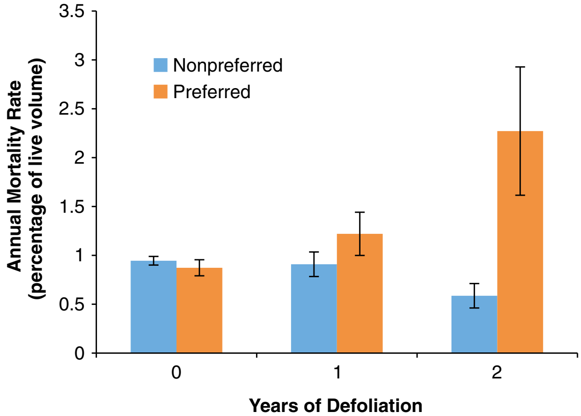

Figure 83.—Annual mortality rate by gypsy moth host preference, Pennsylvania, 2011. Error bars represent a 68 percent confidence interval around the estimated mean. Years of defoliation is based on the number of defoliations that occurred on a plot within the 10 years prior to measurement.

What this means

Gypsy moth has been affecting the forests of Pennsylvania for more than 40 years. During that time defoliation has been cyclical with peaks every 5 to 10 years (Fig. 84). Although defoliation does have an impact on the health and survival of host tree species, the Pennsylvania Department of Conservation and Natural Resources has a comprehensive suppression program to reduce the impacts of gypsy moth which includes aerial spray treatments when gypsy moth population cycles peak.

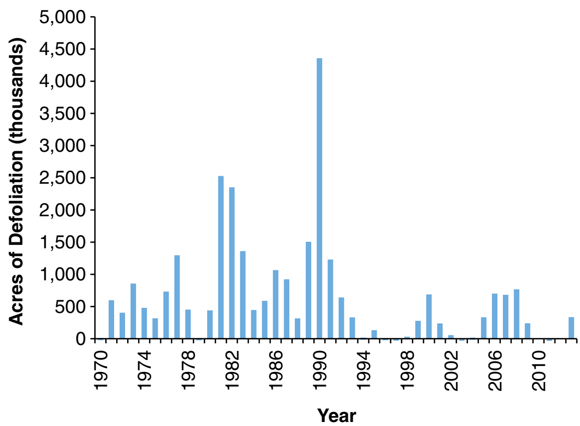

Figure 84.—Acres defoliated by gypsy moth, Pennsylvania, 1970 through 2013.

Source: U.S. Forest Service, State and Private Forestry, 2015 Gypsy Moth Digest – defoliation data.

BEECH BARK DISEASE

Background

American beech is a major component of the maple/beech/birch forest-type group, which covers 33 percent of the forested area in Pennsylvania (Fig. 20). American beech is an important pulpwood and firewood species and is also an important wildlife mast producer. Beech bark disease (BBD) is an insect-fungus complex involving the beech scale insect (*Cryptococcus fagisuga* Lind.) and the exotic canker fungus *Neonectria coccinea* (Pers.:Fr.) var. *faginata* Lohm. or the native *Neonectria galligena* Bres. This complex kills or injures American beech. Three phases of BBD are generally recognized: 1) the "advancing front," which corresponds to areas recently invaded by scale populations; 2) the "killing front," which represents areas where fungal invasion has occurred and tree mortality begins (typically 3 to 5 years after the scale insects appear, but sometimes as long as 20 years); and 3) the "aftermath forest," which are areas where the disease is endemic (Houston 1994, Shigo 1972). BBD was inadvertently introduced via ornamental beech trees into North America at Halifax, Nova Scotia, in 1890 and then began spreading to the south and west. By 1975 beech bark disease had been discovered in much of northeastern Pennsylvania and it has since spread across most of the State, including where beech densities are highest (Fig. 85).

What we found

Currently, the annual mortality rate for American beech by live volume per year is 1.4 percent, 50 percent higher than the average rate of 0.9 percent for all tree species (see Tree Mortality section starting on p. 74). Consequently, the impacts of BBD mortality have resulted in reductions of large diameter beech along with corresponding increases in small diameter beech since 1989 (Fig. 86). The number of beech seedlings (including root sprouts) increased by 9 percent between 2009 and 2014 while the number of sawtimber size trees (11 inches and larger) decreased 3 percent over the same period.

What this means

Most of Pennsylvania's forest infested by BBD is in the aftermath phase. Aftermath forests are often characterized by a dearth of large beech trees due to BBD-induced mortality and increasing numbers of beech seedlings and saplings. This condition, often referred to as "beech brush," can interfere with regeneration of other hardwood species such as sugar maple (Hane 2003). The condition consists of trees with low vigor and slow growth that often succumb to the disease before making it into the overstory. These trees are also unlikely to reach sawtimber size or produce mast. Efforts to mitigate the effects of beech brush on regeneration can incur significant costs for mechanical or chemical controls.

