Pennsylvania's Forest 2004

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Abstract

In 2000, the Pennsylvania Department of Conservation's Natural Resources, Bureau of Forestry and the Northern Research Station's Forest Inventory and Analysis unit implemented a new annual system for inventorying and monitoring Pennsylvania's forests. This report includes data from 2000 to 2004. Pennsylvania's forest-land base is stable, covering 16.6 million acres or 58 percent of land area. More than 660,000 acres of forest land were lost from 1989 to 2004, mostly to residential or industrial development. However, there was a 617,500-acre gain in forest land, mostly from agricultural land. Fifty-four percent of forest land is owned by families and individuals. Forest types with red maple as a dominant species have increased, while stands with sugar maple as a dominant have decreased. The distribution of forest land by stand-size class has been shifting toward large stands that now account for 6 of 10 acres. The area of forest has increased in the poor and moderate stocking classes and decreased in the full and overstocked classes. Hemlock, sugar maple, and oaks are poised to be less dominant in the future. Increases in red maple are slowing while black birch continues to increase. Sawtimber volume totals 88.9 billion board feet, an average of about 5,000 board feet per acre. Increases in sawtimber inventory have slowed over time. Currently, only half of the forest land that should have advance regeneration is adequately stocked with high-canopy species, and only one-third has adequate regeneration for commercially desirable timber species. Grass/forb and rhizomous ferns dominate understory communities, accounting for nearly one-third of the total nontree vegetative cover sampled. Several exotic diseases and insects threaten the health of Pennsylvania's forests. Exotic-invasive plants threaten native plant diversity and forest health; however, monitoring efforts are only beginning to quantify their distribution and abundance. Stressors such as drought, acidic deposition, and ground-level ozone pollution are adversely affecting the State's forests. Continued monitoring is required to gain a more complete understanding of these impacts on this valuable resource.

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Pennsylvania's Forest 2004

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Northern Research Station—Forest Inventory and Analysis

Sugar maple fall foliage.

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HIGHLIGHTS

- Forests account for 16.6 million acres or 58 percent of Pennsylvania's land area, a decrease of 100,000 acres since 1989. More than 660,000 acres of forest land were lost from 1989 to 2004, an average of about 44,000 acres per year. Twenty-eight thousand acres per year were converted to residential and industrial development. However, losses of forest land were offset by additions from agricultural land reversion.

- Fifty-four percent of forest land is owned by families and individuals. Family and individual owners cite numerous reasons for holding forest land, with timber harvesting a relatively minor objective. Only 2 percent of these owners have a written management plan and only 8 percent have sought professional management advice. Another 2.8 million acres (17 percent) are owned by other private entities such as corporations. Public agencies control 4.8 million acres (29 percent).

- There were no substantial changes in the distribution of forest land by major forest-type group, but there have been significant changes in composition and structure. Forest types with red maple as a dominant species have increased while stands with sugar maple as a dominant have decreased.

Cut-over forest at turn of the century. Photo from the Lycoming County Historical Society.

- The distribution of forest land by stand-size class has been shifting toward large stands that now account for 6 of 10 acres.

- The area of forest has increased in the poor and moderate stocking classes and decreased in the full and overstocked classes. These shifts were most prominent on private forest land.

- The number of smaller trees is decreasing and the number of larger trees is increasing, characteristic of a maturing forest. Relative differences between species indicate that hemlock, sugar maple, and the oaks are decreasing in importance. Increases in red maple are slowing while black birch continues to increase.

- The current sawtimber inventory (expressed in board feet, International ¼-inch rule) is the highest recorded since the inception of the Forest Inventory and

Analysis program in 1955. Sawtimber volume totals 88.9 billion board feet, or more than 5,000 board feet per acre. Increases in sawtimber inventory have slowed over time.

- Currently, only half of the forest land that should have advance regeneration is adequately stocked with high-canopy species and only one-third has adequate regeneration for commercially desirable timber species. Northern tier and southeastern counties have the lowest levels of advance regeneration.

- Grass/forb and rhizomous ferns dominate understory communities, accounting for nearly one-third of the total nontree vegetative cover sampled.

- Several exotic diseases and insects are threatening the health of Pennsylvania's forests. Gypsy moth, hemlock woolly adelgid, and beech bark disease are among those currently active. Sudden oak death (SOD) and the Asian long-horned beetle could inflict severe damage should they become established in Pennsylvania. The discovery of emerald ash borer in the State is particularly troublesome.

- Exotic-invasive plants pose a threat to native plant diversity and forest health. Abundant understory exotics include multiflora rose, Russian/autumn olive, garlic mustard, Japanese stiltgrass, and bush honeysuckles. Tree-of-heaven has expanded to the point where there is an average of one stem for every acre in the State.

Unbroken forested landscape.

- Monitoring lichen communities can help gauge the impact of air pollution and indicate broad trends in biodiversity. Lichen species richness is higher in central Pennsylvania. Species-richness scores generally are lower in areas where sulfate deposition is high.

- Stressors such as drought, acidic deposition, and ground-level ozone pollution are adversely affecting the Commonwealth's forests. Continued monitoring is required to gain a better understanding of these impacts on this valuable resource.

Susquehanna River Log Boom. Photo from the Lycoming County Historical Society.

INTRODUCTION

Credible information on Pennsylvania's forests is essential to understanding the condition of this important natural resource. A comprehensive set of variables that consistently tracks and describes the forest through time is needed to accurately inform policies, guide management decisions, examine trends, chart trajectories, and formulate critical research questions. The Northern Research Station's Forest Inventory and Analysis (NRS-FIA) unit is uniquely positioned to provide pertinent data and information about Pennsylvania's forests to help achieve these and other objectives.

NRS-FIA has been conducting forest inventories in Pennsylvania since the 1950s. Periodic reports on the status of and changes in forest conditions were completed for 1955 (Ferguson 1955), 1965 (Ferguson 1968), 1978 (Considine and Powell 1980), and 1989 (Alerich 1993).

In 2000, the NRS-FIA and the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry implemented a new annual system for inventorying and monitoring Pennsylvania forests, completing full inventories every 5 years. The new system combines features of the periodic system with a new sample-plot grid that now incorporates measurements of forest health (see Appendix). Also new to the program is the Pennsylvania Regeneration Study, which collects additional data on forest regeneration and understory conditions. The 2004 results represent the first complete set of annual inventory measurements collected over the first 5 years (2000-04).

CHAPTER 1: FOREST LAND-USE DYNAMICS

Central to understanding Pennsylvania's forest resource is placing it in context within the State's evolving landscape. The forest is not an isolated entity but a product of the landscape interactions that occur within and aside its borders. In this chapter, we explore the complex land-use dynamics that affect the basic character and distribution of Pennsylvania's forests.

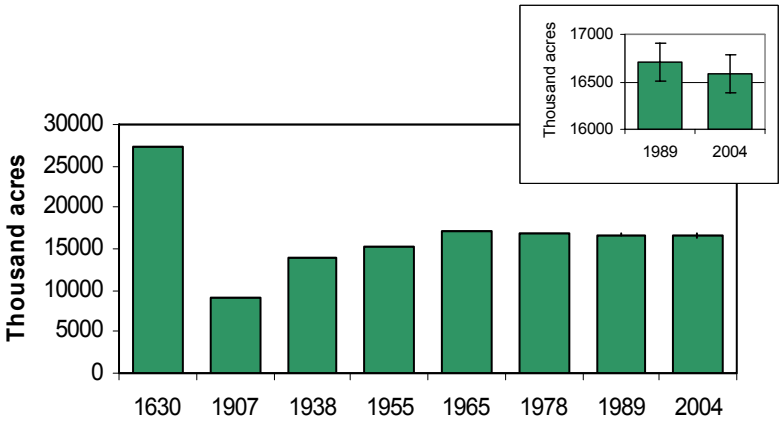


Figure 1.—Area of forest land in Pennsylvania, 1630, 1907, 1938, 1955, 1965, 1978, 1989, and 2004.

Forest-Land Base: Distribution and Trends

Historical data suggest that forest once covered more than 90 percent (27.3 million acres) of Pennsylvania's land area in the pre-European settlement era (1630s) (Fig. 1). By the early 1900s, industrial timber harvesting and agricultural land clearing had diminished the forest land base to only 32 percent (9.2 millions acres). Following this period of extensive reduction, forest land increased steadily as it reclaimed former sites.

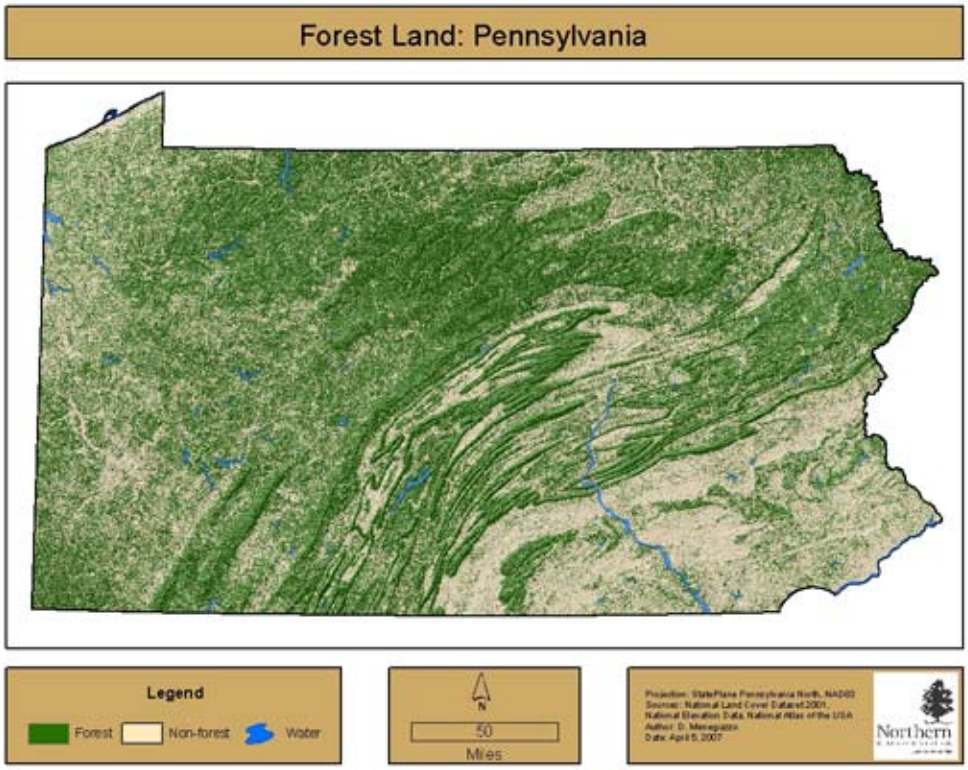


Figure 2.—Forest land in Pennsylvania, 2000.

The forest-land base has been relatively stable for the last half century and now is the dominant land class at 58 percent. Forest land is defined as land at least 10-percent stocked with trees of any size, or that formerly had such tree cover and is not currently developed for a nonforest use. The minimum area for classification of forest land is 1 acre. The 16.6 million acres of forest land reported for Pennsylvania's 2004 inventory represents a slight but not statistically significant decrease from the previous inventory's estimate (16.7 million acres).

Patterns in forest-land cover can be seen from satellite imagery (Fig. 2) taken in 2000 (Warner 2002). Large, contiguous patches of forest extend across the Allegheny Plateau in the north-central portion of the State. In central Pennsylvania, forest-land distribution follows the topographical contours of the ridges that divide agricultural valleys. Smaller, more fragmented blocks of forest land are noticeable in more urban and agricultural regions, especially across southern-tier counties.

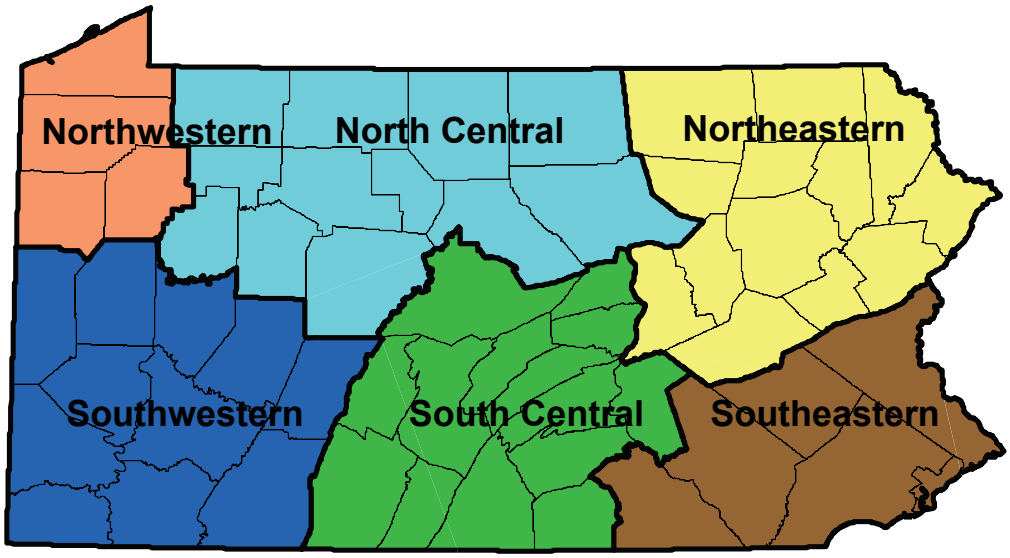


Figure 3.—Ecopolitical regions of Pennsylvania.

A complex mix of biotic and abiotic factors determines forest composition, structure, and function. Traditional geopolitical boundaries, e.g., county maps, are not always correlated with these natural phenomena or specific resource issues. Figure 3 shows ecopolitical regions developed by the Bureau of Forestry to address sustainability issues. These partition Pennsylvania's diverse landscape into meaningful areas that address ecological differences, e.g., Plateau versus Ridge and Valley forests, as well as cultural and political concerns, e.g., issues germane to the urban southeastern region versus the rural north-central region. These regions provide context for other maps and analyses in this report.

There was little net change in total area of forest land within all ecopolitical regions between 1989 and 2004 (Fig. 4). Although not statistically significant, all of the southern regions posted smaller acreages of forest land in the 2004 inventory. The north-central region, which includes the Allegheny National Forest and large tracts of state-owned forest, predictably contains the largest amount of forest land (79 percent). The southeastern region is the least forested at 22 percent. This is not surprising given that the region includes the Philadelphia metropolitan area and is host to the greatest proportion of agricultural land uses (35 percent) of any region in Pennsylvania. In fact, there is more agricultural land than forest in most of the counties in this region.

County-level changes in forest land are shown in Figure 5. Many counties in the north-central and northeastern regions indicate an overall gain in forest land. Losses in forest land at the county level are prevalent in more urbanized counties, particularly in the southeastern region and in some counties in the south-central region. Many counties that show a net loss of forest land are located near urban centers or major connecting highways. Eastern Pennsylvania is part of the band of

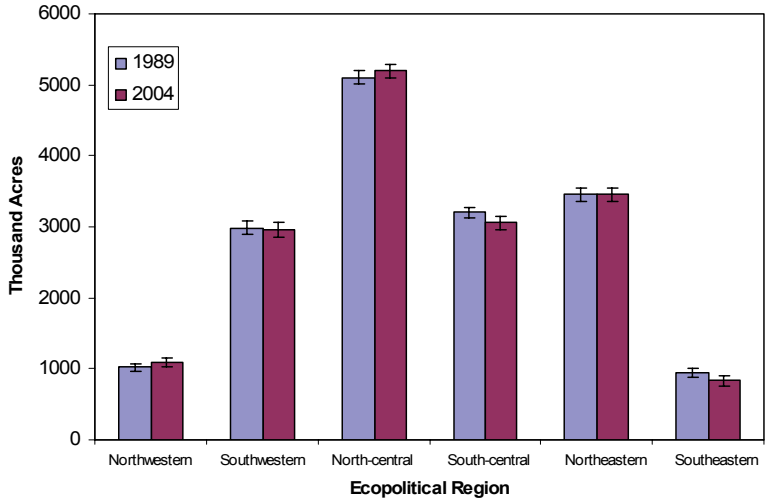


Figure 4.—Area of forest land by ecopolitical region, Pennsylvania, 1989 and 2004.

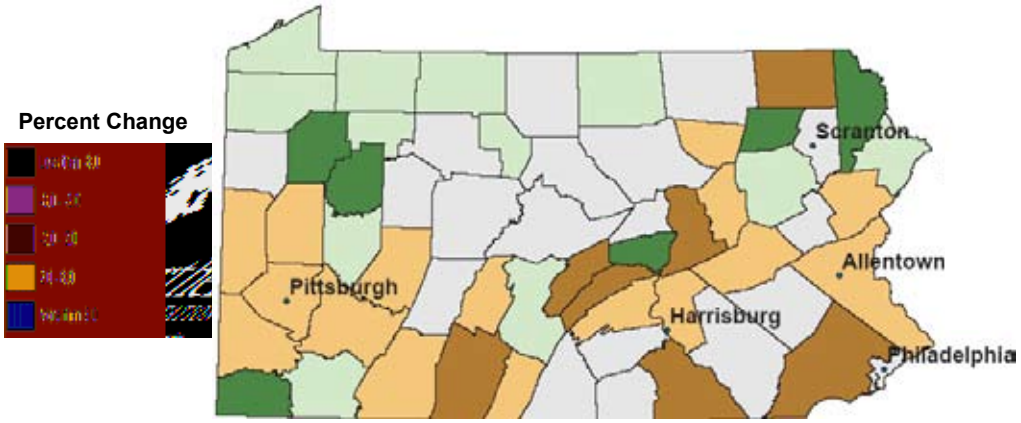


Figure 5.—Percent change in area of forest land, Pennsylvania, 1989 to 2004.

urban development that follows Interstate 95 along the East Coast. These areas are characterized by large cities, e.g., Philadelphia, with little forest land. Surrounding areas often include development patterns that have led to small patches of highly fragmented forests.

Forest-Land Loss and Gain

Although no significant net change has occurred in Pennsylvania's total forest area, both losses and gains in forest continue at various scales. In such a dynamic, the total acreage of forest area may remain the same while shifts occur in the forest-land base. Therefore, characterizing this base as having "no net change" may not accurately represent actual changes in forest distribution, character, and composition.

NRS-FIA data indicate that more than 663,000 acres of forest land were lost from 1989 to 2004, an average of about 44,000 acres per year. Nearly two-thirds of the forest land, or 28,000 acres per year, was diverted to residential and industrial development and likely is permanent.

An example of forest lost to residential development is shown in Figure 6. Remote sensing data make it possible to identify pockets of land conversion, for example, in the northeastern region. This pattern of forest loss is common throughout Pennsylvania. Additional factors contributing to the loss of forest land include agricultural expansion and other localized disturbances such as mining. Timber harvesting does not contribute to this

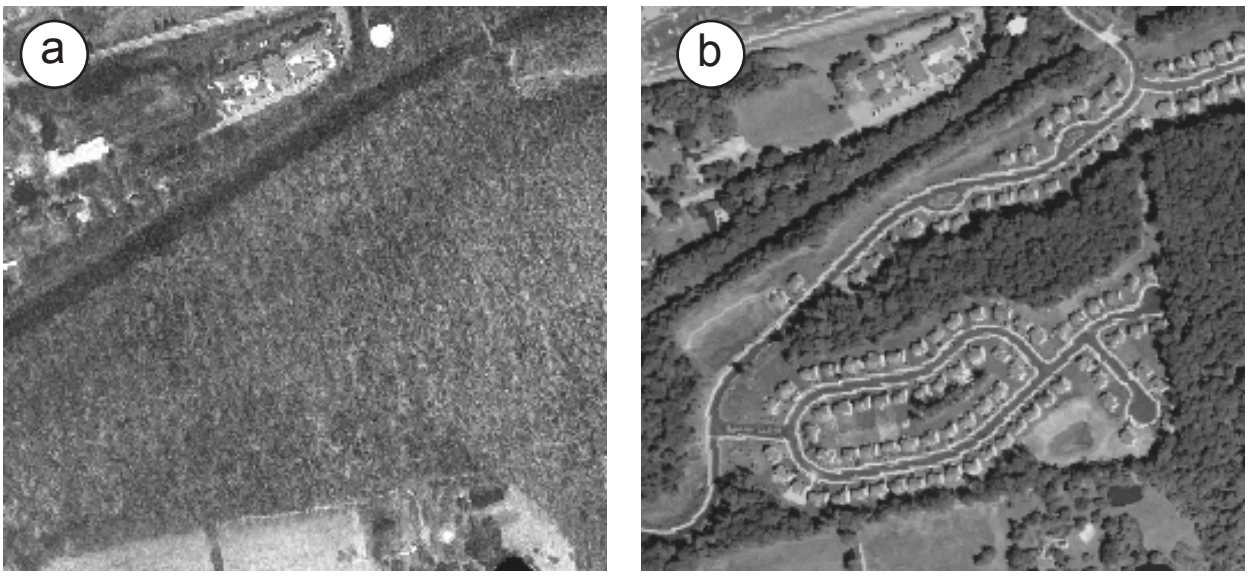


Figure 6.—Forest-land conversion to residential development, Pennsylvania, 1985 (a) and 1997 (b).