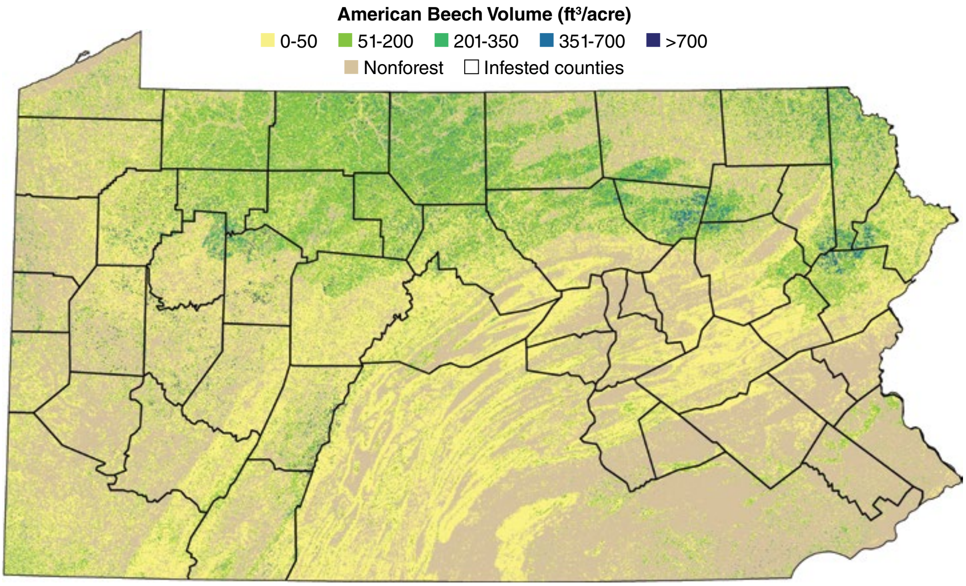

Figure 85.—American beech volume (trees at least 5 inches d.b.h.) on forest land, Pennsylvania, 2009, with beech bark disease-infested counties displayed.

Projection: Pennsylvania State Plane North, NAD83. Source: U.S. Forest Service, Forest Inventory and Analysis program, 2009. Geographic base data are provided by the National Atlas of the USA®. FIA Data and Tools are available online at http://www.fia.fs.fed.us/tools-data/.
Cartography: R.S. Morin, U.S. Forest Service, November 2015.

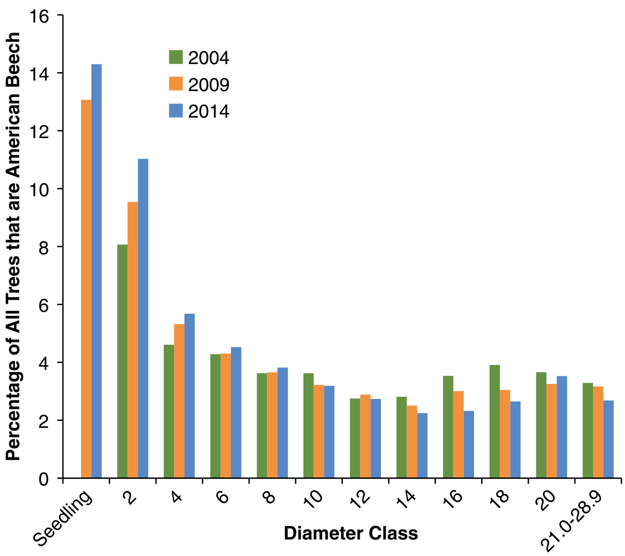

Figure 86.—Proportion of all trees that are American beech, by diameter class and inventory year on timberland, Pennsylvania.

Forest Economics

Logging operation in Berks County. Photo by Richard Widmann, U.S. Forest Service.

Timber Products

Background

Pennsylvania's forest industry provides jobs and income from harvesting timber and producing products, such as lumber and pulp. In 2012, the industry had more than $11 billion in sales and contributed $19 billion to the overall economy (Pennsylvania Department of Conservation and Natural Resources 2015). At that time, it was estimated there were more than 2,100 forest products processors supporting about 58,000 jobs. The industry has a presence in all counties, particularly in the rural counties, where forests and timber processors are concentrated. It is important to track species used and products manufactured to better manage and sustain the Commonwealth's forest resources, support rural economies, and fill a critical information need for policy makers and others.

This section combines information on harvest removal estimates on FIA plots and the results of a timber products output survey conducted for 2012 (Pennsylvania Department of Conservation and Natural Resources 2015). The FIA harvest estimates represent the volume of stumpage removed from the State's public and private forest land. These estimates provide contextual information on Pennsylvania's harvest relative to other eastern States and trends in FIA. The timber products output survey contacted 430 primary processing facilities in Pennsylvania with a response rate of 73 percent, or 312 facilities. Product output statistics are estimates of the volume of stumpage converted to products and hence do not match FIA's removals. Estimates of the amount of wood processed are based on 253 mills that reported product volume and 192 that reported residue volume. The information includes product output by region, product type, and species.

A previous report published for 2009 was devoted to understanding the impact of the nationwide recession that decreased production starting around 2007 (McCaskill et al. 2013, Smith and Guldin 2012). In 2010, the Pennsylvania Hardwoods Development Council reported the industry was in "terrible trouble" and the recession resulted in the closing of many small and medium-size mills and decreased production by large mills (Pennsylvania Hardwoods Development Council 2010). This section focuses on Pennsylvania's harvest and production trends since then.

What we found

Pennsylvania has long been a leader in the harvest of hardwood sawtimber. Despite the economic downturn just before the last forest inventory, the State now ranks fourth nationally for hardwood sawtimber removals based on the FIA estimates, with

0.9 billion board feet (Fig. 87). Tennessee ranks first in hardwood sawtimber removal with 1.2 billion board feet, followed by North Carolina and Mississippi, each with about 1.0 billion board feet. Although Pennsylvania's hardwood harvest estimate ranks below these States, the estimates for North Carolina, Mississippi, and Pennsylvania are not statistically different at the 68 percent confidence level.

Examination of total harvest removals highlights the importance of hardwoods, which account for about 90 percent of total harvest volume for both sawtimber and growing stock (Fig. 88). Estimates from the 1978 and 1989 periodic inventories are not directly comparable to the results of the annual inventory because they include removals attributed to land-use change and are limited to removals from timberland (Alerich 1993, Considine and Powell 1980). Removal estimates are not available for 2004 due to the inconsistencies with the 1989 periodic inventory. Despite these limitations, the removals reported for 2009 represent a peak in FIA removals estimates for Pennsylvania.

Information from the annual inventory shows that harvest of hardwood growing stock and sawtimber decreased by 22 and 27 percent, respectively, since 2009. Although a relatively minor component of total removals, harvest removals of softwood growing stock and sawtimber increased by 27 and 23 percent, respectively.

The survey of timber products industries revealed that the total volume processed in 2012 was 184.7 million cubic feet based on 253 respondents, which is equivalent to about 1.2 billion board feet (Pennsylvania Department of Conservation and Natural Resources 2015). The North Central and South Central regions accounted for 59 percent of total production (Fig. 89).

The mixed hardwood species group made up most of the product volume with 20 percent of the total (Table 11). The remaining 12 percent of volume processed was composed of ash, hemlock, chestnut oak, hickory, black oak, and other species.

Logs processed into lumber and other sawn products accounted for 637.9 million board feet, equivalent to 100.8 million cubic feet (Fig. 90). Using supplemental information, the Pennsylvania Department of Conservation and Natural Resources' mill study estimated that non-respondents represented about 25 percent of statewide saw-log production, which means that actual saw-log production could be as high as 850 million board feet. Pulp and chips totaled 2.5 million green tons, produced primarily for the paper industry. Exported log production was 14.9 million board feet. In addition, 66.3 million cubic feet of residues were produced as by-products of primary roundwood processing (Fig. 91). Most of this material (96 percent) was bark, coarse residues, and sawdust.

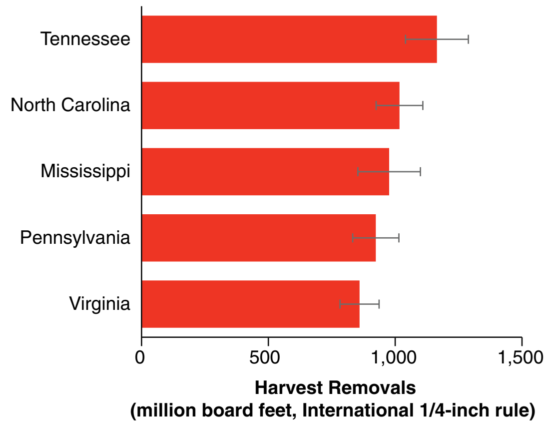

Figure 87.—Average annual hardwood sawtimber harvest removals for the five leading states in hardwood sawtimber removals, 2014. Error bars represent a 68 percent confidence interval around the estimated mean.

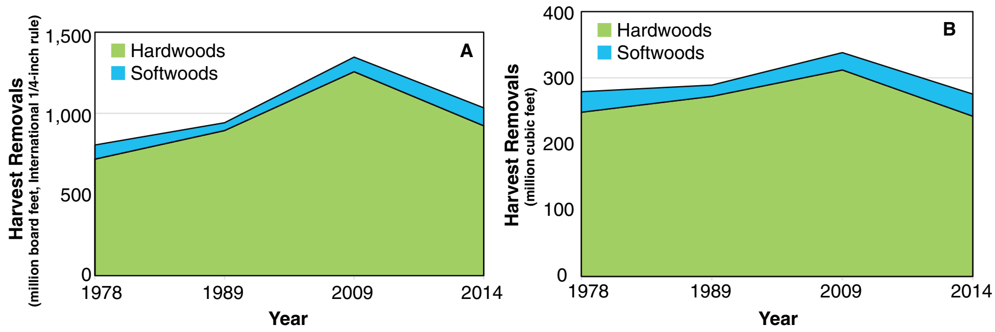

Figure 88.—Average annual harvest removals for sawtimber (A) and growing-stock trees (B) on forest land by inventory year, Pennsylvania.