Land-clearing equipment.

type of forest loss so long as the tract continues to meet the definition of forest land.

During the same period, there was a 617,500-acre gain in forest land. About 350,000 acres (58 percent) of the gain was from agriculture. In this situation, abandoned fields commonly revert to forest through natural succession. This trend has offset most of the observed permanent loss of forest land and has allowed for the stable acreage in forest. That the most common agricultural land conversion is to urban land uses might limit this land type as a source for gain in forest land in the future. Reclaimed mine land and rights-of-way were other significant sources of forest gains.

Urbanization and Fragmentation

Urbanization of the landscape significantly affects the amount of forest land and also its species composition, health, and overall sustainability. Urbanization of forest land is the process of increasing urban (versus agricultural) development, either replacing or coming into increasing proximity to forest land. The process of urbanization is illustrated by comparing county-level estimates of forest area loss between 1989 and 2004 and change in housing and population density over roughly the same period (Figs. 7-8). Many areas with the greatest loss of forest land also experienced the highest urbanization rates, supporting the finding that most forest is being lost to residential and commercial development.

Table 1 and Figure 9 show forest-land distribution by population density. Also shown is the proportion of forests by ecopolitical region that falls in Census Bureau urban areas, a more restrictive definition that includes contiguous densely settled area but doesn't include many suburban and exurban areas (U.S. Census Bureau 2003). Averaged across the State, 6 percent of the forest is in Census-classified urban areas. The southeastern region has the highest amount at 28 percent.

Table 1.—Forest land in Pennsylvania by region and population density class (source: U.S. Bureau of Census and National Land Cover Data project)

People/mi^2	Forest land					
(no.)	Northwestern	Southwestern	North-central	South-central	Northeastern	Southeastern
	Percent					
0 to 25	9	11	63	27	20	0
26 to 50	40	25	23	37	32	4
51 to 100	34	30	10	22	24	11
101 to 250	12	21	3	11	18	45
251 to 500	3	7	1	2	4	24
501 to 1000	1	3	0	1	1	9
1001+	1	2	0	0	1	7

Note: Percentage of total forest land in urban forest: Northwestern (3); Southwestern (9); North-central (0); South-central (1); Northeastern (2); Southeastern (28).

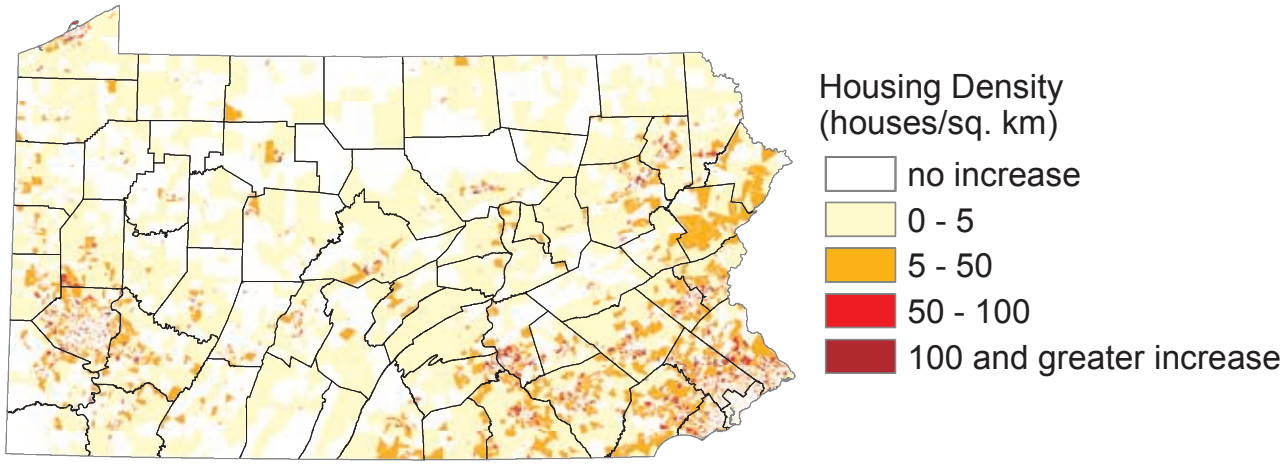


Figure 7.—Increases in housing density, Pennsylvania, 1990 to 2000.

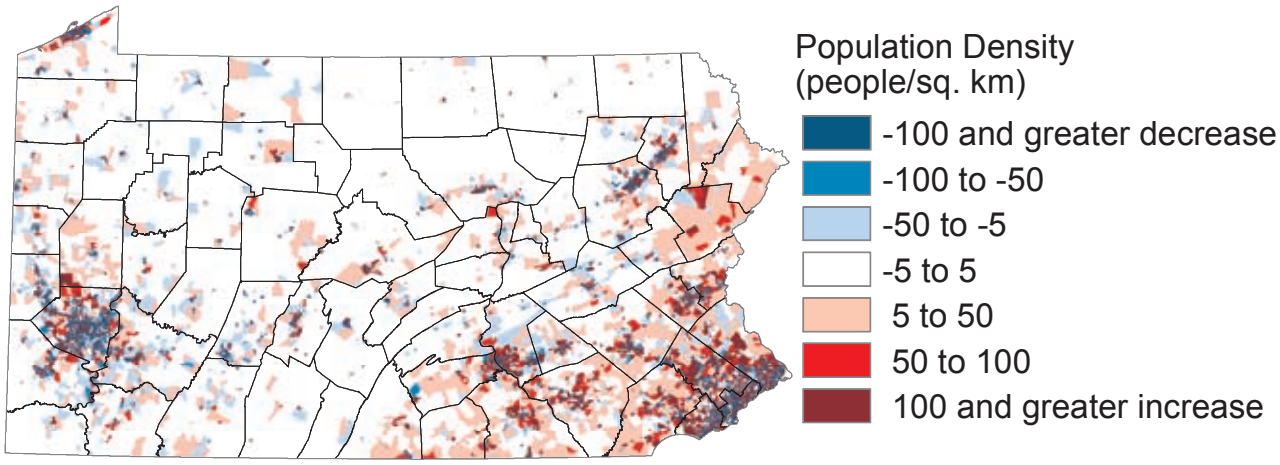


Figure 8.—Change in population density, Pennsylvania, 1990 to 2000.

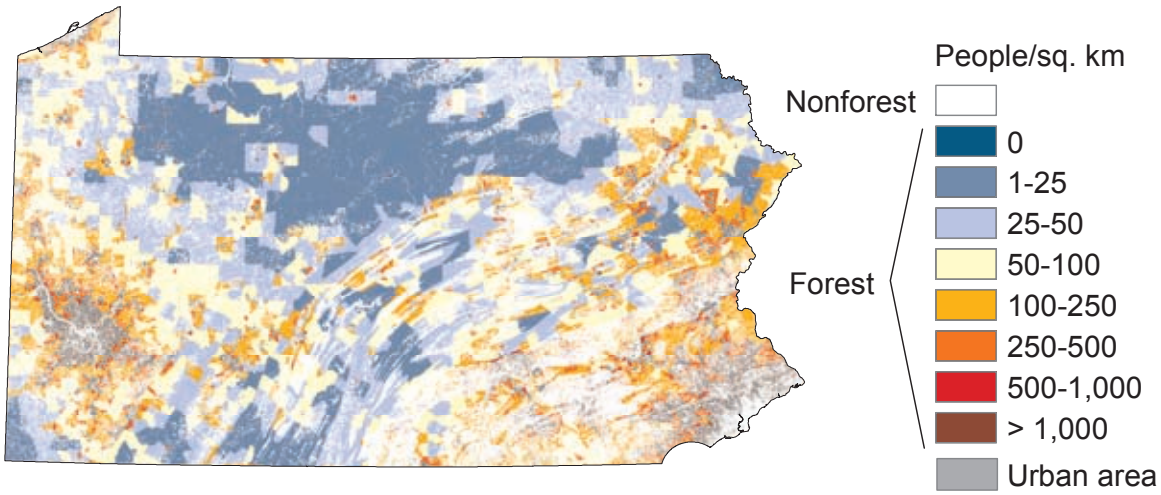


Figure 9.—Forest land by population density and urban status, 2000.

The rate of growth in Census-classified urban areas in the United States over the next several decades was modeled by Nowak and Walton (2005). Counties on the East Coast, including those in Pennsylvania, are projected to have some of the highest rates of urbanization over the next 50 years. The study projected that U.S. urban land will increase from 3 percent in 2000 to 8 percent in 2050. This growth could significantly transform the Commonwealth's forests and attitudes regarding those forests, particularly in the northeastern and southern regions.

New construction in the woods.

Forest fragmentation is defined as the division of contiguous or adjoining forest land into smaller patches. Fragmentation can be caused by urbanization, or as in Lancaster, Lebanon, and York counties, agriculture is a primary cause of fragmentation of forest land. Fragmentation analysis, the study of spatial patterns of forest patch distribution and dynamics, reveals information about the Pennsylvania's forests that is not apparent from simple statistical summaries. For example, examining and measuring the relative distribution and interface between forest land and developed land uses provide insight into landscape characteristics that may influence the character and ecological function of the forest and aids in assessing its susceptibility to a broad range of anthropogenic impacts, e.g., invasive species. Such analyses also provide insight into the range and magnitude of ecosystem services that may be demanded of these remaining forests. Examples include water-quality protection, carbon sequestration, pollution removal, wildlife habitat, and recreation.

Mountain biker in the woods.

Losses of forest land to development can fragment remaining forest lands into smaller patches that are farther apart, reducing the chance that remaining wildlife populations are sustainable. And as the amount of direct interface or "forest edge" increases, interior or core forest areas are lost, increasing the chances for invasive species to be introduced and reducing the amount of habitat available for interior forest species. The characteristic of this edge environment and its effect on the forest varies according to the type of adjacent land use.

NRS-FIA researchers conducted a forest fragmentation assessment of Pennsylvania based on the 2001 National Land Cover Data project (Yang 2003). Calculating patch size from this dataset provides an indication of the continuousness of the forest cover (Fig. 10). Evident here are the smallest patch sizes in the southeast, followed by western Pennsylvania. In general, patches less than 100 acres in size depend on the amount and proximity of other forest patches for sustaining viable wildlife populations of interior species. However, this analysis does not account for additional interruptions by roads. In Pennsylvania, 72 percent of the forest is less than 0.25-mile from a road; Figure 11 shows the proportion of forest that close to a road by county.

Core forest is defined as forest more than about 100 feet from a nonforest edge. Figure 12 shows the proportion of core forest by county. Forests in the north-central region contain the highest proportion of core forest and also the least amount of fragmentation. Not surprisingly, the region hosts the largest forest-patch sizes. The Allegheny National Forest and State Forests contain the largest patches in Pennsylvania. Forest land in the southeastern region is the most highly fragmented, with small patches and minimal core forest.

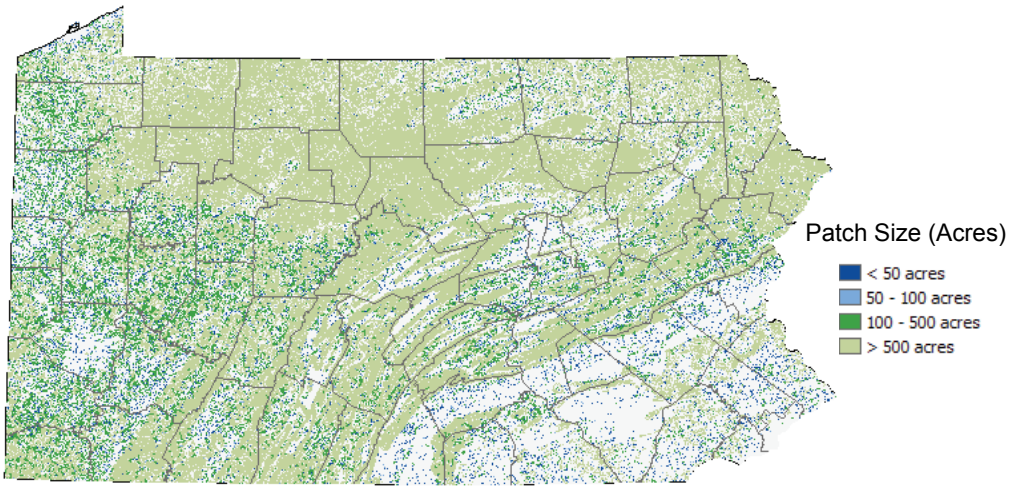


Figure 10.—Average forest patch size, Pennsylvania, 2000.

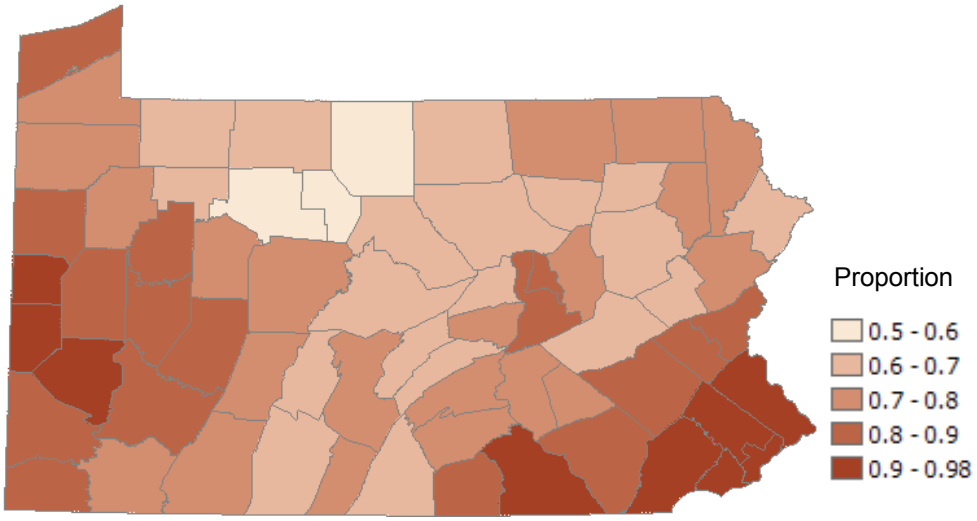


Figure 11—Proportion of forest land that is less than 0.25-mile from a road, by county, Pennsylvania, 2001.

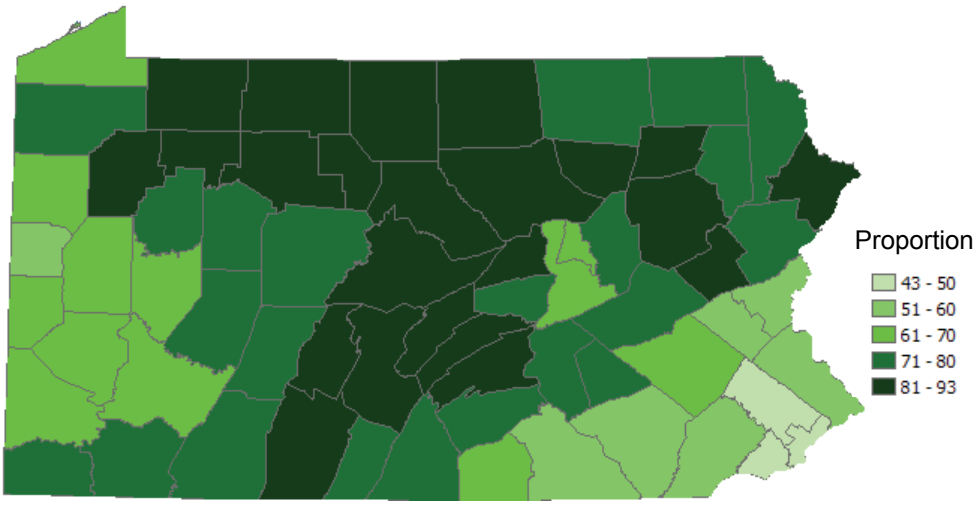


Figure 12.—Proportion of forest that is core forest by county, Pennsylvania, 2000.

Allegheny National Forest, northwestern Pennsylvania

CHAPTER 2: FOREST-LAND OWNERSHIP

Who owns Pennsylvania's forest? While there is no simple answer, ownership is an important aspect in characterizing the status of the forest. Land owners often are positioned at a critical juncture where forest management practices intersect with broader societal values and economic pressures and realities. Discerning ownership trends and patterns is imperative to understand how Pennsylvania's many forest-land owners collectively translate the Commonwealth's economic and social landscape into that of the forests they own.

Pennsylvania hosts a diverse mix of public and private-forest land owners, including federal, state, and local governments; and corporations, individuals, and other private groups (Figs. 13-14). The following tabulation shows the acres of forest land and associated estimates of the number of private owners:

	Acres		Private owners	
Owner category	Number	Percent	Owners	Percent
	Thousands		Thousands	
Federal	611.1	4		
State	3,813.5	23		
Local	413.7	2		
Total public	4,838.3	29		
Corporate:				
Forest industry	234.0	1	<1	<1
TIMO	246.9	2	<1	<1
Misc. corporate	1,658.4	10	26.5	5
Noncorporate:				
Families and individuals	8,906.4	54	501.5	94
Noncorporate	698.1	4	4.7	1
Total private	11,743.8	71	533.0	
Total	16,582.1			

The Commonwealth's state-owned forest is the fourth largest in the United States at 3.8 million acres, or roughly one-fourth of the total forest land. The primary state agencies are the Bureau of Forestry with 2.1 million acres and the Game Commission with 1.5 million acres. The Allegheny National Forest comprises most of the federal forest land in Pennsylvania; federal forests in total represent about 4 percent of the Commonwealth's forest land (611,100 acres). Local, county, and municipal owners control 2 percent (413,400 acres).

Grey Towers, Milford, Pennsylvania

Despite these vast acreages of public forests, private owners hold the majority of Pennsylvania's forest land. An estimated 533,000 private owners own 71 percent of the forest (11.7 million acres). The broadest grouping of private owners is corporate and noncorporate. The 506,000 non-corporate owners account for 82 percent of Pennsylvania's private forest (9.6 million acres); families and individuals are the dominant group in this category and overall. Miscellaneous noncorporate owners including nongovernmental organizations, e.g., Boy Scouts of America, clubs e.g., hunting clubs, and associations hold 4 percent. Corporate owners account for the remaining 18 percent (2.1 million acres) of Pennsylvania's private forests. Corporate owners include:

- Companies that own primary wood processing facilities,
- Forest-management firms that do not own primary processing facilities,
- Timber investment management organizations (TIMO) that manage land on behalf of institutional investors, and
- Companies for which forest management is not the primary objective (such as mining or manufacturing firms).

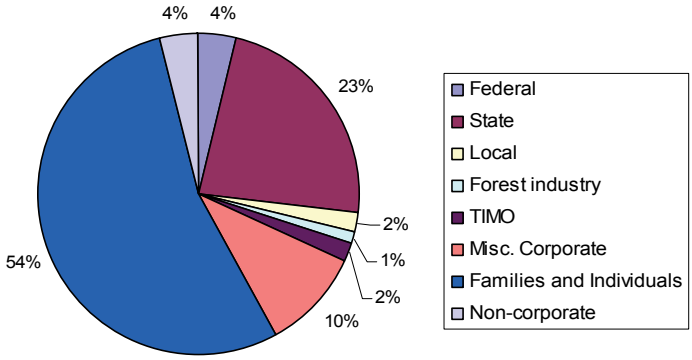


Figure 13.—Forest ownership in Pennsylvania, 2004.

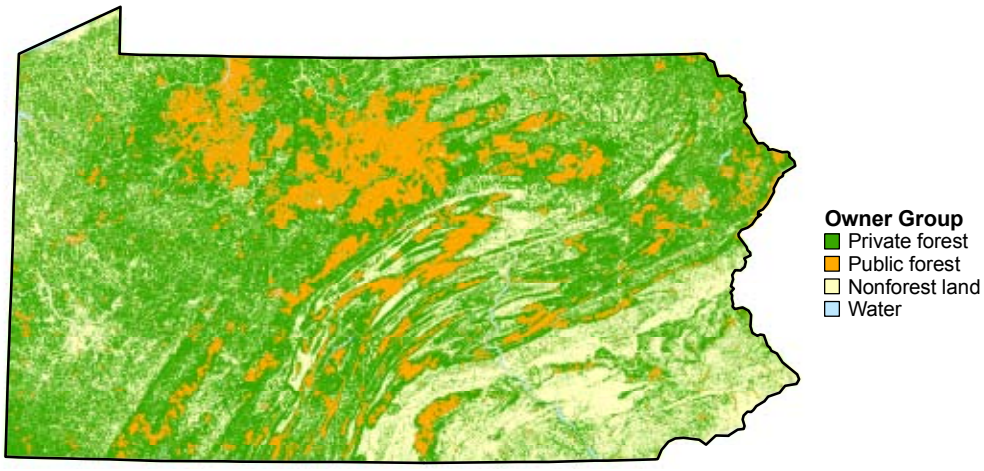


Figure 14.—Distribution of forest land by ownership, Pennsylvania, 2004.