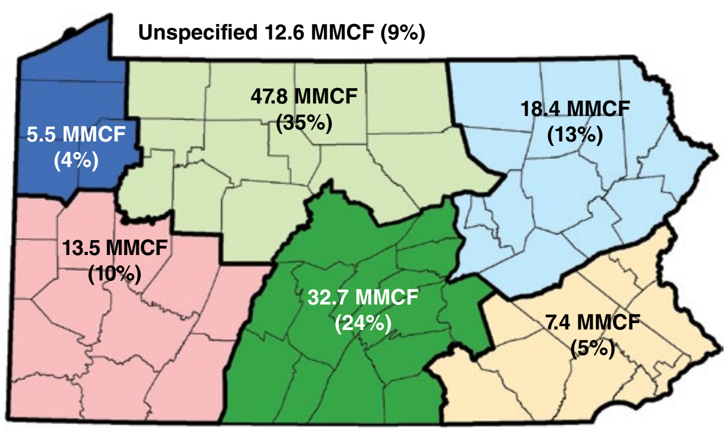

Figure 89.—Total volume (million cubic feet) and percentage of primary timber product production by region, Pennsylvania, 2012 (Pennsylvania Department of Conservation and Natural Resources 2015). [Note: based on 242 mill responses.]

Table 11.—Volume (million cubic feet) and percentage of total timber products processed by the nine species/species groups contributing at least 5 percent of total product volume, Pennsylvania, 2012

Species/Species group	Volume (million cubic feet)	Percent
Mixed hardwoods	36.7	20
Red oak	24.2	13
Miscellaneous softwood	22.9	13
Other species	15.8	9
Red (soft) maple	15.0	8
Black cherry	12.6	7
Yellow-poplar	12.5	7
White oak	11.1	6
Sugar (hard) maple	9.0	5

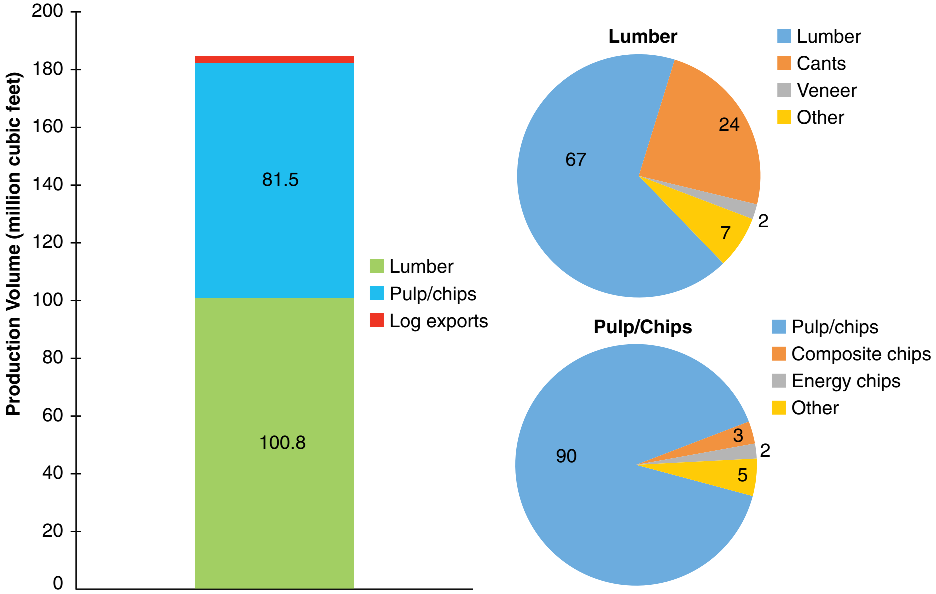

Figure 90.—Total volume of production by product and percentage of production for lumber and pulp/chips by product type, Pennsylvania, 2012 (Pennsylvania Department of Conservation and Natural Resources 2015). [Note: based on 253 mill responses.]