Timber Investment Management Organizations

TIMO is a relatively new type of owner that emerged in the 1980s. Due to attractive rates of return and as hedges against stock market trends, timberland has become an attractive asset to such investors. TIMO purchase, manage, and sell forest land on the behalf of their clients, primarily institutional investors, e.g., pension funds. Most of these lands are in pooled funds with fixed-time horizons. On average, they mature in 7 to 12 years, at which time the assets are liquidated and redistributed to investors. Billions of dollars have been invested by TIMO across the United States and the world. They now control millions of acres of U.S. forest land and continue to acquire more. The large-scale divestment of forest holdings by traditional companies, i.e., vertically integrated firms, has provided ample investment opportunities for TIMO.

Posted private forest land

Six major TIMO currently operate in Pennsylvania. They own 246,900 acres, or 2 percent of the forest, and are located primarily in the north-central portion of the State. As with most asset managers, TIMO are focused on maximizing profits for their investors. Their activities are strongly tied to timber and land markets and the performance of other asset classes, i.e., alternative rates of return. Many of these funds will be maturing over the next several years, at which time their impact on Pennsylvania's forests will be better understood.

National Woodland Owner Survey

FIA conducts the National Woodland Owner Survey (NWOS) to better understand family forest owners and their motivations and intentions (Butler and others 2005). Family and individual-owned forests, hereafter referred to as family forests, includes forested parcels that are at least 1-acre in size, 10-percent stocked, and owned by individuals, couples, estates, trusts, or other groups of unincorporated individuals (Butler and Leatherberry 2004).

Sixty-four percent of the family forest owners in Pennsylvania hold fewer than 10 acres and account for 10 percent of the family forest-land base (Fig. 15-16). Thirty-three percent own forests ranging in size from 10 to 99 acres; these owners represent 53 percent of the family forest land. Three percent own forest tracts larger than 100 acres; they represent 37 percent of the family forest land base.

The reasons for owning their forests are as diverse as the families and individuals themselves. Amenity values are reported to be more important to families and individuals than financial objectives. Four of the top five ownership objectives relate to beauty/scenery, home ownership, privacy, and nature protection (Fig. 17). The fifth objective relates to the family legacy value of the land. This is not to suggest that families and individuals oppose commercial activities on their forest land. Twenty-three percent of the family forest owners, who hold 50 percent of the family forest land, have commercially harvested trees at least once since purchasing their land.

A written management plan is one metric for measuring forethought and science-based forest management. According to the NWOS, only 2 percent of family forest owners, who hold 7 percent of the family forest land, indicated that they have a written plan to guide management activities. Federal and state outreach programs have focused on providing technical assistance to private owners through cost-share programs; however,

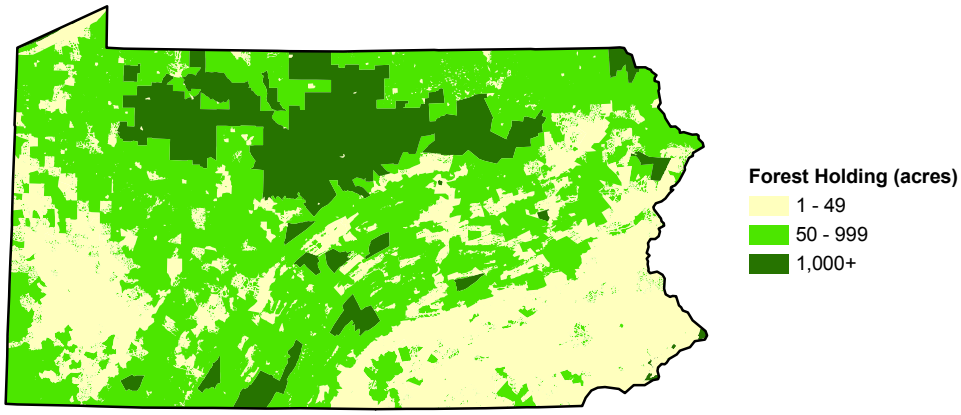


Figure 15.—Distribution of forest land by size of forest holding, Pennsylvania, 2004.

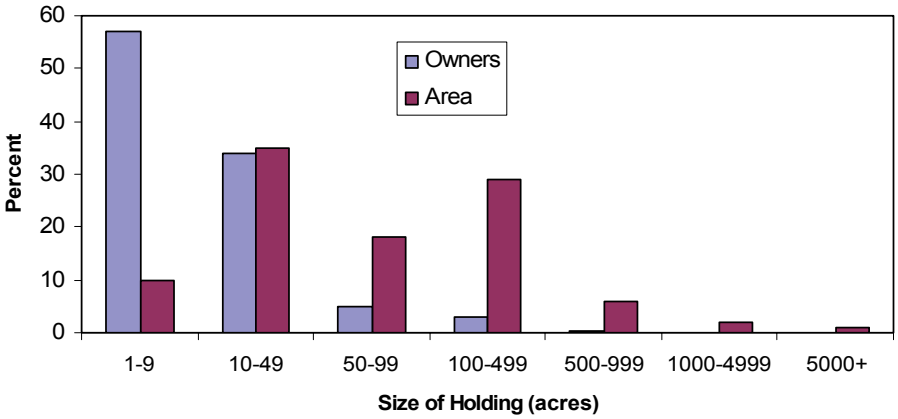


Figure 16.—Percentage of area and number of families and individuals by size of holding, Pennsylvania, 2004.

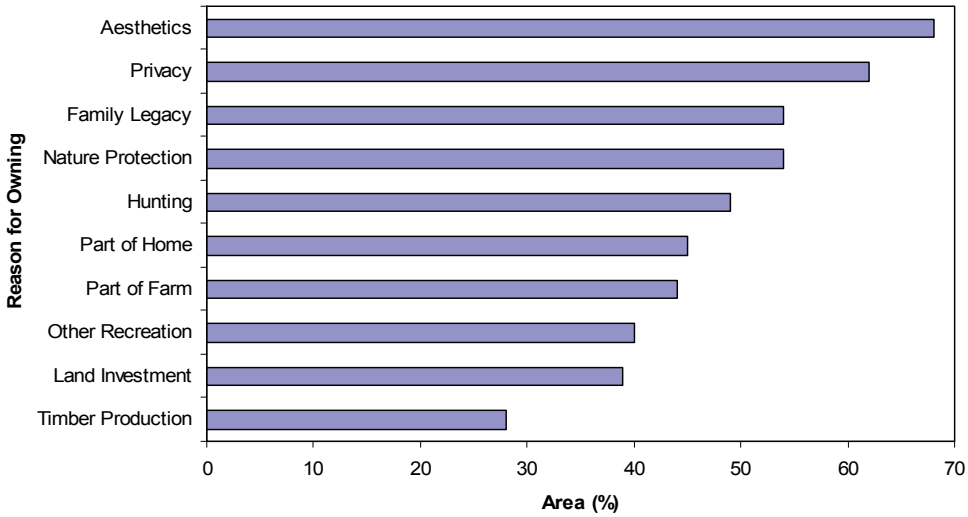


Figure 17.—Percentage of forest land held by families and individuals by reason for owning forest land, Pennsylvania, 2004.

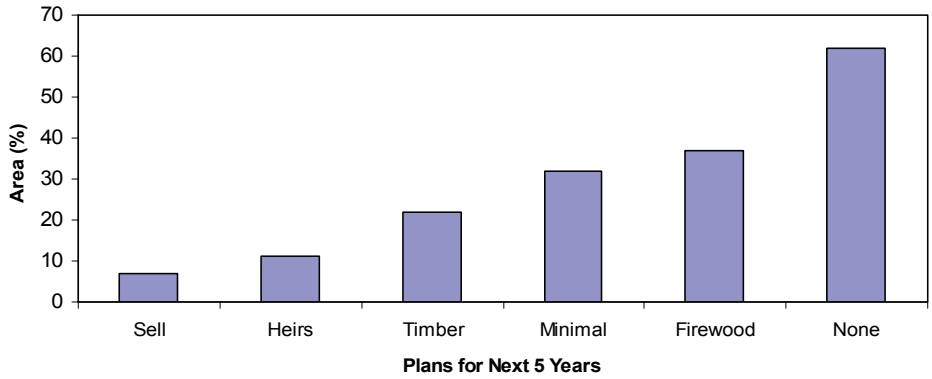


Figure 18.—Percentage of forest land held by families and individuals by plans for next 5 years, Pennsylvania, 2004.

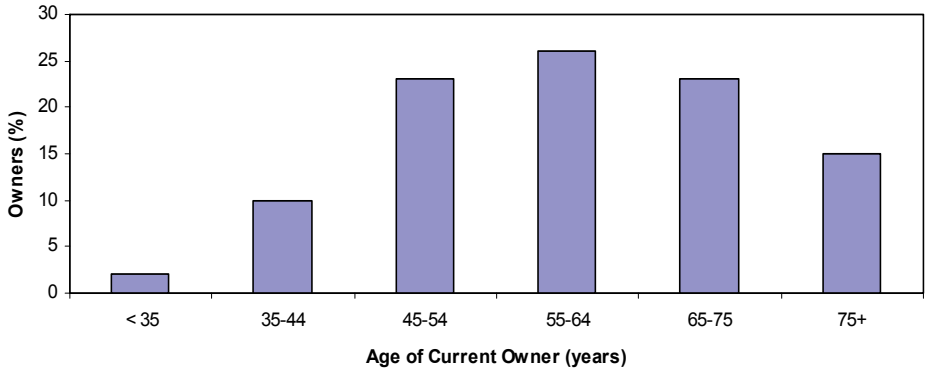


Figure 19.—Percent of families and individuals by age of current owner, Pennsylvania, 2004.

less than 2 percent of the owners, who hold 6 percent of the family forest land, have participated in a cost-share assistance program.

Most family forest land is owned by people who do not have major activities planned for their land (Fig. 18). Of those who intend to actively manage their land, harvesting firewood or sawlogs are the most commonly planned activities. Ten percent of family forest owners, who hold 18 percent of the family forest land, intend to sell or transfer their land in the next 5 years. These owners represent a significant portion of Pennsylvania's forest.

Family forest owners tend to be older, white males nearly one-third of whom have earned a college degree. Fifteen percent of family forest land is held by someone who is 75 years or older and 38 percent is held by individuals older than 65 years (Fig. 19), another indication that these lands will soon change hands.

Ownership Trends

Through purchases and other acquisitions, public forest land in Pennsylvania has increased by about 11 percent over the last decade, primarily due to increases of state-owned land.

Although the number of private forest owners has increased over the last decade by about 4 percent, their total private forest area actually decreased by nearly 5 percent. This indicates more owners with smaller parcels, a trend likely to continue as aging landowners divest their properties. Forest industry also has divested much of its land over the last decade, with much of the former forest industry land now controlled by TIMO. It is not known whether the new owners have the same attitudes, needs, and management objectives as the current owners. What is certain is that private owners, including corporate and noncorporate, will have a profound impact on the future of Pennsylvania's forests.

Turn-of-the-century logging. Photo from the Lycoming County Historical Society.

CHAPTER 3: COMPOSITION AND STRUCTURE

The NRS-FIA program collects a wealth of data that address forest composition and structure. Traditional measures of composition include forest types, relative importance of tree species, and spatial distribution of individual species. Measures of structure include stand-size class, stocking class, number of trees, volume, biomass, and down woody material. This information provides valuable insights into the condition, composition, and structure of Pennsylvania's evolving forest resources.

Forest-Type Groups

NRS-FIA categorizes forests using a classification of forest land based on the species that form a plurality of live-tree stocking. Individual forest types are aggregated into forest-type groups to allow broad comparisons. The traditional forest-type names and conventions have remained the same over time to allow for consistent trend analysis. Changes in the distribution of forest land by forest-type group depend on natural and anthropogenic impacts on the forest canopy, for example, succession, pests and diseases, harvesting, and shifts in the forest-land base.

Regional analysis and comparisons of forest-type group, stand-size class, and stocking class are not available for inventories prior to 1989 because digital data could not be recomputed to meet current standards. Some state-level comparisons can be made for inventories before 1989 as appropriate.

The distribution of forest land by the major forest-type group has remained relatively stable since 1989 (Fig. 20). There were no significant decreases at the 95-percent confidence level; however, analysis of the means implies a decrease in the mixed oak group. This finding would substantiate trends in oak discussed elsewhere in this report.

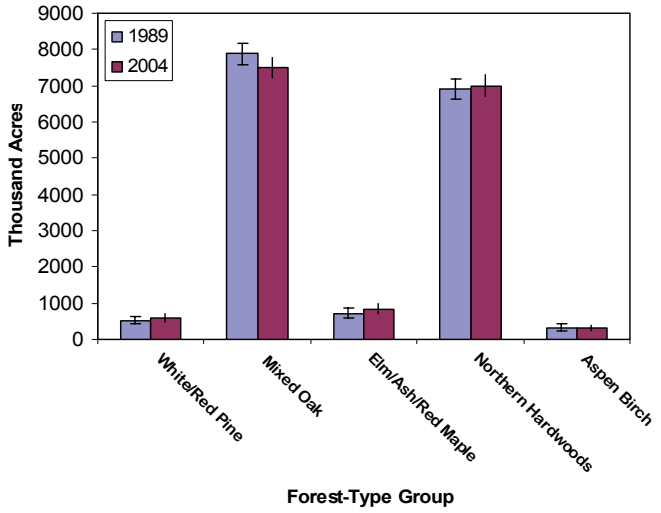


Figure 20. —Area of forest land by forest-type group, Pennsylvania, 1989 and 2004.

Maps that generalize the distribution of mixed-oak and northern hardwoods forest-type groups (Fig. 21) were derived from NRS-FIA inventory data using geostatistical techniques that represent the most probable distribution for a given group. (Maps of less common groups are not feasible due to limited sample size.) Maps of forest-type groups should not be confused with the distribution maps for individual species. Both types of map are included to provide a more complete analysis of species occurrence. For example, red maple is common in multiple forest-type groups but is singled out in the species distribution map. The maps provide a graphical depiction for forest-type groups often scattered geographically. In some areas, distributions overlap.

The northern hardwoods forest-type group (sometimes referred to as maple/beech/birch), while found across most of Pennsylvania, is concentrated primarily along the Allegheny Plateau in the north-central region. The mixed-oak forest is concentrated along the ridges and valleys of central Pennsylvania.

Although forest-type groups were stable, there were noticeable changes in two forest types. Figure 22 shows statistically significant gains in specific forest types where red maple is the principal dominant and losses in the sugar maple/beech/yellow birch type.

Stand-Size Class

To gain a general indication of the stage of stand development, standard NRS-FIA tree-size measurements are used to arrive at stand-size class. Sampled stands are assigned to one of three categories—small, medium, and large—based on the class that accounts for the most stocking of live trees per acre. Small stands have a plurality of trees less than 5 inches in diameter at breast height (d.b.h.). Medium stands are dominated by trees at least 5 inches d.b.h. but less than large size. Large stands are at least 9 inches in d.b.h. for softwoods and 11 inches for hardwoods.

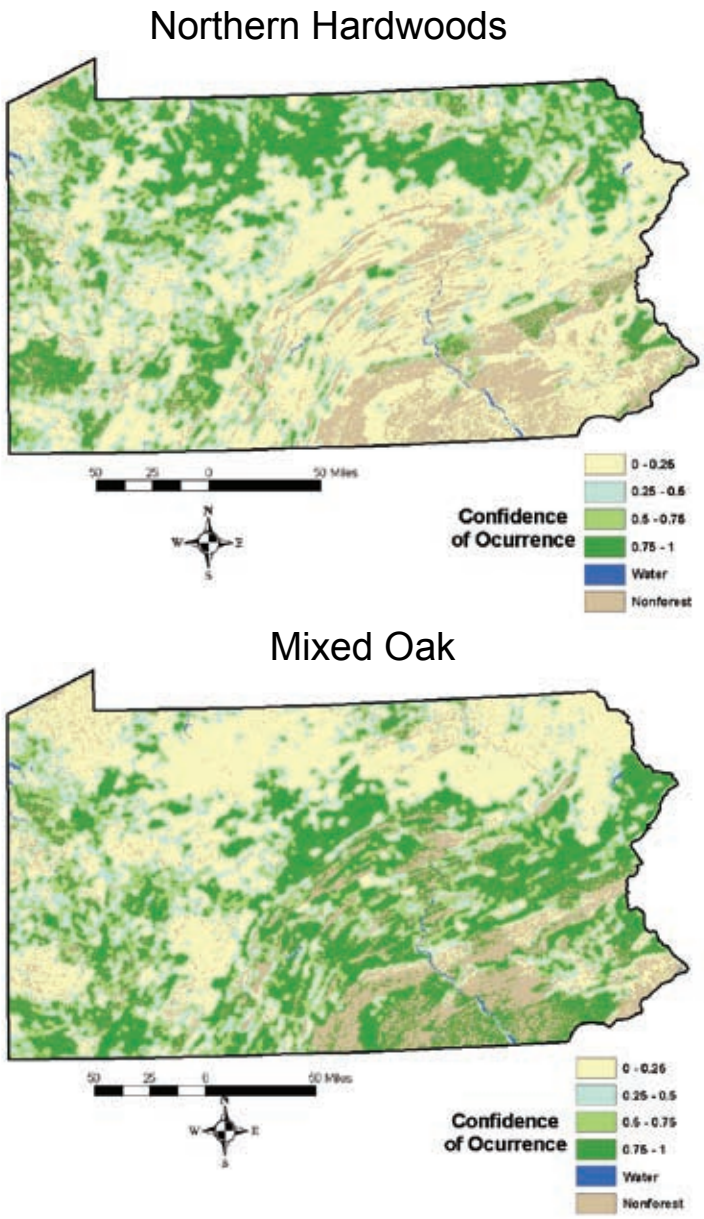


Figure 21.—Distribution of northern hardwoods and mixed-oak forest land, Pennsylvania, 2004.

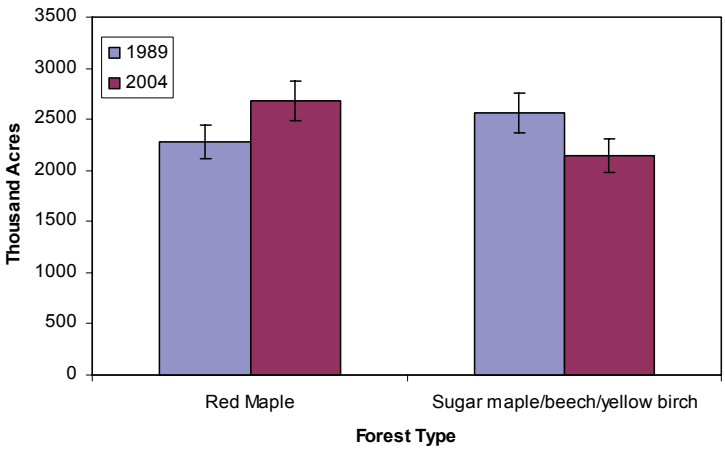


Figure 22. —Area of forest land classified as red maple and sugar maple/beech/yellow birch forest types, Pennsylvania, 1989 and 2004.

Major changes have occurred in the distribution of forest land by stand-size class. Statistically significant changes have occurred in all classes since 1989, with small stands and medium stands decreasing and large stands increasing (Fig. 23). This trend is more pronounced when these results are compared with those from the 1955 inventory (Fig. 24). Since that time, small stands have decreased by 44 percent and large stands have increased by 33 percent. The current stand breakdown is 11 percent small, 30 percent medium, and 59 percent large.

The distribution of stand sizes across Pennsylvania is shown in Figure 25. The prevalence of large stands is evident. Medium stands are scattered throughout the State. Small stands, or typically early successional forest, also are distributed widely, with concentrations along the western edge of the ridges and valleys near Clearfield County. The map depicts generalized distribution. Each pixel is modeled according to the most likely stand class based on surrounding pixels. Large areas depicted as a single size class often are mixed with other classes.

Few of the changes in stand size for the six ecopolitical regions were significant. The progression of medium stands to large stands is apparent in the north-central, south-central, and northeastern regions. The decrease in small stands is occurring mostly in the southeastern, southwestern, and south-central regions and the northeastern region.

Stocking

Stocking is a measure of the occupancy of land by trees in relationship to the growth potential of the site (see Definition of Terms). Four stocking classes generally are reported: poor (10 to 34 percent), moderate (35 to 59 percent), full (60 to 100 percent), and overstocked (101+ percent). The nonstocked class (0 to 9 percent) is ignored in this analysis because it represents a small area.

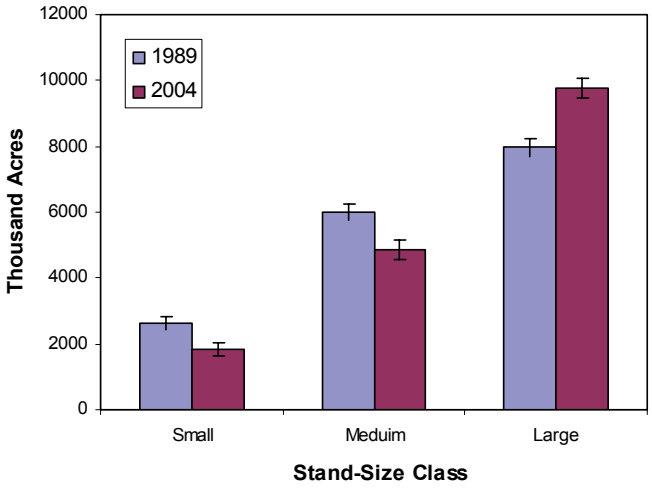


Figure 23. —Area of forest land by stand-size class, Pennsylvania, 1989 and 2004.

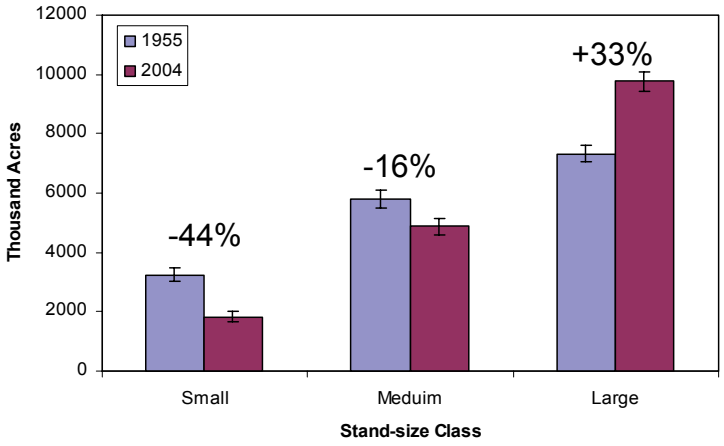


Figure 24. —Area of forest land by stand-size class, Pennsylvania, 1955 and 2004.

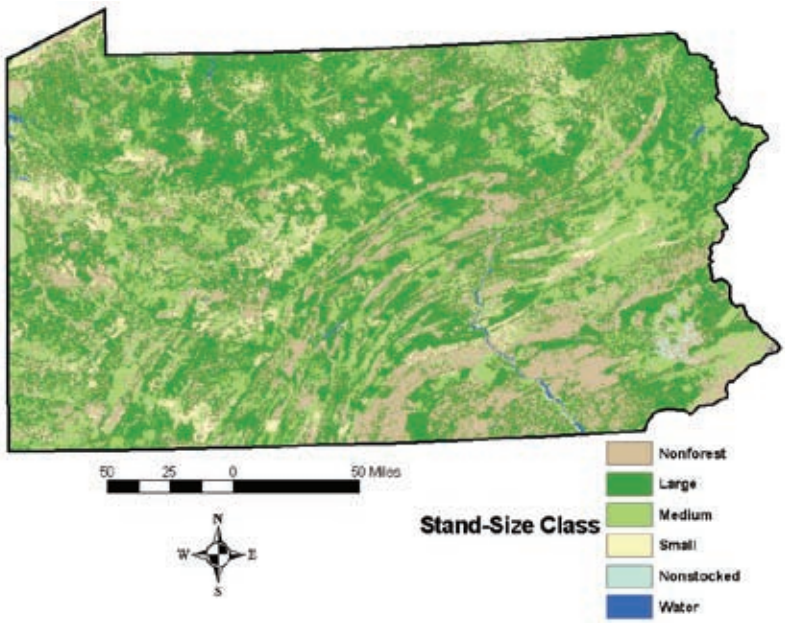


Figure 25.—Distribution of forest land by stand-size class, Pennsylvania, 2004.

The NRS-FIA stocking classes roughly correspond to traditional stocking guides for the Eastern United States. Using the terminology of Gingrich (1967), Leak (1981), and others, the stocking classes relate to the A, B, and C levels of stocking guides. The overstocked class represents conditions above the A level. The full stocking class represents the area between the A and B levels where stocking is considered adequate. The moderate stocking class represents the area between the B and C levels where B level stocking is expected within 10 years. The poor class represents conditions below the C level—a stand that is considered in need of restocking or regeneration.

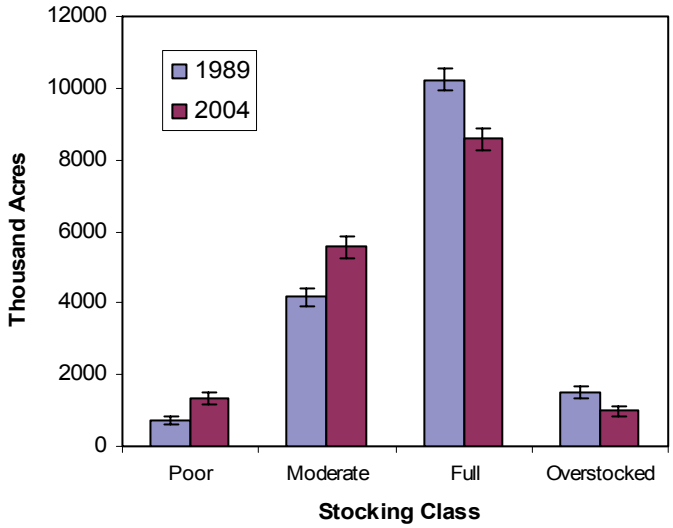


Figure 26. —Area of forest land by live-tree stocking class, Pennsylvania, 1989 and 2004.

Since 1989, forest-land area in the poor and moderate classes increased by 82 and 34 percent, respectively (Fig. 26). Reductions in stocking can result from a variety of events and disturbances, e.g., destructive weather, pests and diseases, and timber harvesting. Forest-land area in the full and overstocked classes decreased by 16 and 33 percent, respectively. This represents a reduction of 1.8 million acres in the two classes. However, most of the reduction was in the full stocking class. Changes appear to have occurred mostly in the western half of the State based on a map of canopy loss, a surrogate for stocking (Fig. 27). The reduction in both the full and overstocked classes occurred primarily on private land (Fig. 28).

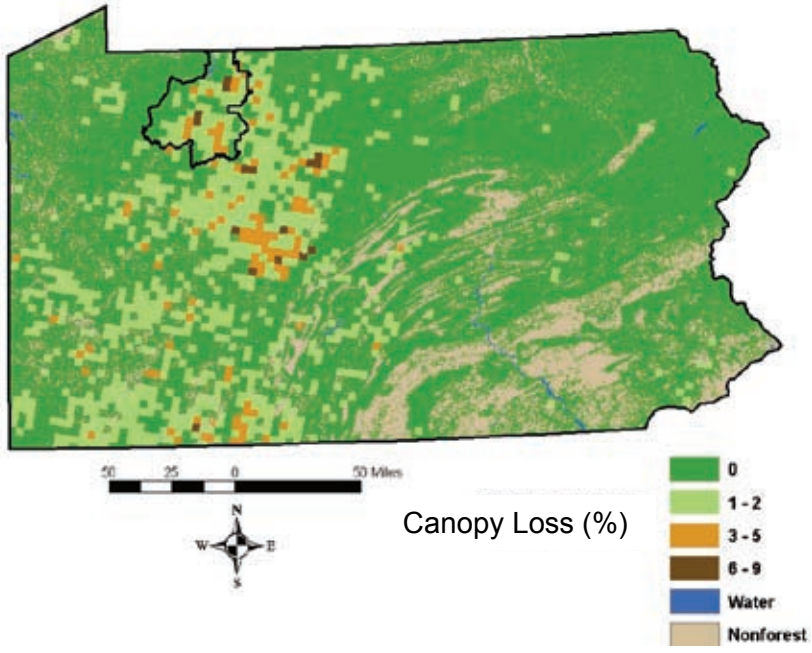


Figure 27.—Distribution of forest land by percent canopy loss, Pennsylvania, 1990 to 2000.

Stocking was examined for all forest land and trees, including reserved areas and cull trees. Another way to analyze stocking levels across Pennsylvania is to examine only commercial timberland and growing-stock trees (Definition of Terms). The results for this type of analysis are similar to those for all forest land and trees (Figs. 29-30). The reduction in fully stocked stands is somewhat more pronounced because only commercial trees are considered by this method of analysis.

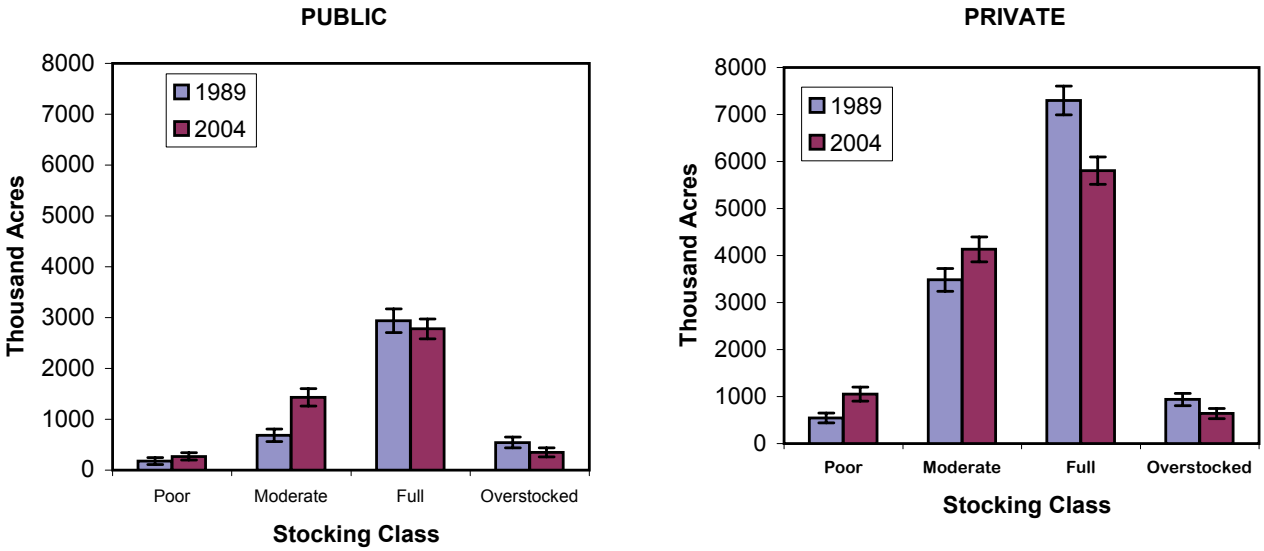


Figure 28. —Area of forest land by live-tree stocking class and ownership, Pennsylvania, 1989 and 2004.

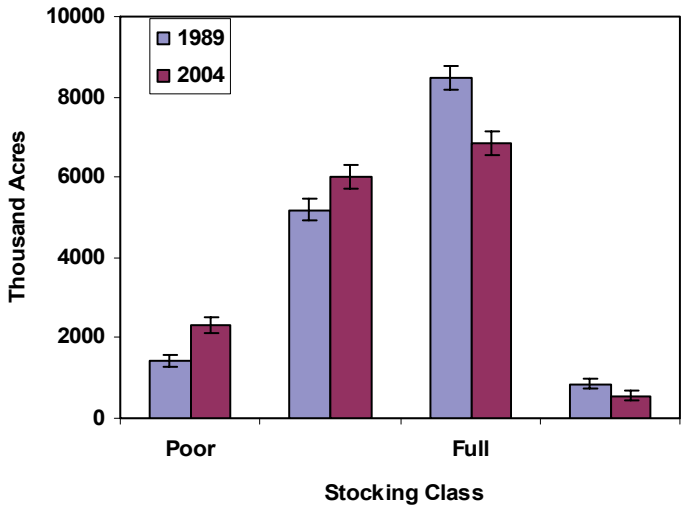


Figure 29. —Area of timberland by growing-stock stocking class, Pennsylvania, 1989 and 2004.

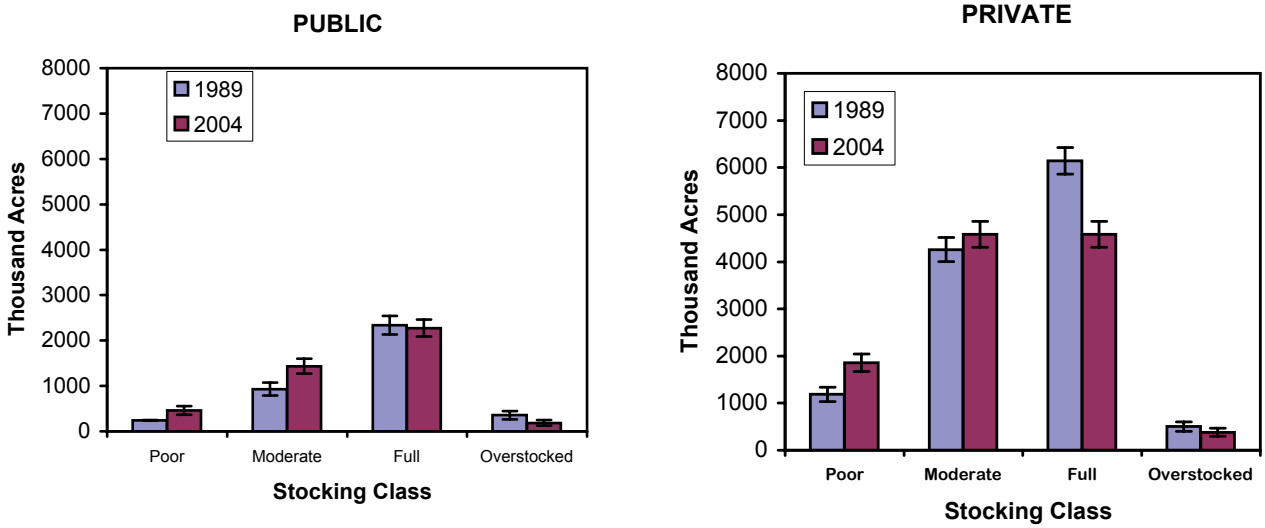


Figure 30.—Area of timberland by growing-stock stocking class and ownership, Pennsylvania, 1989 and 2004.

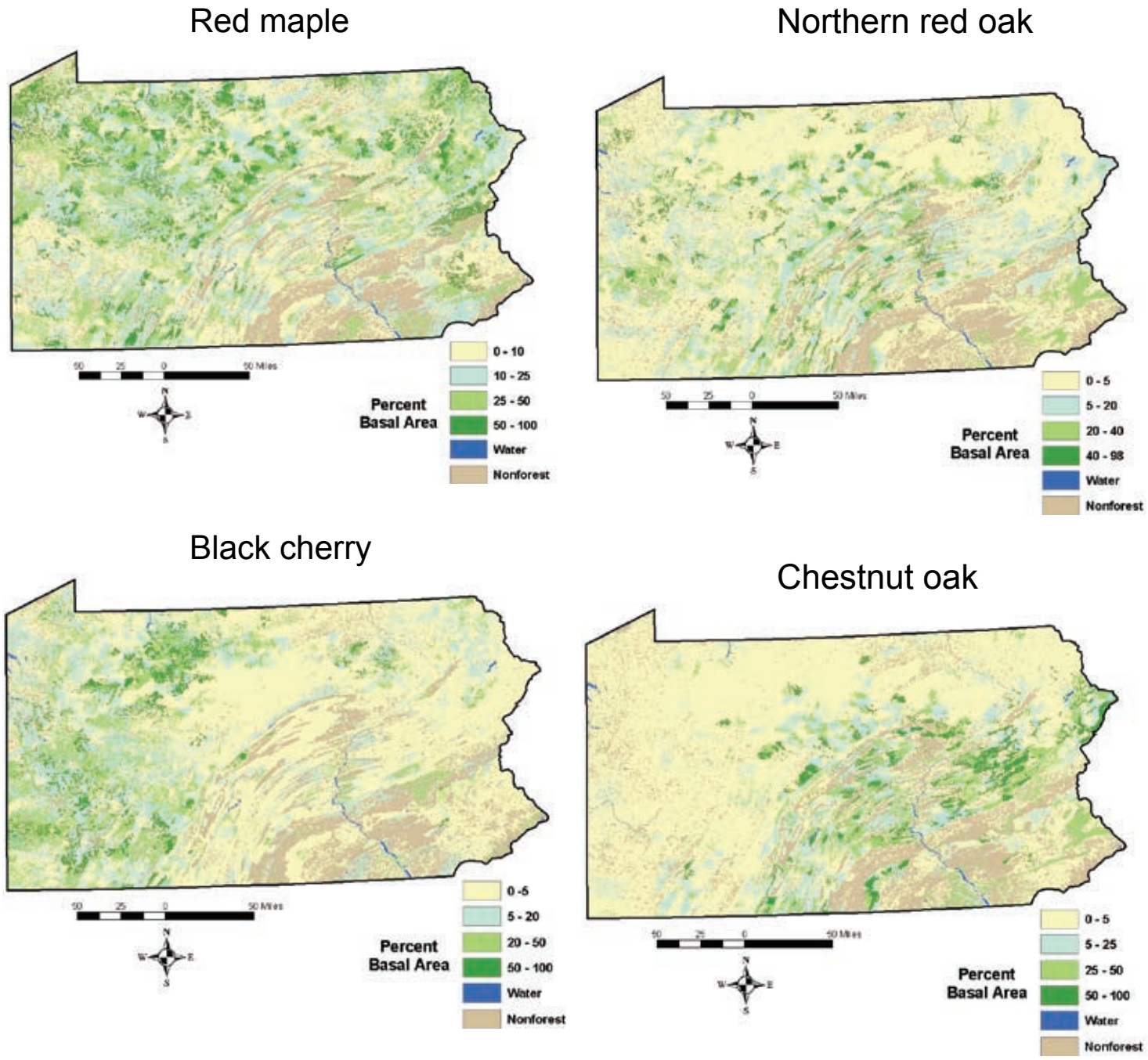


Figure 31.—Estimated percentage of basal area for selected species, Pennsylvania, 2004.

Distribution of Tree Species

Maps showing the distribution of selected tree species were developed using percent basal area on sampled plots (Fig. 31). Twelve species provided the sample size necessary for this analysis. The resulting maps represent the probability of the level of select species dominance. Most of the species mentioned are found throughout the State.

Red maple is a useful species when interpreting distribution maps. Although it is most prevalent across the northern tier counties, with pockets in the western regions, red maple is common throughout Pennsylvania.

Allegheny hardwoods is a subgroup within the northern hardwoods forest-type group that occurs primarily on the Allegheny Plateau. NRS-FIA does not compute the

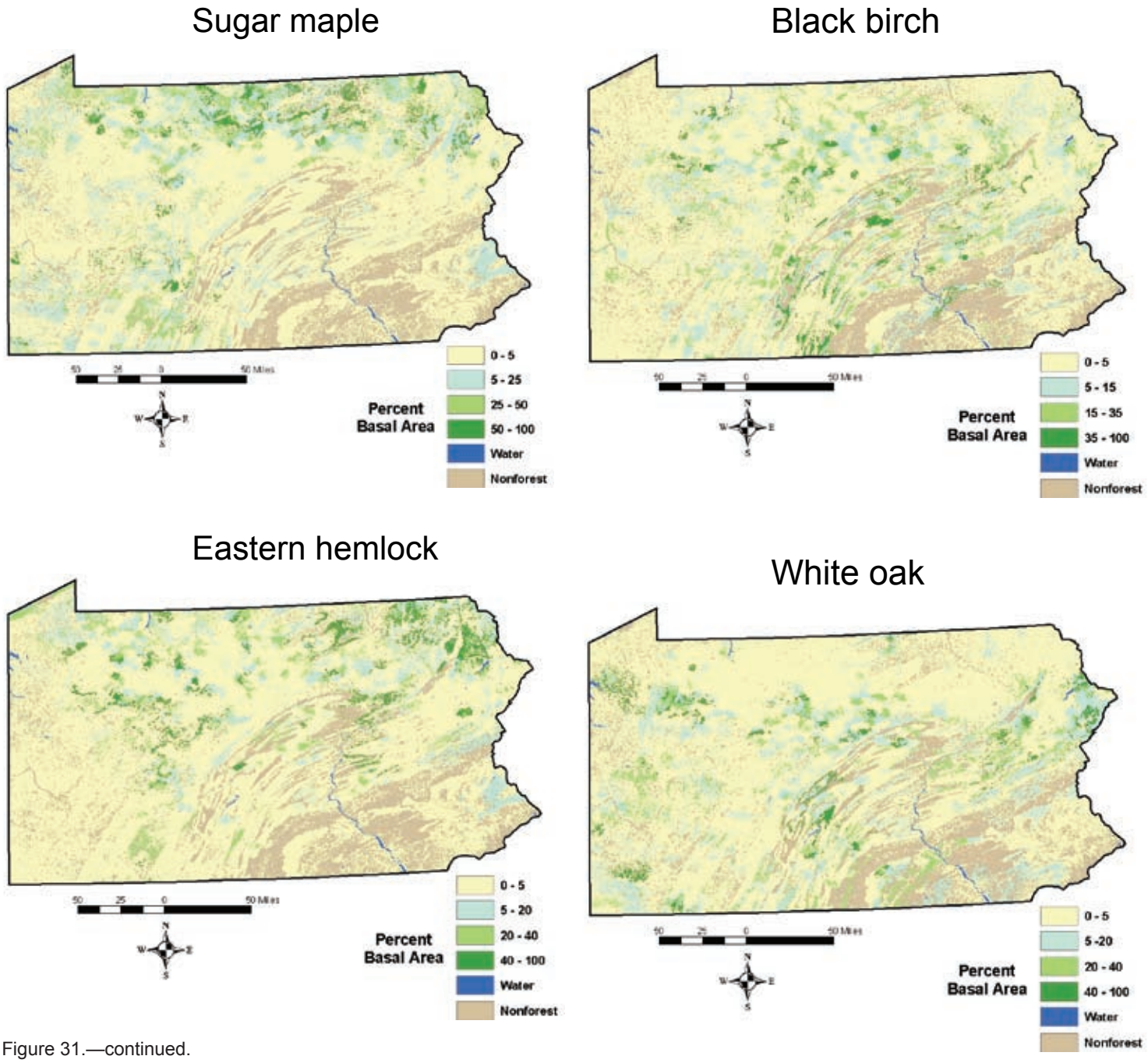


Figure 31.—continued.

area of Allegheny hardwoods because it is not part of the national forest-typing methodology. The dominance of black cherry, a major species within the type, serves as an indicator for Allegheny hardwoods as its dominance across the Allegheny Plateau is evident. Black cherry also is common in western Pennsylvania but is a relatively minor species in the eastern counties.