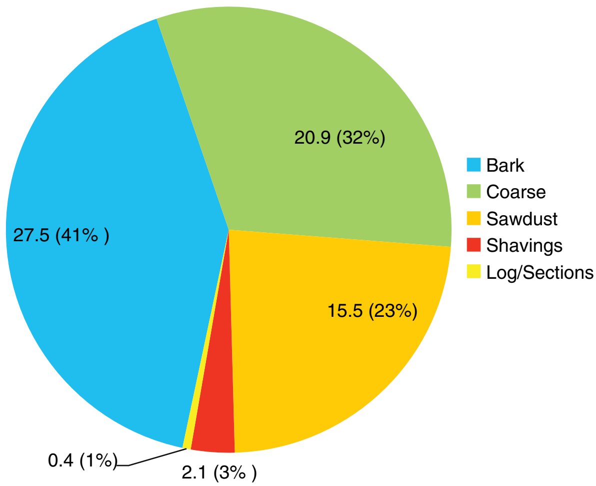

Figure 91.—Total volume (million cubic feet) and percentage of residue by-products by residue type, Pennsylvania, 2012 (Pennsylvania Department of Conservation and Natural Resources 2015). [Note: based on 192 mill responses.]

What this means

Perhaps the most important issue to address with the harvest and timber products information is how the timber industry of Pennsylvania has fared since the economic recession of a decade ago. The results indicate that harvest has not recovered to 2009 levels for both growing-stock and sawtimber trees. The decrease was most apparent for sawtimber; however, Pennsylvania still ranks among the leading states for hardwood sawtimber removals. This means that the recession has affected hardwood sawtimber harvest across many states, and Pennsylvania's situation mirrors others. One important factor is how timber prices have trended over the past decade. Timber market reports compiled by Penn State's Cooperative Extension Service (Pennsylvania State University 2016a) show mixed trends by species and region. In general, prices for black cherry and sugar maple have both trended downward. Red maple prices have remained level, while prices for oak have increased slightly in some markets.

Having markets for wood is essential to forest management. Despite the loss of some milling capacity, Pennsylvania's mills continue to provide landowners markets for their timber. The income landowners receive from selling timber is an incentive to keep land in forest. Income from harvests can help pay property taxes and fund forest management activities such as wildlife habitat improvements and invasive species control. Careful monitoring of timber products output is needed to formulate policies and programs that support the State's wood economy.

Looking Forward

Rock walls lining an abandoned road in Bradford County. Photo by Thomas Albright, U.S. Forest Service.

Future Forests of Pennsylvania

Background

This section focuses on anticipated changes to the forests of Pennsylvania between 2010 and 2060. The analysis is derived entirely from the Northern Forest Futures study (Shifley and Moser 2016). A large component of future forest change will be the result of normal forest growth, aging, natural regeneration, and species succession. In addition, the following external forces will drive forest change:

- Population increases will cause conversion of roughly 1.6 million acres of forest land to urban land (Nowak and Walton 2005)
- Economic conditions will affect forest products consumption, production, and harvest rates
- Invasive species will spread and affect forest change
- Changes in population, the economy, energy consumption, and energy production will affect future climate change
- Climate change will affect patterns of forest growth and species succession.

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

The three storylines are:

1) A1B—Rapid economic globalization. International mobility of people, ideas, and technology. Strong commitment to market-based solutions. Strong commitment to education. High rates of investment and innovation in education, technology, and institutions at the national and international levels. A balanced energy portfolio including fossil fuel-intensive and renewable energy sources. Utilizes the CGCM3.1 climate model (Canadian Centre for Climate Modelling and Analysis 2014).

2) A2—Consolidation into economic regions. Self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between regions. Technology diffuses more slowly than in the other scenarios. International disparities in productivity, and hence income per capita, are largely maintained or increased in absolute terms. Utilizes the CGCM3.1 climate model.

3) B2—A trend toward local self-reliance and stronger communities. Community-based solutions to social problems. Energy systems differ from region to region, depending on the availability of natural resources. The need to use energy and other resources more efficiently spurs the development of less carbon-intensive technology in some regions. Utilizes the CGCM2 climate model (Canadian Centre for Climate Modelling and Analysis 2014).

The three storyline variations are as follows:

- C—Continuation of the observed recent rates of forest removals due to timber harvesting and land use conversion from forest to another land use.
- BIO—Increased harvest and utilization of woody biomass for energy variation, available for all three storylines (A1B, A2, and B2).
- EAB—Potential impact of continued spread of the emerald ash borer with associated mortality of all ash trees in the affected areas – available for only one scenario (A2).

What we found

Anticipated declines in forest land in Pennsylvania from 2010 to 2060 break the recent observed stability in forest land area since the 1989 inventory (Fig. 92). Specifically, over the next 50 years forest land area is projected to decline from an estimated 16.7 million acres in 2010 to 15.0 million acres (a loss of 10 percent) in 2060 under scenario A1B-C; to 15.3 million acres (a loss of 8 percent) under scenario A2-C; and to 15.9 million acres (a loss of 5 percent) under scenario B2-C. Only three scenarios are represented in Figure 92 as the climate model and variations on the storylines do not affect projections of forest land area under this model. Only the storylines developed around differing demographics and levels of economic activity alter the modeled area of forest land. Scenarios with increasing population and economic activity project less forest land over the time period.