The distribution map for northern red oak shows clumps of this species through the central part of the State, particularly in the Ridge and Valley area. Red oak is relatively rare across the northern tier.

Chestnut oak also is concentrated in the ridges and valleys, occurring north of Blue Mountain and westward to the Allegheny Front. Sugar maple is clearly a northern Pennsylvania species. Concentrations are heaviest in glaciated soils that favor the development of this species. Eastern hemlock also is concentrated in the northern counties, with a strong presence west of the

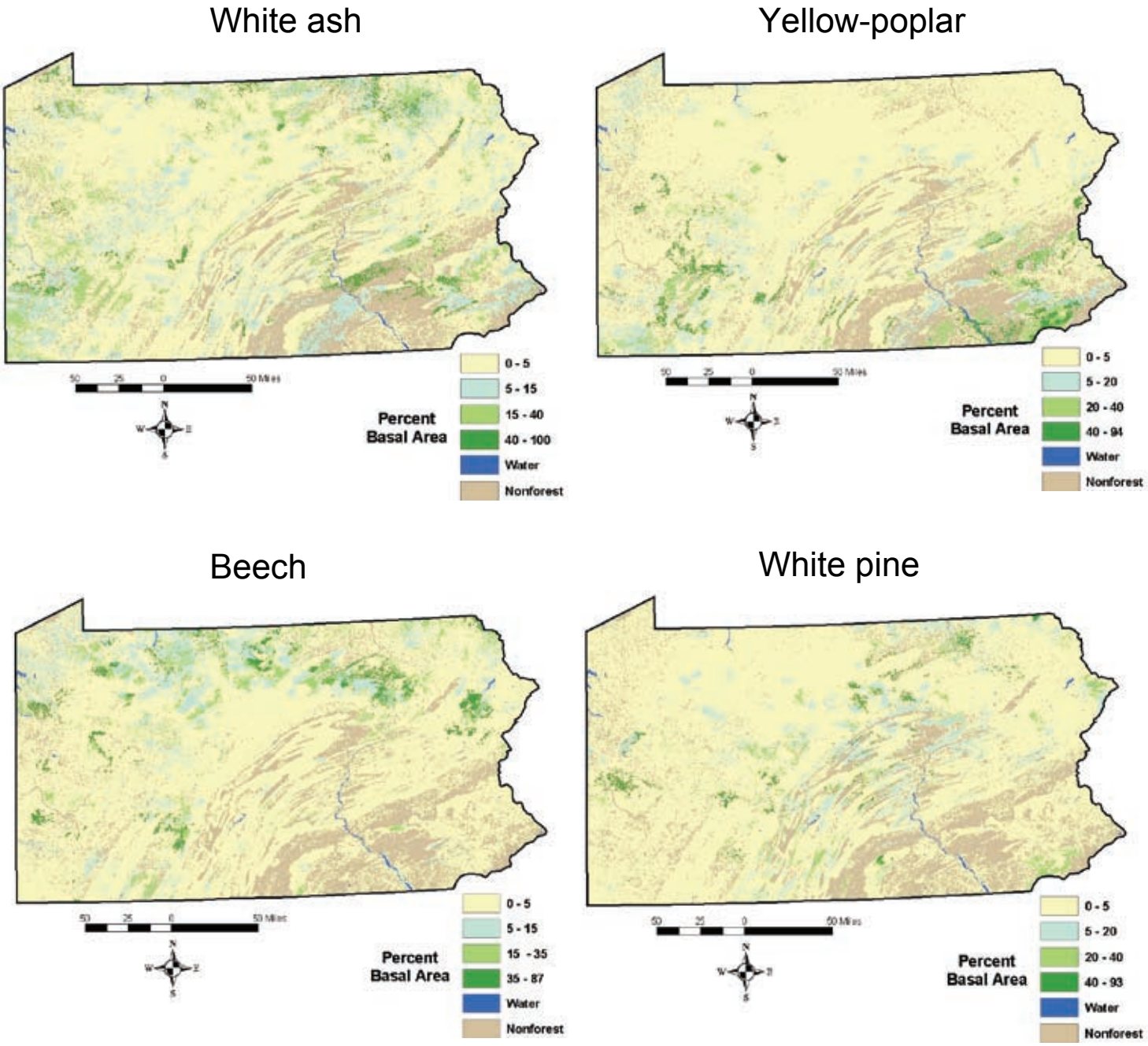


Figure 31.—continued.

Allegheny Front and in the Pocono Mountains. Black birch is scattered throughout the Ridge and Valley area and in pockets across the northern counties. White oak is common across the State except along the northern tier. The heart of the Ridge and Valley area hosts concentrations of this species. White ash is dominant in a several areas in the southern half of the State, particularly southeastern Pennsylvania; it is widely scattered elsewhere. Beech's prevalence across the northern counties is readily apparent. There are several clusters in western counties and a sizeable concentration in the Pocono Mountains. Yellow-poplar is clearly a southern tier species with heaviest concentrations in the southwestern and southeastern regions. The high concentration in the extreme southeastern portion of the State is notable because this area contains some of the Commonwealth's oldest and largest forests. Yellow-poplar is the dominant species in many of these forests. White pine is highly concentrated in some locations, though occurrence is dispersed and this species is a minor component of the forest types in which it is found.

LOW-USE WOOD RESOURCE

Interest in utilizing wood that has traditionally been in low demand has increased recently due to higher energy costs, improved utilization technology, and opportunities for improving rural economies. Pennsylvania's forests are characterized by expansive tracts of relatively similar age that are developing into a highly valuable sawtimber resource. As the process of economic maturing continues, there also has been a tremendous buildup of wood material that is underused. This resource includes trees that are of poor form, quality, size, and value. Utilization of low-use wood (LUW) also improves forest health and sustainability. LUW removal is essentially an intermediate treatment that opens stands to light, thus enhancing the establishment and development of tree seedlings and understory flora, and improving wildlife habitat. Currently, the use of LUW is being recommended to policymakers as an opportunity that ranges from wood-chip utilization in energy generation, composite panels, paper, and cellulosic ethanol to associated secondary industries. This opportunity supports policies aimed at sustainable development for rural Pennsylvania.

LUW Estimation

The use of the term LUW was chosen over low grade or low value because many candidate trees have no grade or even value when the economics of availability, harvest, transport, and use are considered (Luppold and Baumgardner 2003). NRS-FIA has developed estimates of LUW under the guidance of the Secretary of Agriculture's Hardwood Blue Ribbon Task Force. A series of simple filters and constraints was developed and used to estimate the amount of LUW that may be available. For example, all rough and rotten trees, those with intermediate or overtopped crown positions, and stems with less than 10 percent crown ratio were included as LUW.

Pile of wood chips.

Actual availability of wood resources depends on multiple factors, e.g., operability, economic, legal, social, and other interacting factors (Luppold and McWilliams 2000; Luppold and Bumgardner 2003). The principal variables for reporting are ownership (public and private), biomass per acre in classes, and slope class. To approximate actual availability of LUW based on operability constraints, the analysis of "available LUW" excludes wood on sites with fewer than 30 tons of LUW per acre and on slopes greater than 40 percent.

LUW Resource

The total wood biomass on Pennsylvania's timberland is 1,145.8 million green tons. Fifty-seven percent of the total biomass—657.8 million tons—is classified as LUW. Applying the LUW operability constraints yields an estimate of available LUW of 468.7 million tons, or 71 percent of the LUW in the State. Nearly three-fourths of this material is on privately owned timberland (Fig. 53).

LUW is an abundant resource across Pennsylvania. Opportunities for supporting a variety of wood-use industries are apparent. Two important issues facing the State's forestry community are how to manage the tremendous volume/value of existing stands while improving current advance regeneration and biodiversity for the Commonwealth's future forest. As mentioned earlier, opening stands to improved light conditions promotes the development of tree seedlings and healthy understory flora (Marquis 1994). So long as den trees and other conditions are considered, wildlife should prosper from an increase in available food. Other benefits of LUW utilization include ecosystem health, economic growth, rural development, and forest sustainability.

Factors related to supply and demand and owner preferences are broad with respect to the assumptions in this analysis. Additional information can be obtained and tailored to more specific resource questions, such as citing industrial plant. Summaries of NRS-FIA data are available at http://fia.fs.fed.us/tools-data/tools/.

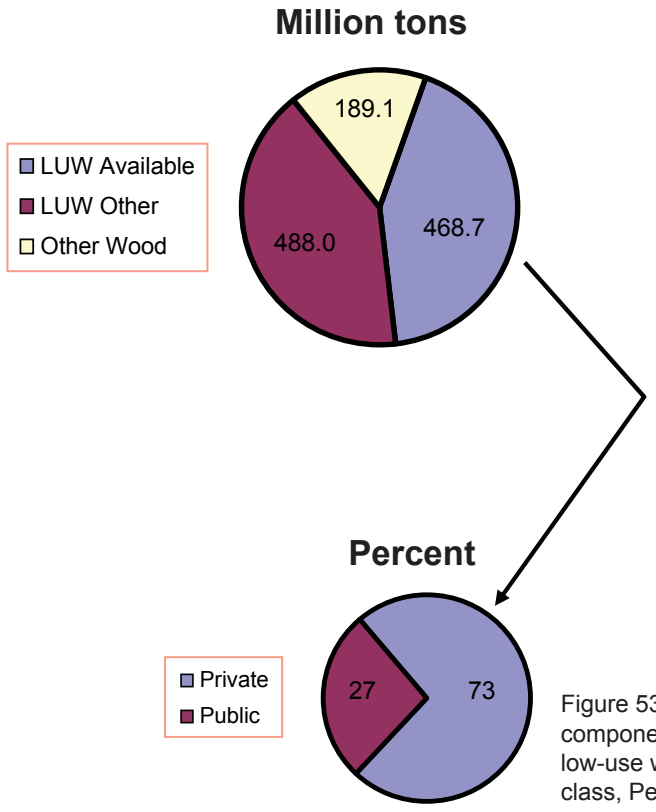


Figure 53.—Low-use wood by component and percent of available low-use wood by broad ownership class, Pennsylvania, 2004.

Number of Trees

Forest stands are commonly examined by a "stand table" that charts the number of trees by diameter class. This information highlights changes in stand structure and indicates future trends. For example, a species may show gains in larger diameters but decreases in smaller diameters, suggesting lesser importance in the future forest.

Changes in stand structure occur due to natural and anthropogenic influences. As the forests of Pennsylvania mature, decreases in smaller diameter classes should be expected as natural thinning occurs and trees grow larger. Figure 32 aptly illustrates this trend as the 4- through 8-inch classes posted decreases from 1989 to 2004. There was a slight increase in the 10-inch class and moderate increases in the 12- and 14-inch classes. Increases in the 16-inch and larger classes exceeded 20 percent. Although not statistically significant, there was a slight increase in the number of 2-inch trees statewide.

Mature stand of Allegheny hardwoods.

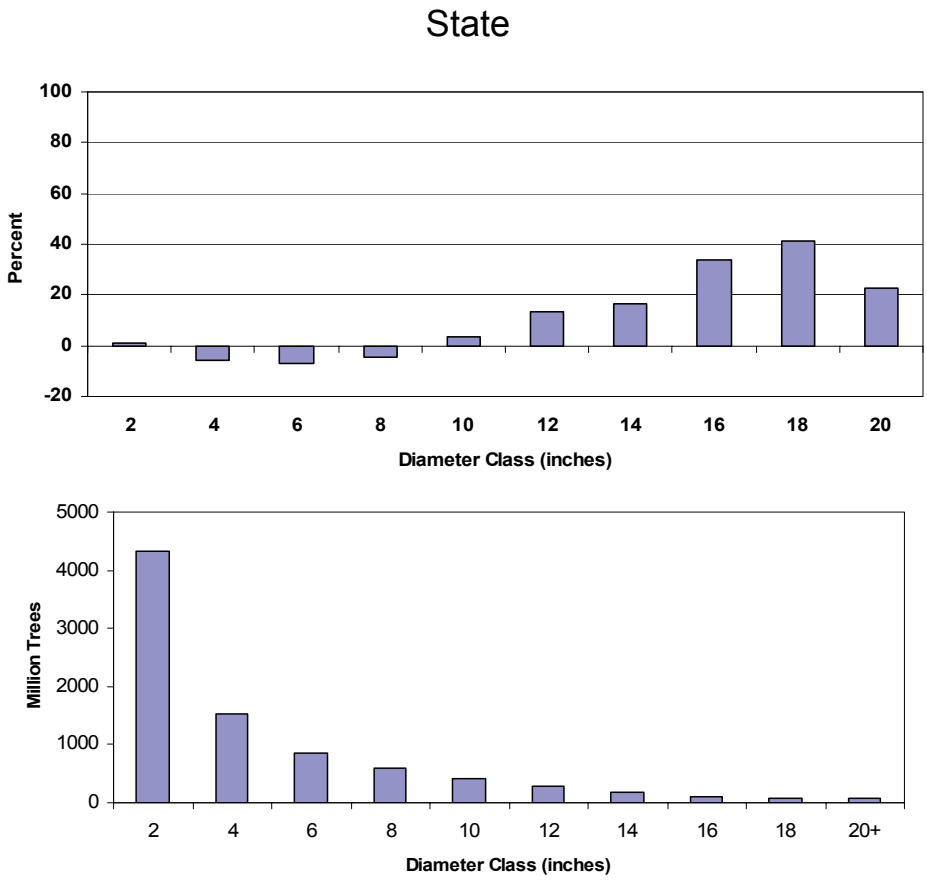
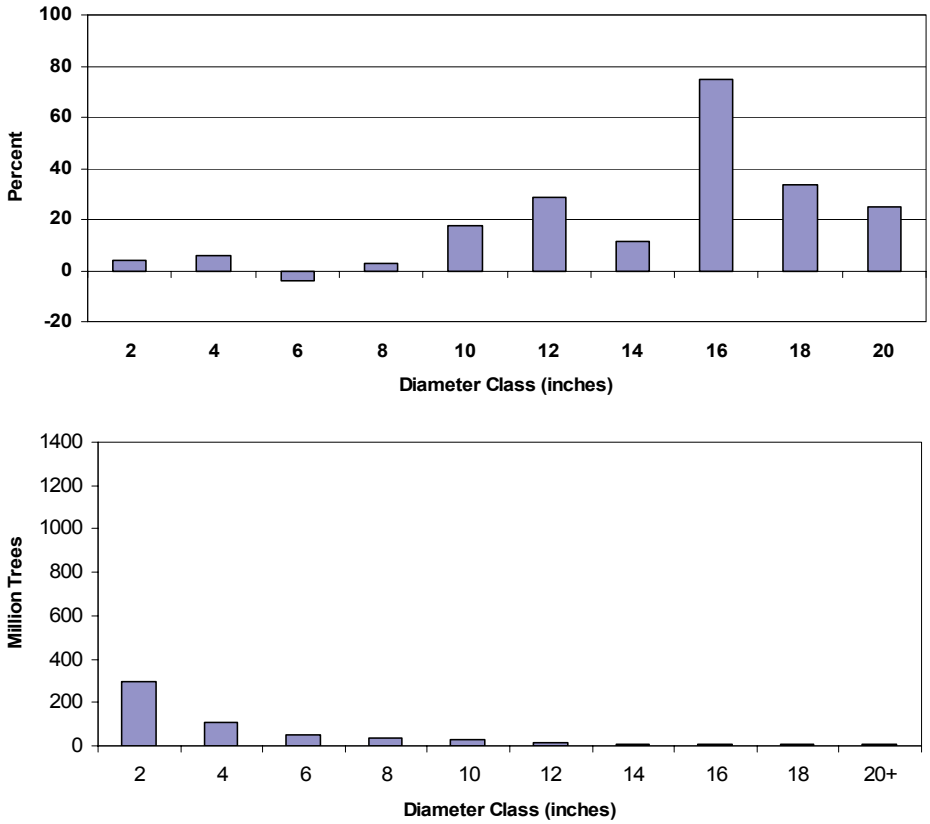
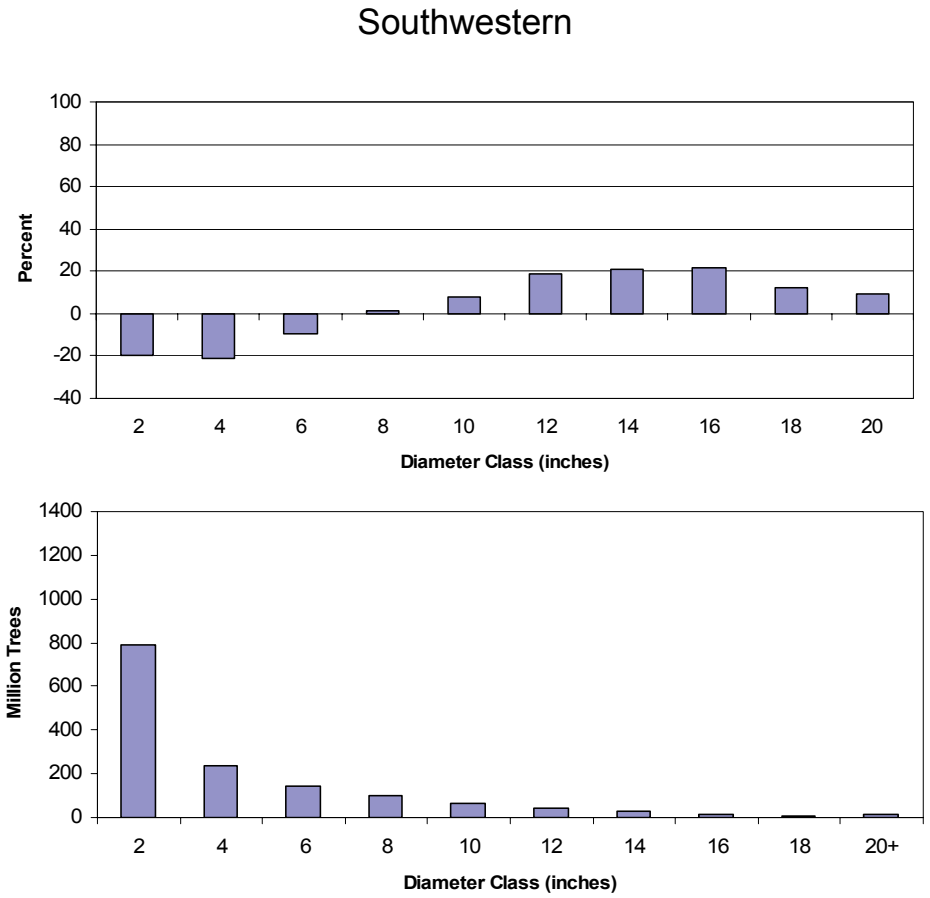


Figure 32.—Percent change and number of live trees on forest land by diameter class, by ecopolitical region, all species, Pennsylvania, 1989 to 2004.





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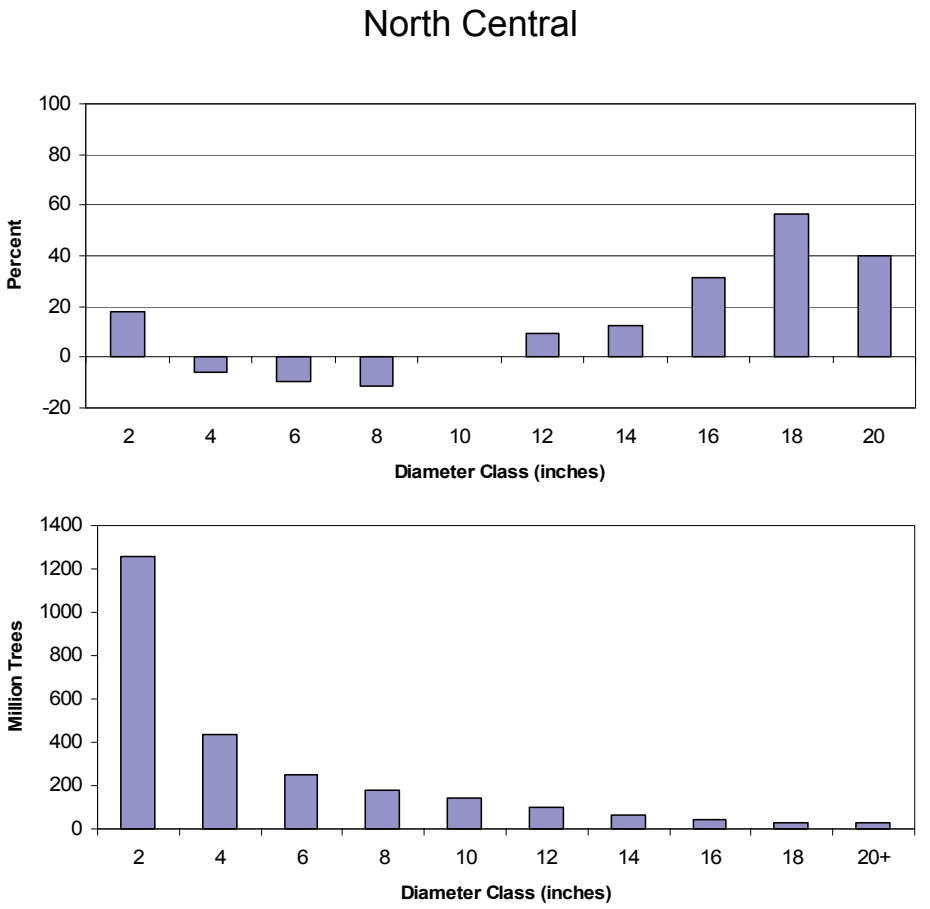

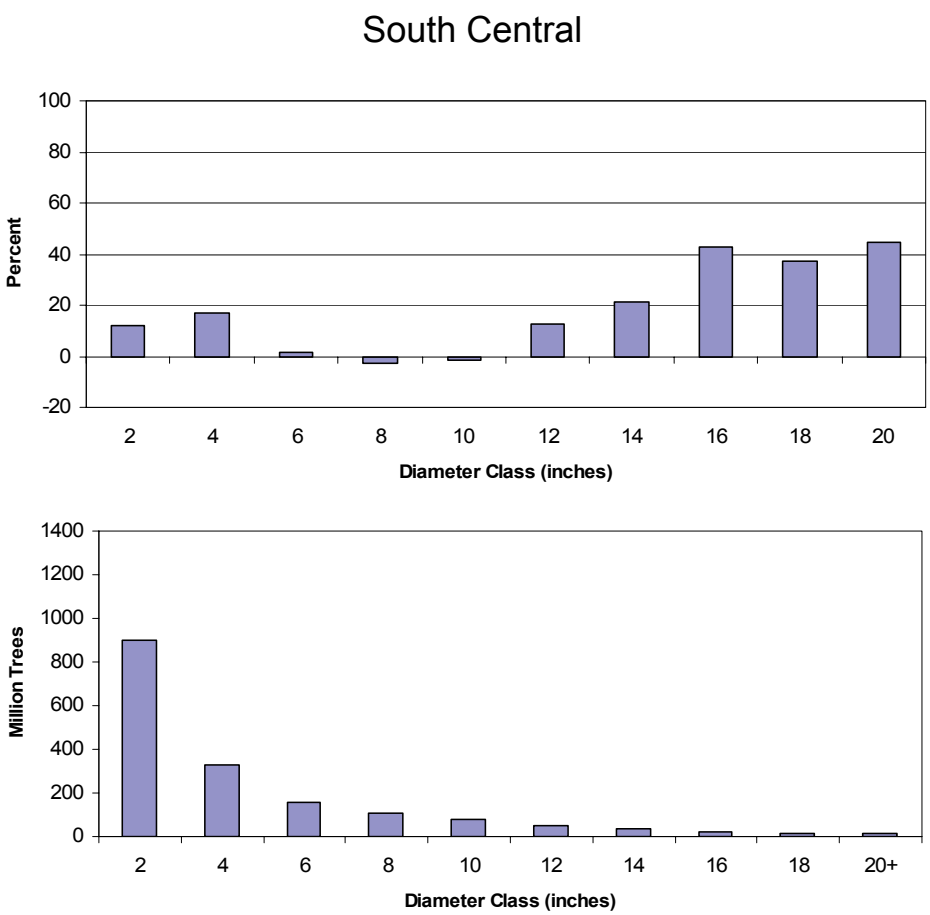

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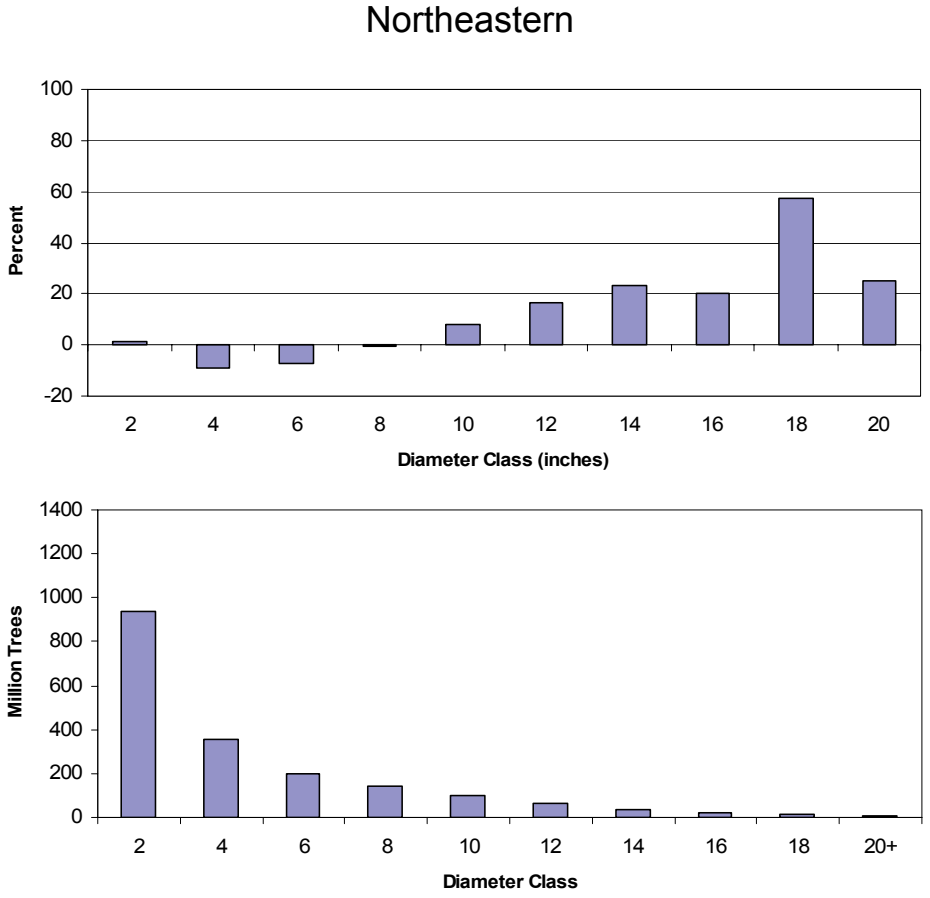


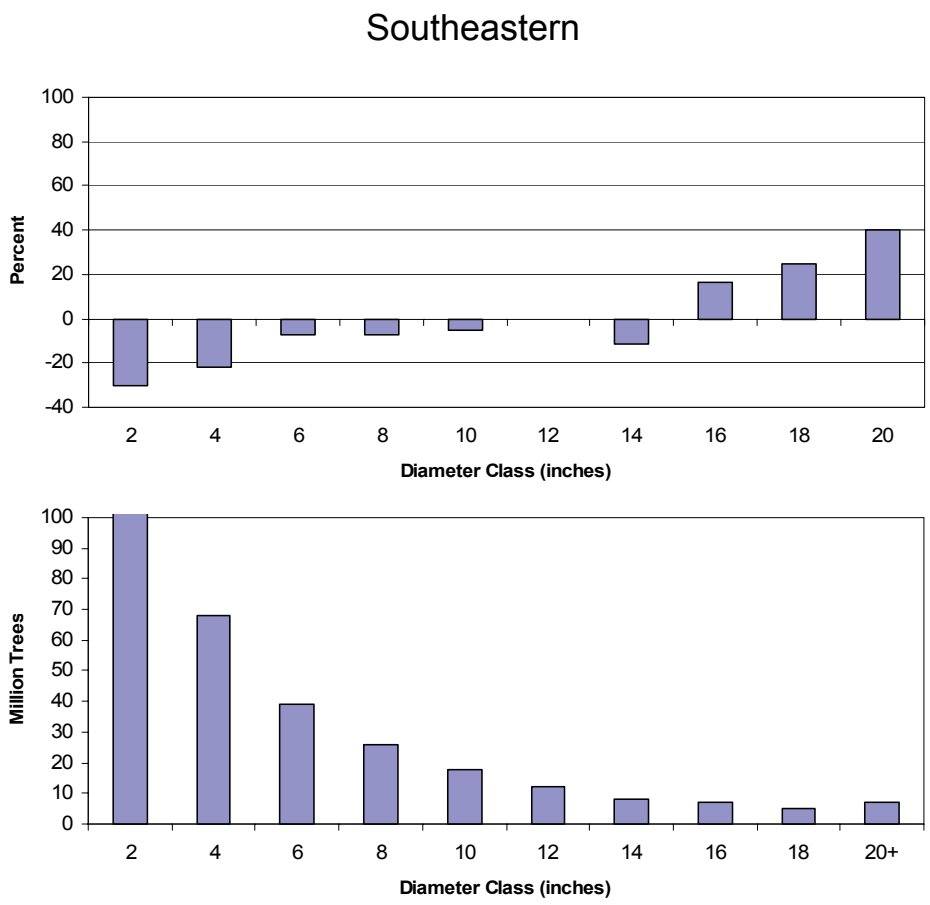


Figure 32.—continued.

Figure 33 summarizes changes among species for all size classes. Included are all species that contributed at least 1 percent of the total number of live trees in 2004. The results are influenced heavily by small trees because of the typical reverse J shape of the stand tables. This shape reflects typical conditions for most deciduous forests in the Mid-Atlantic region, i.e., there are numerous small stems and a smaller number of large trees.

Species with decreases in the total number of trees include red maple, sugar maple, hemlock, northern red oak, chestnut oak, hawthorn, sassafras, white oak, serviceberry, and hornbeam. The most significant increase was in the number of black birch trees.

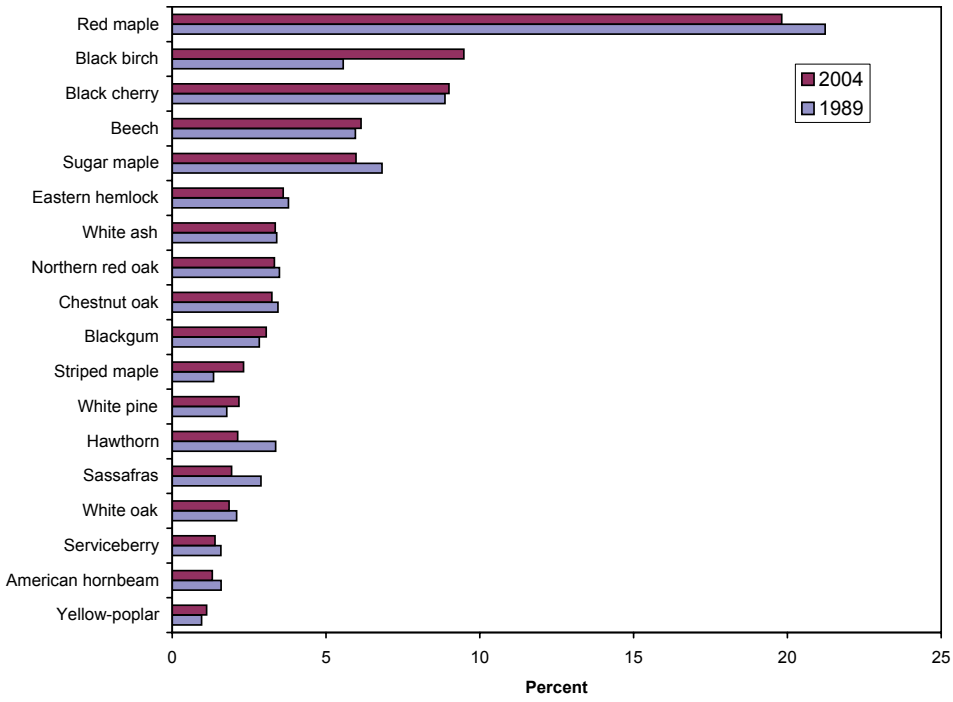


Figure 33.—Percentage of live trees on forest land by species/species group, all sizes, Pennsylvania, 1989 to 2004.

Figure 34 shows how stand tables for selected species are changing by diameter class. For example, recent trends in red maple indicate that this species decreased in the 2- to 6-inch classes and increased in larger diameters. Black cherry showed increases in all diameter classes except the 2-inch class.

Oak species were combined to ensure statistical confidence and to allow for a concise evaluation of their status. Oaks in Pennsylvania continue to mature, though all of the smaller diameter classes are showing decreases. In the case of the 2-inch class, no statistically significant change was found, indicative of prospective regeneration. The stand table for sugar maple similarly revealed increases in larger diameters but decreases in all diameter classes from 2 through 10 inches. Black birch is a prolific species with a noted advantage in the regeneration component. This is demonstrated in recent stand table changes.

Young stand of black birch.

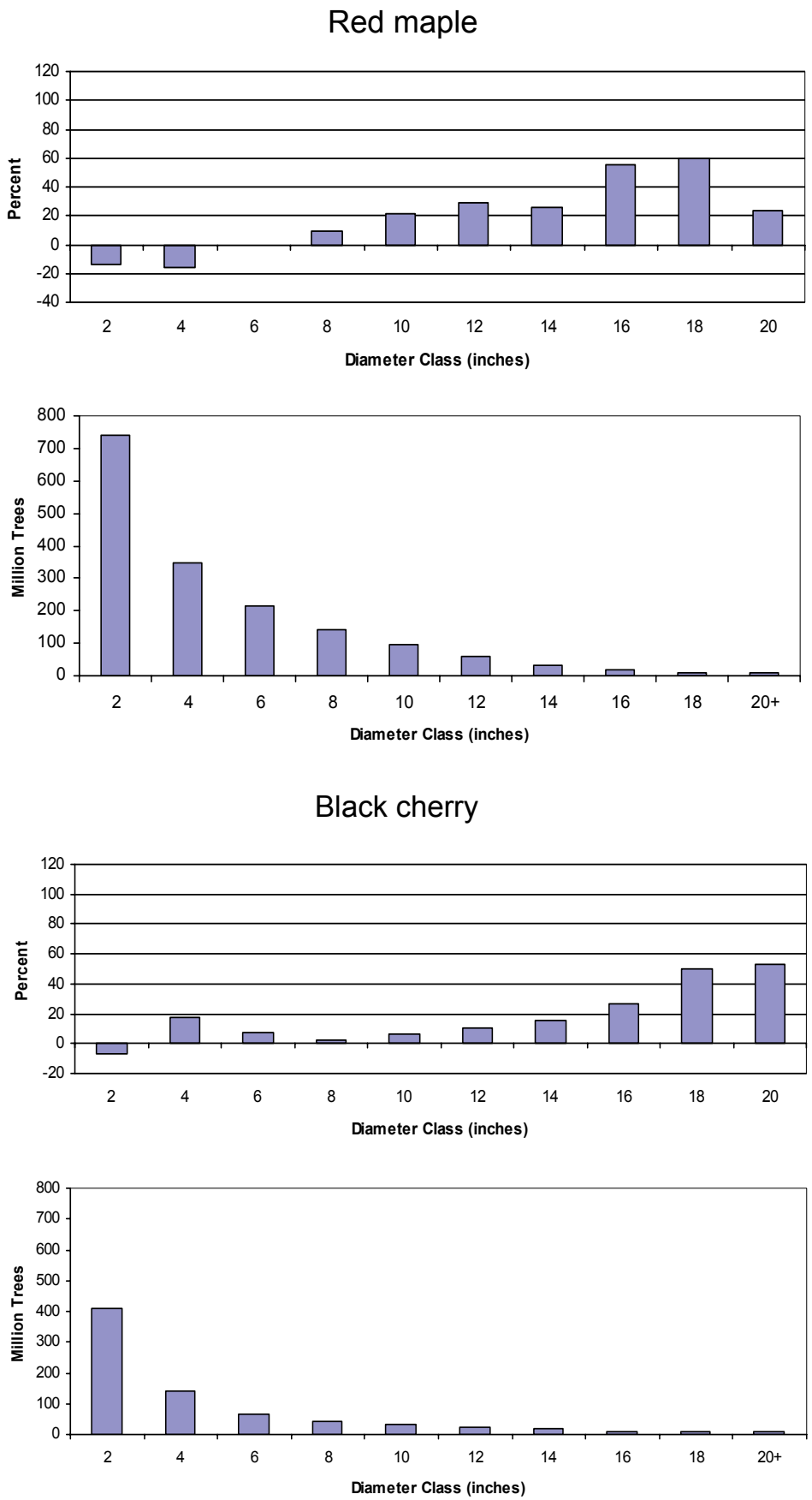
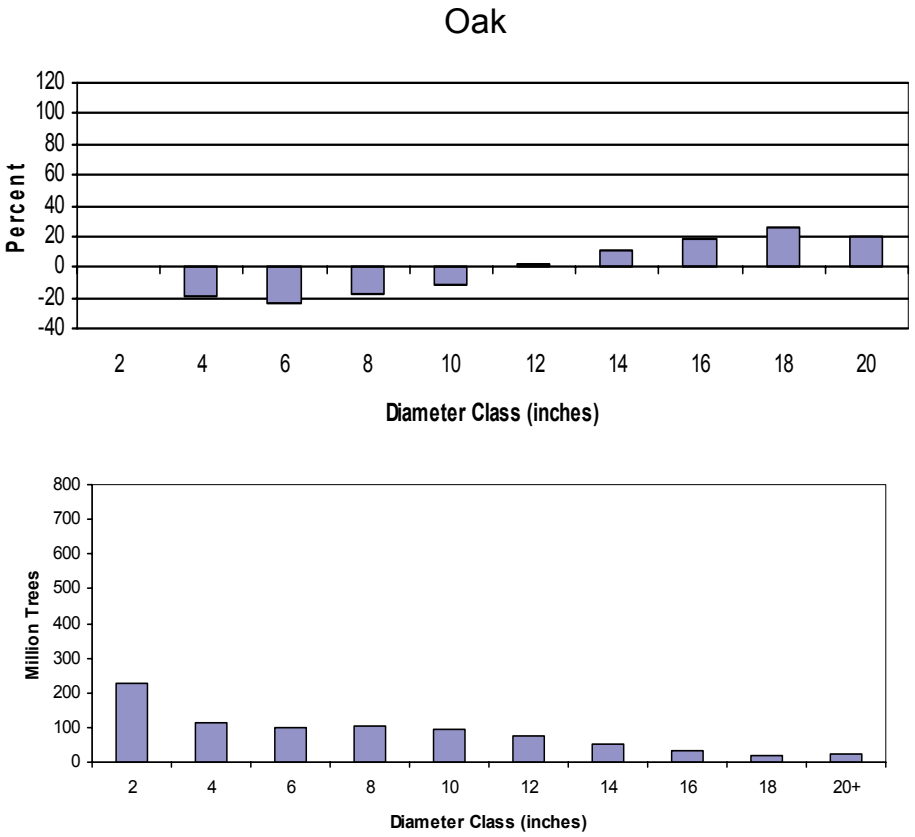
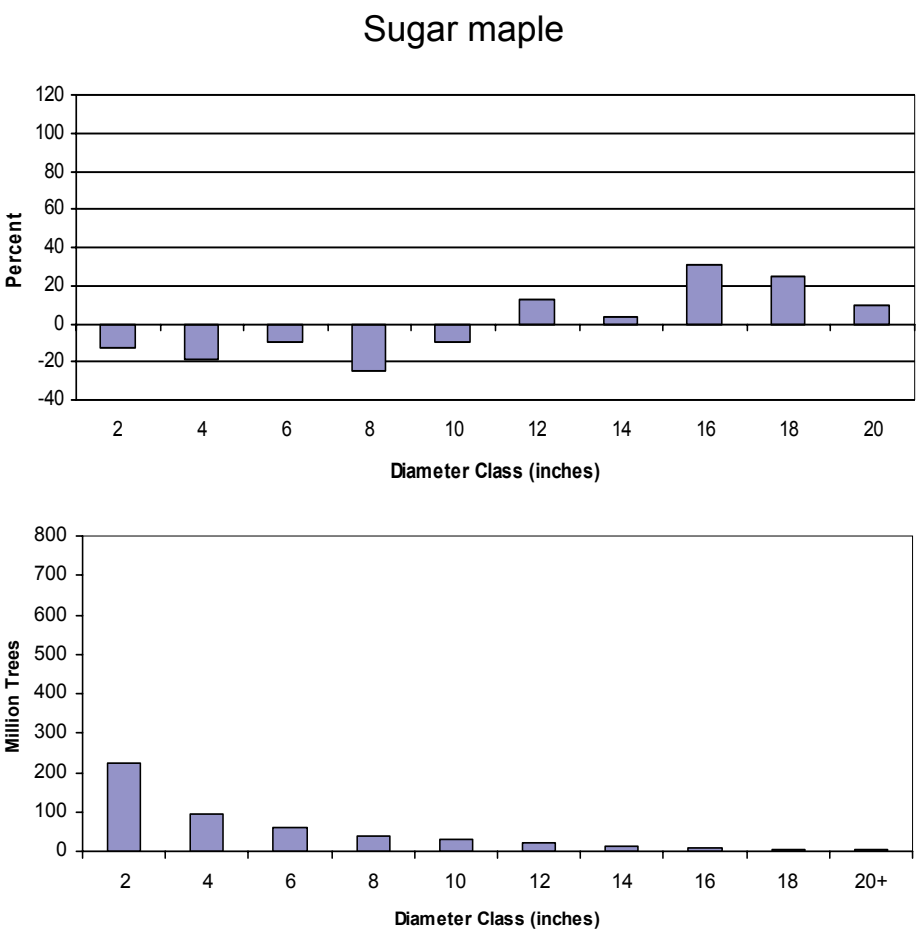


Figure 34.—Percent change and number of live trees on forest land by diameter class, selected species, Pennsylvania, 1989 to 2004.