Emerald ash borer, initially detected in Pennsylvania in June 2007, has been detected in 62 of Pennsylvania's 67 counties (Pennsylvania State University 2016b). Ash species make up 4.7 percent of the current total live tree volume on forest land. Under the A2-EAB scenario live ash volume is projected to go to zero by 2025. The impact on total live tree volume from the loss of the ash component is short-lived as other species are expected to fill the void. The difference in total live tree volume between scenario A2-C and A2-EAB by 2060 is negligible (0.3 percent less under scenario A2-EAB) (Fig. 93).

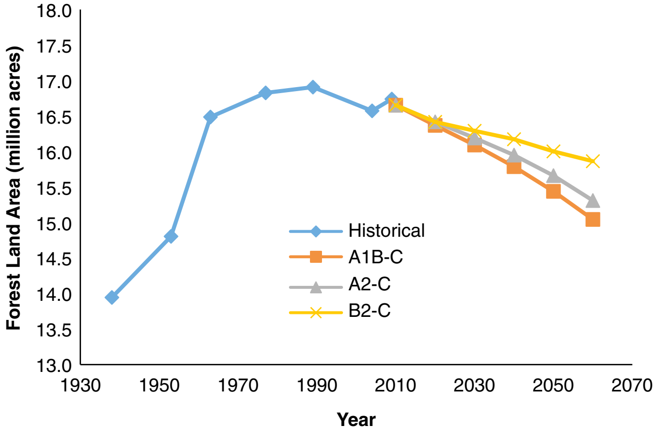

Figure 92.—Projected forest land area for Pennsylvania by scenario, 2010–2060.

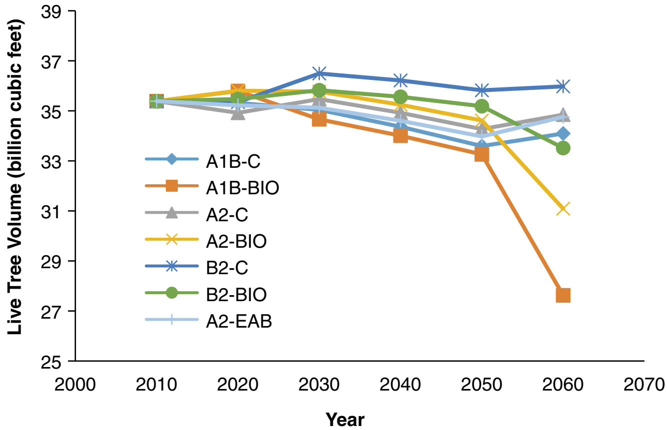

Figure 93.—Live tree volume on forest land in Pennsylvania by scenario, 2010–2060.

Impacts of high biomass utilization on total live tree volume are much more pronounced than the impacts of EAB. As a result of these high levels of removals, live tree volume on forest land is projected to decrease under all three high biomass utilization scenarios (Fig. 94): A1B-BIO (a decline of 22 percent), B2-BIO (a decline of 12 percent), and A2-BIO (a decline of 5 percent).

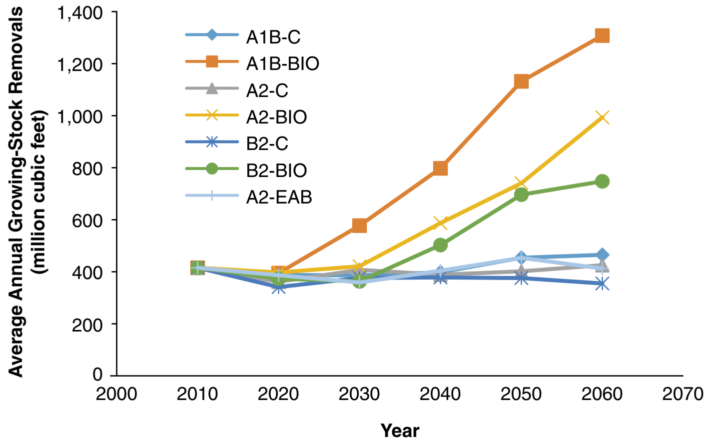

Figure 94.—Average annual growing-stock removals on timberland in Pennsylvania by scenario, 2010–2060.

What this means

The area of forest land is expected to decrease under each of the three storylines in response to increases in population and economic activity. Scenarios assuming greater increases in population and economic activity are projected to have greater losses of forest land.

The projected loss of forest land is substantial. The loss of between 5 and 10 percent of forest land, depending on scenario, is somewhat offset by increases in volume per acre under scenarios A1-C, A2-C, B2-C, and A2-EAB. Harvest rates under the high biomass utilization scenarios (Fig. 94) have a large impact on volumes for those scenarios after 2050, resulting in declining volumes per acre.

It is important to note that predictions are future possibilities, not future truths. Forest and development planning, energy policy, and control of invasive plants and pests can all have a significant mitigating impact on future forest loss.