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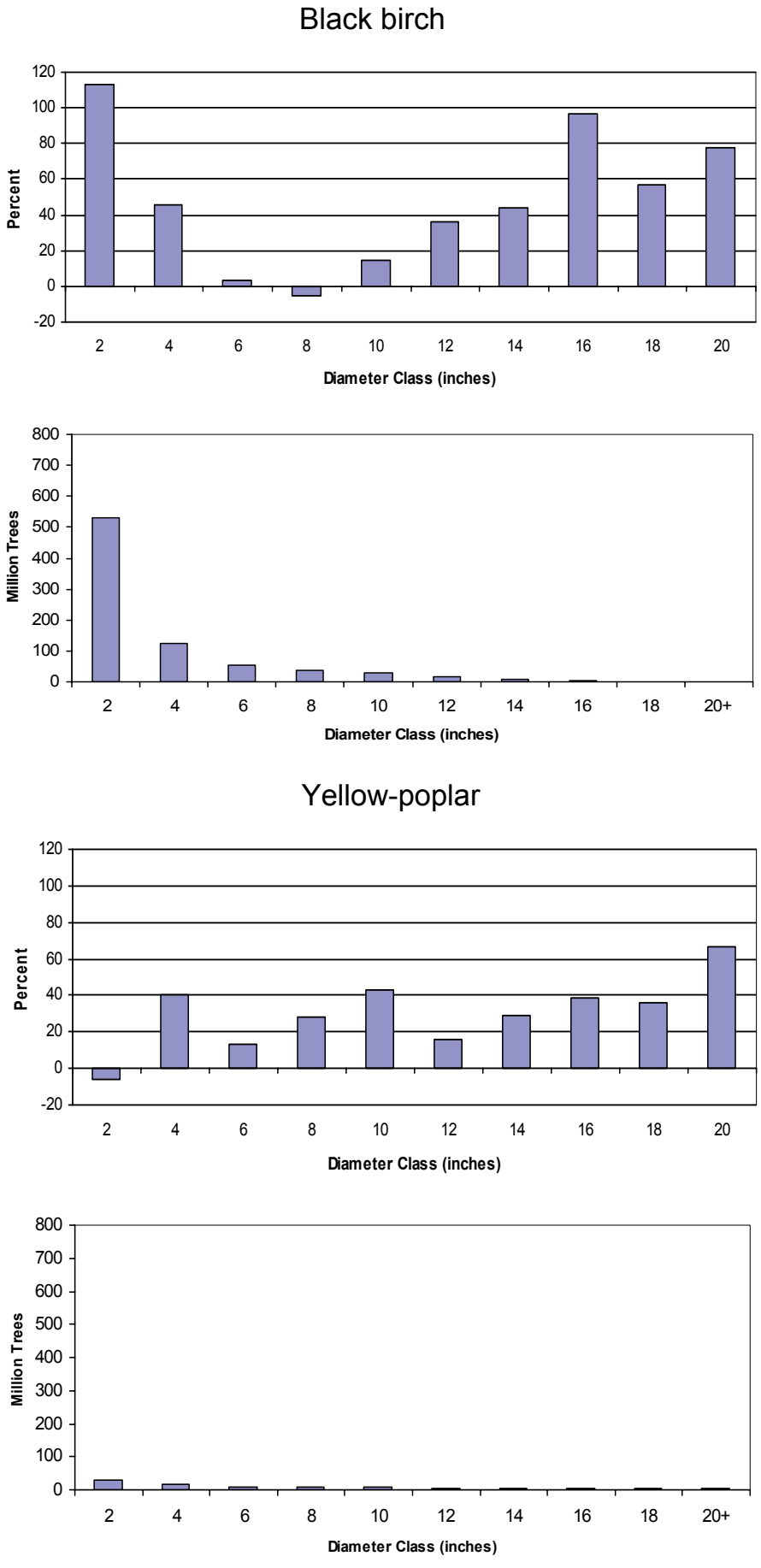


Figure 34.—continued.

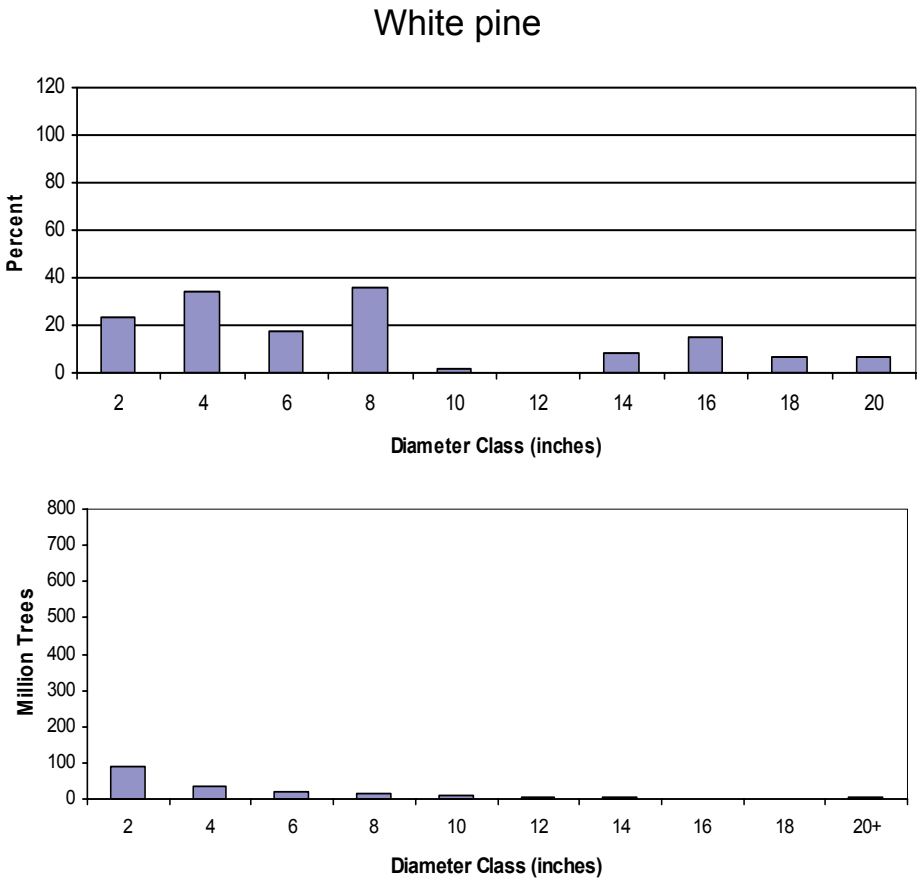


Figure 34.—continued.

Since 1989, this species has increased by more than 100 percent in the 2-inch class and by nearly 50 percent in the 4-inch class. Yellow-poplar is maintaining its relative importance in all classes except for a slight decrease in the 2-inch class. The findings for white pine show little change for the midrange diameters but significant increases for the smaller and larger diameters. Increases in the 2- to 8-inch classes suggest that white pine is surviving within the regeneration component and maintaining its importance among medium trees.

Volume

The volume of sampled trees can be categorized by several measurements, the most common of which are biomass, live volume (cubic feet), and sawtimber volume (board feet expressed using the International ¼-inch rule). Total biomass of live trees is a useful indicator of relative tree species dominance. Cubic-foot volume is the measurement of the merchantable portion of the tree stem and represents the amount of wood available for pulp, paper, and secondary roundwood products such as pallets. Sawtimber volume represents the most valuable wood available and is computed for sawtimber-size trees for only the saw log portion (Definition of Terms).

Biomass

The total above-ground biomass of live trees at least 1 inch in d.b.h. is 2 billion green tons. Ninety percent of Pennsylvania's biomass is in hardwood species (Fig. 35). Ranking by species reveals the dominance of red maple, with 18 percent of the total biomass (Fig. 36). The top 10 species account for three-fourths of the State's biomass. Figure 37 shows that, for all species, the main stem accounts for more than half of the total biomass, followed by stumps/roots, branches, cull trees, foliage, and saplings.

Live-Tree Volume

Pennsylvania's total inventory volume comprises large- and medium-size trees (growing stock), as well as rough and rotten trees. Large trees make up nearly two-thirds of the inventory, followed by medium trees (30 percent), rough trees (4 percent), and rotten trees (1 percent) (Definition of Terms).

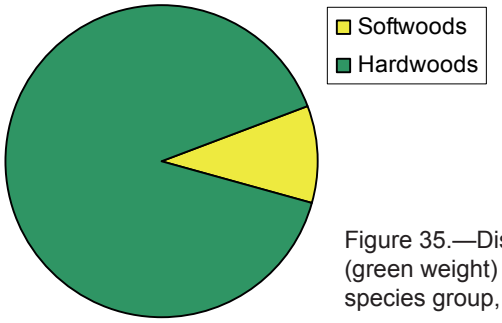


Figure 35.—Distribution of tree biomass (green weight) on forest land by broad species group, Pennsylvania, 2004.

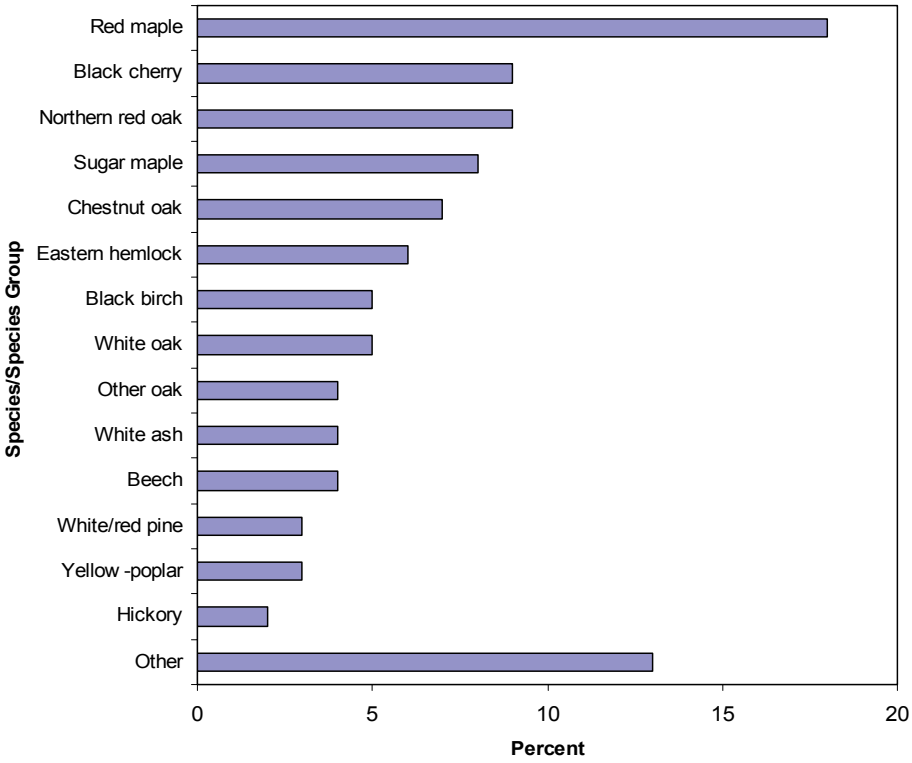


Figure 36.—Distribution of tree biomass (green weight) on forest land by species/species group, Pennsylvania, 2004.

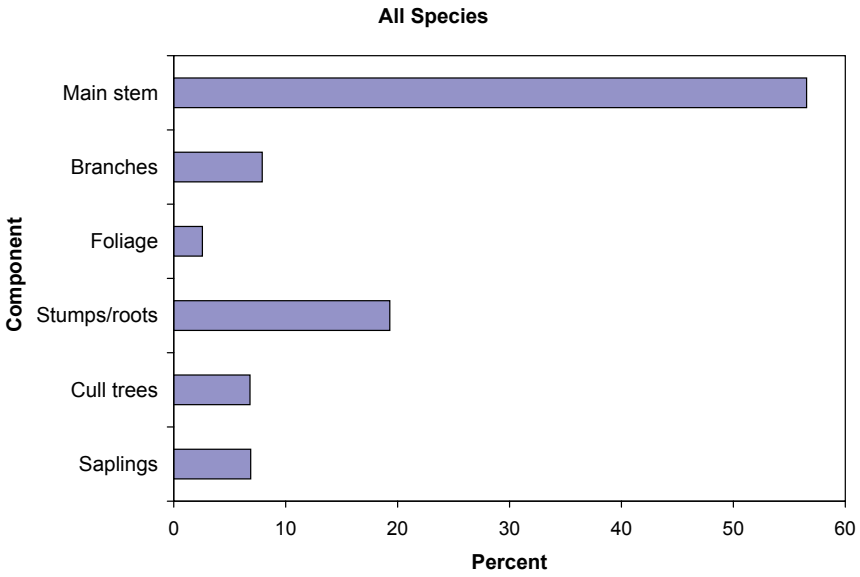


Figure 37.—Distribution of tree biomass (green weight) on forest land by component, all species Pennsylvania, 2004.

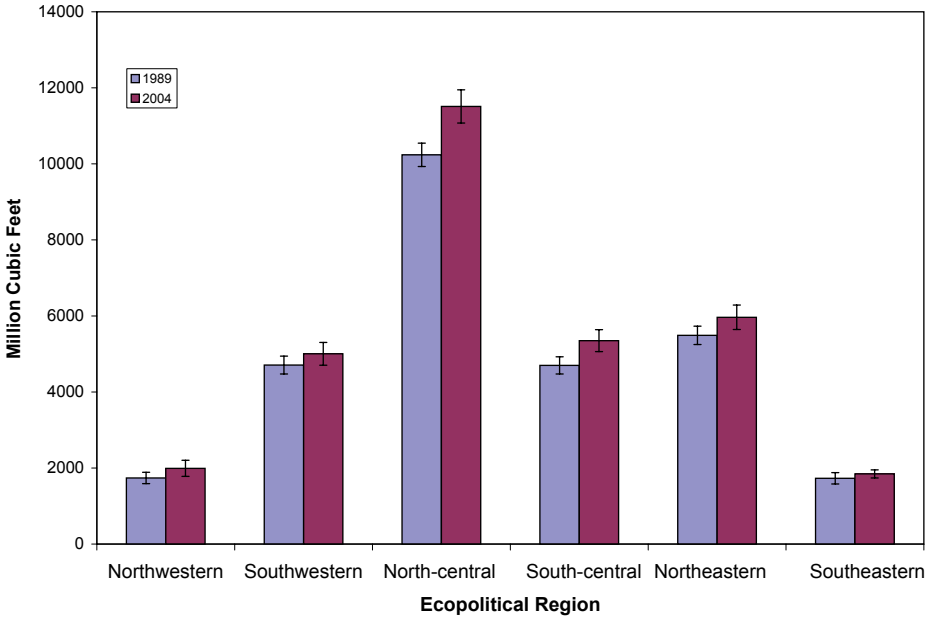


Figure 38.—Volume of live trees by ecopolitical region, Pennsylvania, 1989 and 2004.

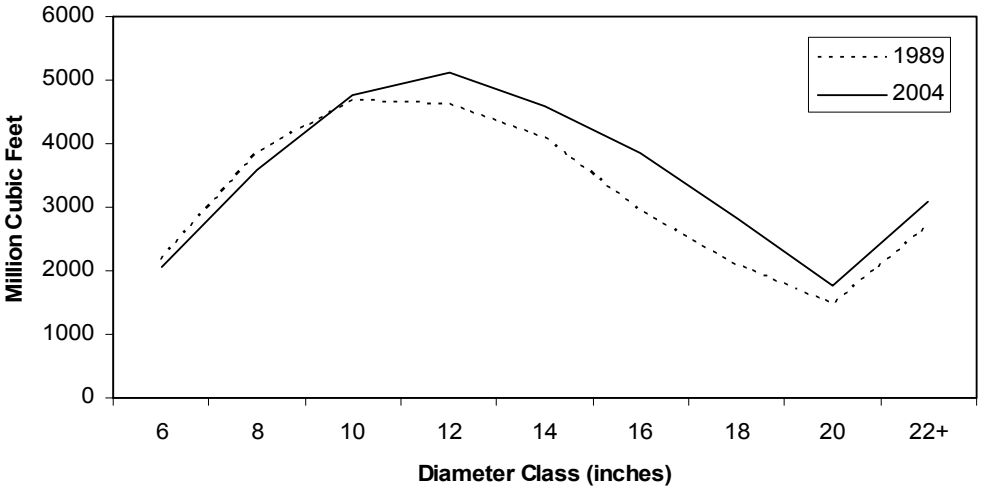


Figure 39.—Net volume of live trees on forest land by diameter class, Pennsylvania, 1989 and 2004.

The total net volume of live trees has increased by 11 percent since 1989 and now totals 31.7 billion cubic feet. The current inventory is the highest recorded since NRS-FIA initiated the inventory process. Volumes increased in all ecopolitical regions (Fig. 38). The northwestern, north-central, and south-central regions posted increases in excess of the State average.

The continued growth of Pennsylvania's forest is evident from changes in volume by diameter class (Fig. 39). Volume decreased in smaller diameters and increased in the larger classes. The greatest gains were in the 16- and 18-inch classes. Volumes in the ecopolitical regions followed the same trend. The north-central region had the greatest increases in the larger classes.

Examining the top 10 species/species groups revealed that all increased in volume except sugar maple (Fig. 40). Some of the increases were not statistically significant at the 95-percent confidence level, but the means were higher. The decrease in sugar maple was not significant but the decrease likely is a reality given other indications of general decline across the northern-tier counties.

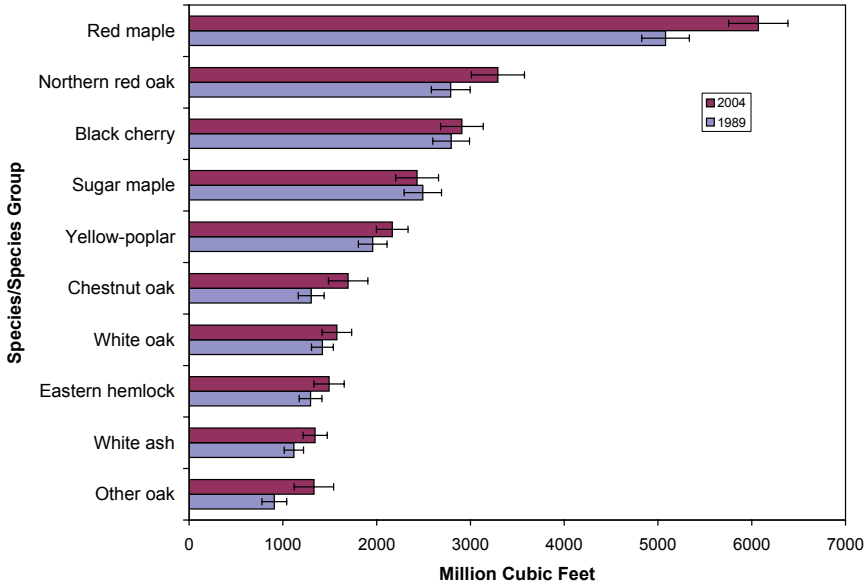


Figure 40.—Net volume of live trees on forest land by species/species group, Pennsylvania, 1989 and 2004.

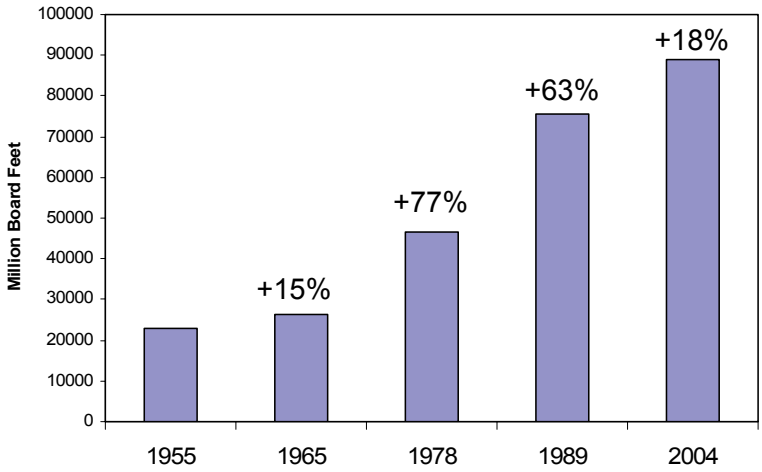


Figure 41.—Volume of sawtimber by inventory date, Pennsylvania, 1955, 1965, 1978, 1989, and 2004.