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Appendix

Tree species, greater than or equal to 1 inch in diameter, found on FIA inventory plots by regeneration species groups, Pennsylvania, 2014

Common name	Genus	Species	Timber species[a]	Timber code	Canopy species[b]	Canopy code
white fir	*Abies*	*concolor*	●	3	■	2
Fraser fir	*Abies*	*fraseri*	●	3	○	3
eastern redcedar	*Juniperus*	*virginiana*	●	3	○	3
tamarack (native)	*Larix*	*laricina*	▼	1	■	2
larch spp.	*Larix*	spp.	▼	1	■	2
Norway spruce	*Picea*	*abies*	●	3	■	2
white spruce	*Picea*	*glauca*	●	3	■	2
blue spruce	*Picea*	*pungens*	●	3	■	2
red spruce	*Picea*	*rubens*	●	3	■	2
jack pine	*Pinus*	*banksiana*	◗	2	■	2
Austrian pine	*Pinus*	*nigra*	◗	2	■	2
table mountain pine	*Pinus*	*pungens*	▼	1	■	2
red pine	*Pinus*	*resinosa*	▼	1	■	2
pitch pine	*Pinus*	*rigida*	▼	1	■	2
eastern white pine	*Pinus*	*strobus*	▼	1	▲	1
Scotch pine	*Pinus*	*sylvestris*	▼	1	■	2
Virginia pine	*Pinus*	*virginiana*	▼	1	■	2
Douglas-fir	*Pseudotsuga*	*menziesii*	●	3	○	3
eastern hemlock	*Tsuga*	*canadensis*	▼	1	▲	1
boxelder	*Acer*	*negundo*	●	3	○	3
black maple	*Acer*	*nigrum*	●	3	■	2
striped maple	*Acer*	*pensylvanicum*	●	3	○	3
Norway maple	*Acer*	*platanoides*	●	3	■	2
red maple	*Acer*	*rubrum*	▼	1	▲	1
silver maple	*Acer*	*saccharinum*	●	3	■	2
sugar maple	*Acer*	*saccharum*	▼	1	▲	1
mountain maple	*Acer*	*spicatum*	●	3	○	3
buckeye, horsechestnut spp.	*Aesculus*	spp.	●	3	■	2
ailanthus (tree of heaven)	*Ailanthus*	*altissima*	●	3	○	3
European alder	*Alnus*	*glutinosa*	●	3	○	3
common serviceberry	*Amelanchier*	*arborea*	●	3	○	3
pawpaw	*Asimina*	*triloba*	●	3	○	3
yellow birch	*Betula*	*alleghaniensis*	◗	2	■	2
sweet (black) birch	*Betula*	*lenta*	◗	2	▲	1

[a] ▼ = Desirable ◗ = Commercial ● = Other

[b] ▲ = High canopy dominant ■ = High other ○ = Other. High-canopy dominants are species that account for at least 2 percent of total live-tree biomass within the State and typically form high canopy.

(continued)

(*Continued*) Tree species, greater than or equal to 1 inch in diameter, found on FIA inventory plots by regeneration species groups, Pennsylvania, 2014

Common name	Genus	Species	Timber species[a]	Timber code	Canopy species[b]	Canopy code
river birch	*Betula*	*nigra*	◗	2	■	2
paper birch	*Betula*	*papyrifera*	◗	2	■	2
gray birch	*Betula*	*populifolia*	●	3	○	3
American hornbeam (musclewood)	*Carpinus*	*caroliniana*	●	3	○	3
mockernut hickory	*Carya*	*alba*	▼	1	▲	1
bitternut hickory	*Carya*	*cordiformis*	▼	1	▲	1
pignut hickory	*Carya*	*glabra*	▼	1	▲	1
shagbark hickory	*Carya*	*ovata*	▼	1	▲	1
American chestnut	*Castanea*	*dentata*	●	3	○	3
catalpa spp.	*Catalpa*	spp.	●	3	■	2
hackberry	*Celtis*	*occidentalis*	◗	2	■	2
eastern redbud	*Cercis*	*canadensis*	●	3	○	3
flowering dogwood	*Cornus*	*florida*	●	3	○	3
hawthorn spp.	*Crataegus*	spp.	●	3	○	3
American beech	*Fagus*	*grandifolia*	◗	2	▲	1
white ash	*Fraxinus*	*americana*	▼	1	▲	1
black ash	*Fraxinus*	*nigra*	▼	1	■	2
green ash	*Fraxinus*	*pennsylvanica*	▼	1	▲	1
ginkgo, maidenhair tree	*Ginkgo*	*biloba*	●	3	■	2
honeylocust	*Gleditsia*	*triacanthos*	●	3	■	2
Kentucky coffeetree	*Gymnocladus*	*dioicus*	◗	2	■	2
American holly	*Ilex*	*opaca*	●	3	○	3
butternut	*Juglans*	*cinerea*	▼	1	■	2
black walnut	*Juglans*	*nigra*	▼	1	■	2
sweetgum	*Liquidambar*	*styraciflua*	◗	2	■	2
yellow-poplar	*Liriodendron*	*tulipifera*	▼	1	▲	1
Osage-orange	*Maclura*	*pomifera*	●	3	○	3
cucumbertree	*Magnolia*	*acuminata*	▼	1	■	2
umbrella magnolia	*Magnolia*	*tripetala*	●	3	○	3
sweet crab apple	*Malus*	*coronaria*	●	3	○	3
apple spp.	*Malus*	spp.	●	3	○	3
white mulberry	*Morus*	*alba*	●	3	○	3
red mulberry	*Morus*	*rubra*	●	3	○	3
mulberry spp.	*Morus*	spp.	●	3	○	3
blackgum	*Nyssa*	*sylvatica*	◗	2	■	2
eastern hophornbeam	*Ostrya*	*virginiana*	●	3	○	3
paulownia, princesstree	*Paulownia*	*tomentosa*	●	3	○	3

[a] ▼ = Desirable ◗ = Commercial ● = Other
[b] ▲ = High canopy dominant ■ = High other ○ = Other. High-canopy dominants are species that account for at least 2 percent of total live-tree biomass within the State and typically form high canopy.

(continued)

(*Continued*) Tree species, greater than or equal to 1 inch in diameter, found on FIA inventory plots by regeneration species groups, Pennsylvania, 2014

Common name	Genus	Species	Timber species[a]	Timber code	Canopy species[b]	Canopy code
American sycamore	*Platanus*	*occidentalis*	●	3	■	2
balsam poplar	*Populus*	*balsamifera*	◗	2	■	2
eastern cottonwood	*Populus*	*deltoides*	◗	2	■	2
bigtooth aspen	*Populus*	*grandidentata*	◗	2	■	2
quaking aspen	*Populus*	*tremuloides*	◗	2	■	2
sweet cherry, domesticated	*Prunus*	*avium*	●	3	○	3
pin cherry	*Prunus*	*pensylvanica*	●	3	○	3
black cherry	*Prunus*	*serotina*	▼	1	▲	1
cherry and plum spp.	*Prunus*	spp.	●	3	○	3
chokecherry	*Prunus*	*virginiana*	●	3	○	3
white oak	*Quercus*	*alba*	▼	1	▲	1
swamp white oak	*Quercus*	*bicolor*	▼	1	■	2
scarlet oak	*Quercus*	*coccinea*	▼	1	▲	1
northern pin oak	*Quercus*	*ellipsoidalis*	▼	1	■	2
scrub oak	*Quercus*	*ilicifolia*	●	3	○	3
shingle oak	*Quercus*	*imbricaria*	▼	1	■	2
bur oak	*Quercus*	*macrocarpa*	▼	1	▲	1
swamp chestnut oak	*Quercus*	*michauxii*	▼	1	■	2
pin oak	*Quercus*	*palustris*	▼	1	▲	1
dwarf chinkapin oak	*Quercus*	*prinoides*	●	3	○	3
chestnut oak	*Quercus*	*prinus*	▼	1	▲	1
northern red oak	*Quercus*	*rubra*	▼	1	▲	1
black oak	*Quercus*	*velutina*	▼	1	▲	1
black locust	*Robinia*	*pseudoacacia*	◗	2	■	2
black willow	*Salix*	*nigra*	◗	2	■	2
sassafras	*Sassafras*	*albidum*	●	3	○	3
American basswood	*Tilia*	*americana*	▼	1	■	2
white basswood	*Tilia*	*heterophylla*	●	3	■	2
American elm	*Ulmus*	*americana*	◗	2	■	2
slippery elm	*Ulmus*	*rubra*	◗	2	■	2

[a] ▼ = Desirable ◗ = Commercial ● = Other

[b] ▲ = High canopy dominant ■ = High other ○ = Other. High-canopy dominants are species that account for at least 2 percent of total live-tree biomass within the State and typically form high canopy.*)*

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This report summarizes the third cycle of annualized inventory of Pennsylvania with field data collected from 2009 through 2014. Pennsylvania has 16.9 million acres of forest land dominated by sawtimber stands of oak/hickory and maple/beech/birch forest-type groups. Volumes continue to increase as the forests age with an average of 2,244 cubic feet per acre on timberland. Sawtimber volume has risen 24 percent in 10 years to 115 billion board feet. Net growth outpaced removals by a ratio of 2.4:1 on timberland. Additional information on land-use change, fragmentation, ownership, forest composition, structure and age distribution, carbon stocks, regeneration, invasive plants, insect pests, and wood products is also presented. Sets of supplemental tables are available online at https://doi.org/10.2737/NRS-RB-111 and contain: 1) tables that summarize quality assurance and 2) a core set of tabular estimates for a variety of forest resources.

KEY WORDS: inventory, land use, fragmentation, forest statistics, forest land, timberland, forest ownership, forest regeneration, volume, carbon, growth, removals, mortality, forest health, timber products, forest pests, invasive plants, Pennsylvania

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