Sawtimber Volume

Sawtimber volume is measured in board feet. In current markets, sawtimber is the most economically valuable wood product in Pennsylvania's forests. As with live-tree volume, the current sawtimber inventory is the highest ever recorded in NRS-FIA inventories.

The accumulation of sawtimber volume is shown in Figure 41. Sawtimber volume has nearly tripled since 1955 and the current inventory is 88.9 billion board feet. On a per-acre basis, sawtimber volume exceeds 5,000 board feet. Although sawtimber inventory is increasing, the rate is slowing. The current increase of 18 percent is much smaller than increases of 77 and 63 percent in the two prior inventories.

Sawtimber quality is gauged by examining volume distribution by tree grade (National Hardwood Lumber Association grades 1-3 and others). Tree grades are assigned to each sawtimber-size tree based on bottom log characteristics using both eastern hardwood grades and conifer grades. Trees that do not qualify for tree grades are placed into the "other" category. Volume estimates by grade were developed to approximate the output of standard lumber. Currently, grades 1 and 2 generally are preferred by sawmills.

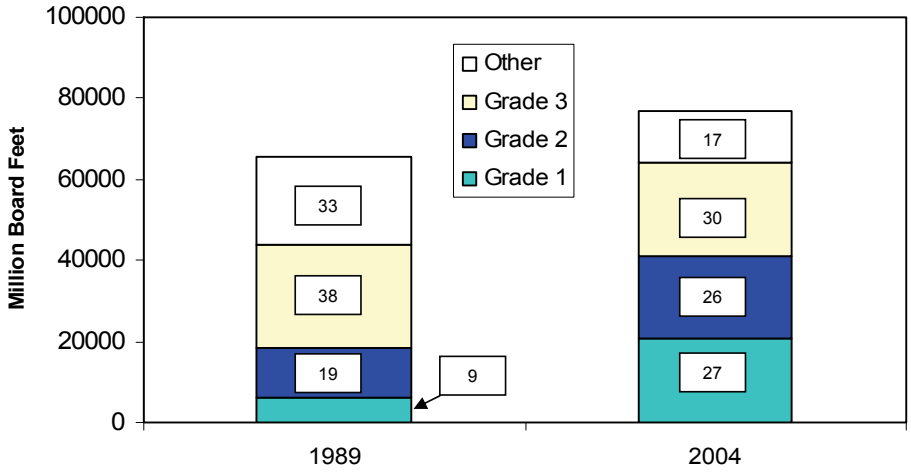


Figure 42.—Net volume of sawtimber and percent of total on timberland by tree grade, Pennsylvania, 1989 and 2004.

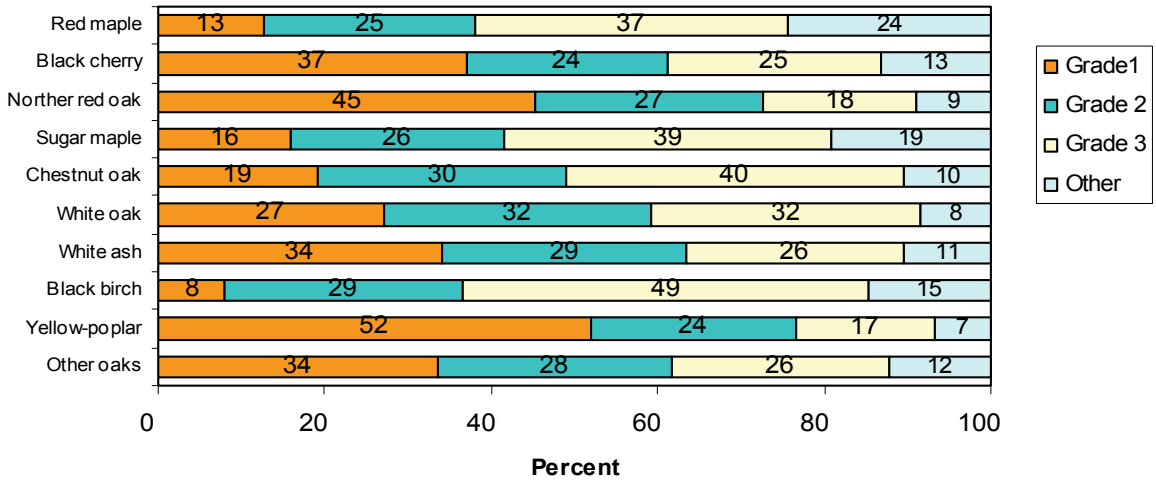


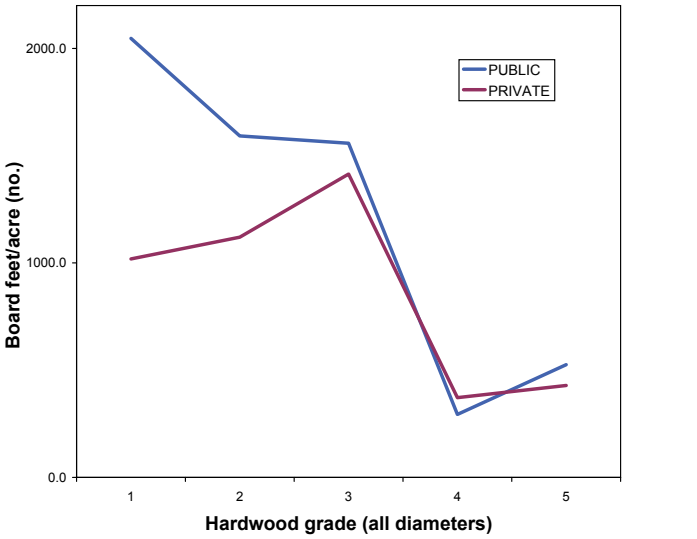
Figure 43.—Net volume of sawtimber and percentage of total on timberland by species/species group and tree grade, Pennsylvania, 2004.

The distribution of volume by grade reveals that more than half of the current volume is in tree grades 1 or 2 (Fig. 42). This segment of the resource has been expanding, more than doubling since 1989, as more trees reach the minimum size for grading purposes.

Quality profiles show that at least half of the sawtimber volume of black cherry, northern red oak, white oak, white ash, and yellow-poplar is in tree grades 1 and 2 (Fig. 43). Public forests have a higher amount of sawtimber volume in the better grades than private land (Fig. 44).

All ecopolitical regions experienced significant increases in sawtimber volume (Fig. 45). The north-central and south-central regions had the largest percentage increases and accounted for 70 percent of the statewide increase in sawtimber inventory.

Statewide, all the major species/species groups had statistically significant increases or higher means (Fig. 46). Red maple had the largest increase in sawtimber volume and all oak species had significant increases. Larger oaks continue to expand in volume while the influx of younger oak trees is decreasing, as shown in the volume trends for live trees.



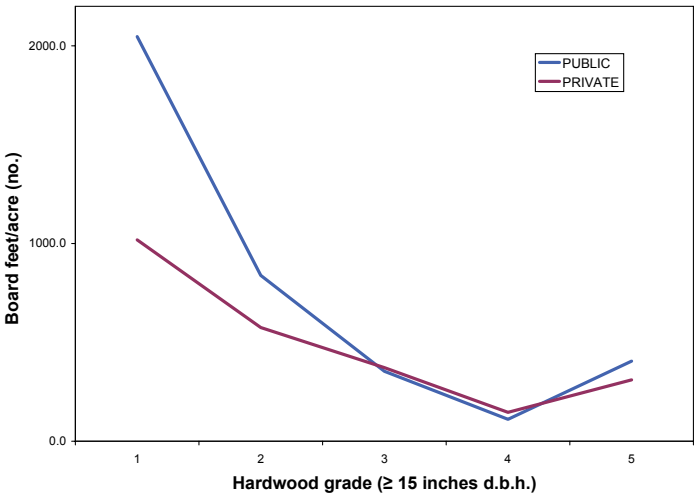


Figure 44.—Distribution of hardwood sawtimber volume per acre by grade, size class, and ownership, Pennsylvania, 2004.

Distribution maps of sawtimber volume depict the location of inventory volume for major species/species groups (Fig. 47). When all species are considered, the areas with the largest sawtimber volume inventories are in the heavily forested northern-tier counties as well as the smaller forested parcels in southeastern corner. Some areas of the State contain more than 14,000 board feet per acre.

Down Woody Material

Down woody material (DWM) is defined as dead material on the ground in various stages of decay. DWM is an important component of forest ecosystems, indicating critical attributes such as quality of wildlife habitats, structural diversity, fuel loading and fire behavior, carbon sequestration, and water storage and cycling (USDA For. Serv. 2002c).

Components measured by the DWM indicator include coarse woody debris (CWD); fine woody debris (FWD); duff; litter; herbs/shrubs; and fuelbed depth. DWM is measured at the transect line. CWD is dead wood 3 inches or larger in diameter (1,000-hour fuels); FWD is dead wood from 0.1 to 2.9 inches in diameter (1-, 10-, and 100-hour fuels). Litter is defined as the loose plant material on top of the forest floor where little decomposition has occurred. Duff is the layer just below the litter, consisting of decomposing leaves and other organic material.

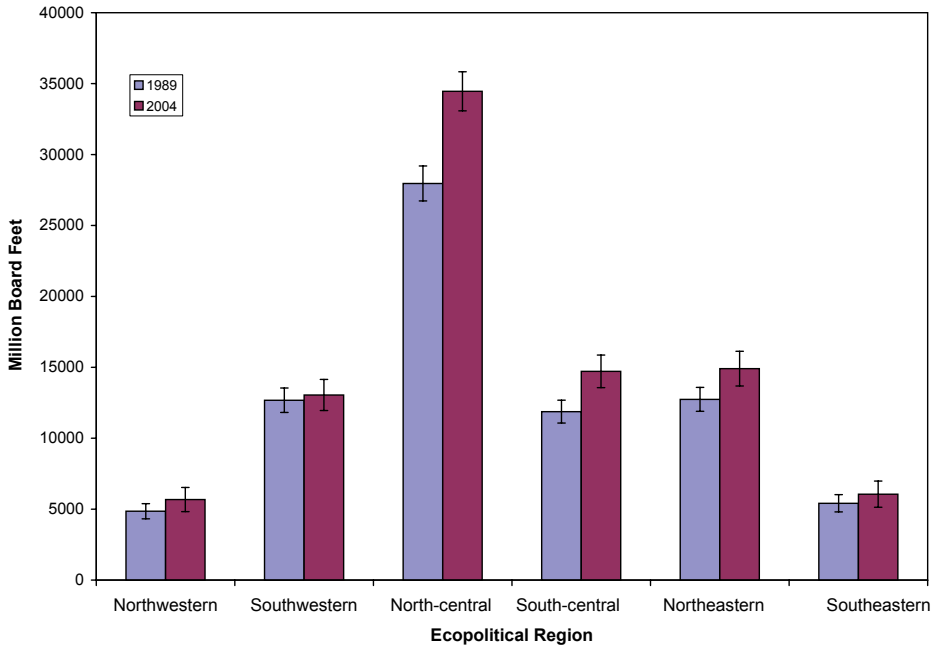


Figure 45.—Volume of sawtimber by ecopolitical region, Pennsylvania, 1989 and 2004.

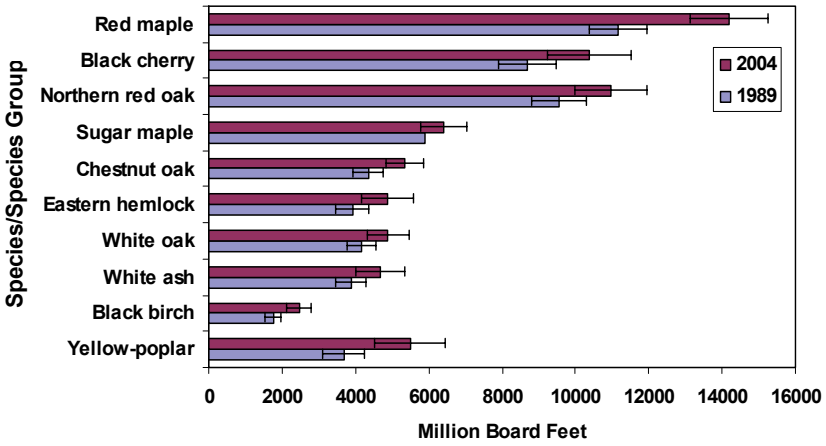
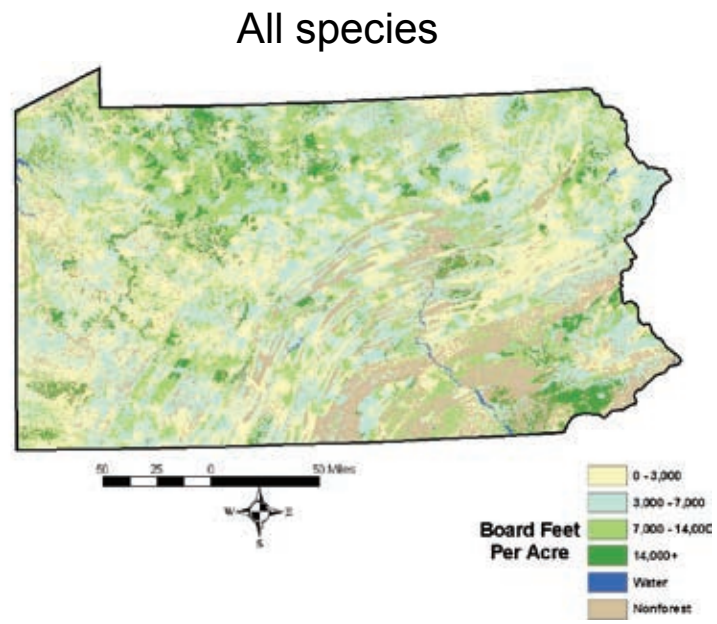


Figure 46.—Net volume of sawtimber on forest land by species/species group, Pennsylvania, 1989 and 2004.



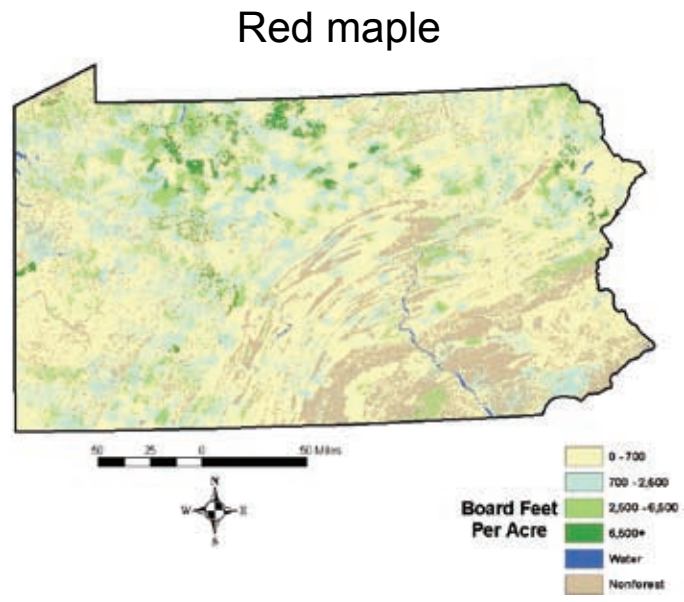
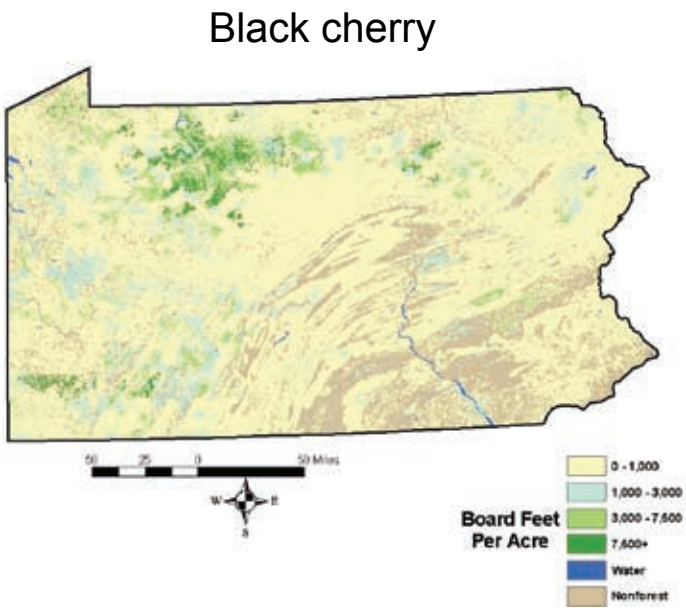
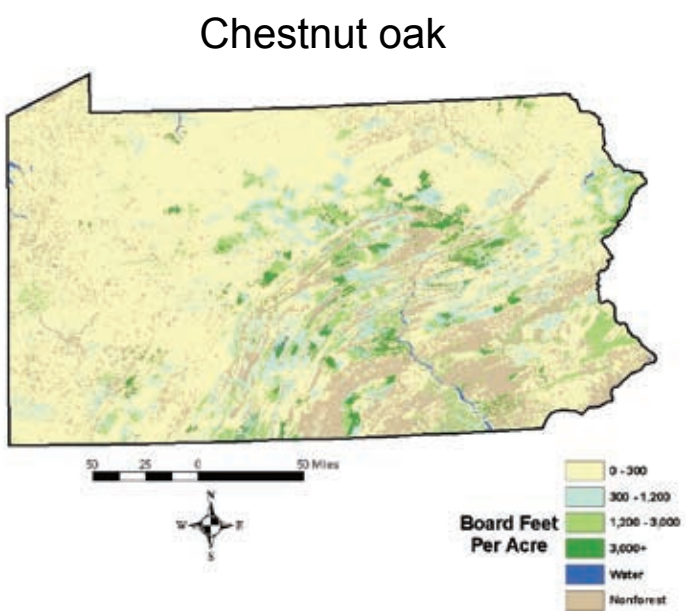
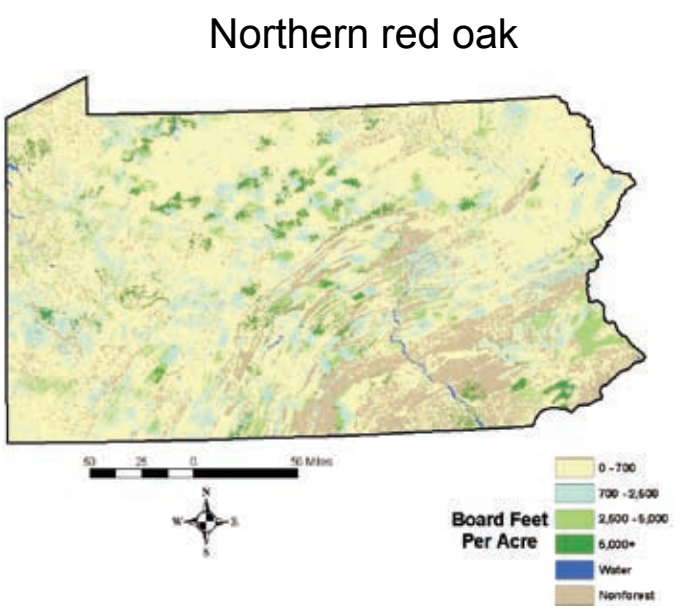
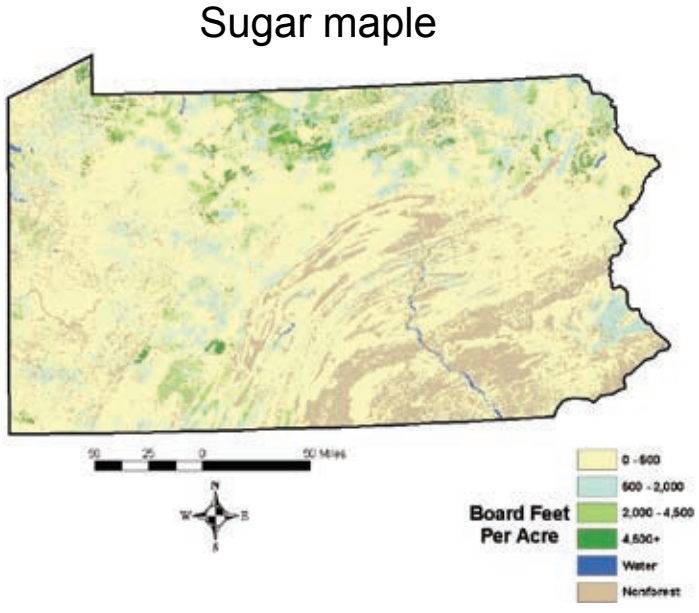


Figure 47.—Distribution of sawtimber volume, Pennsylvania, 2004.









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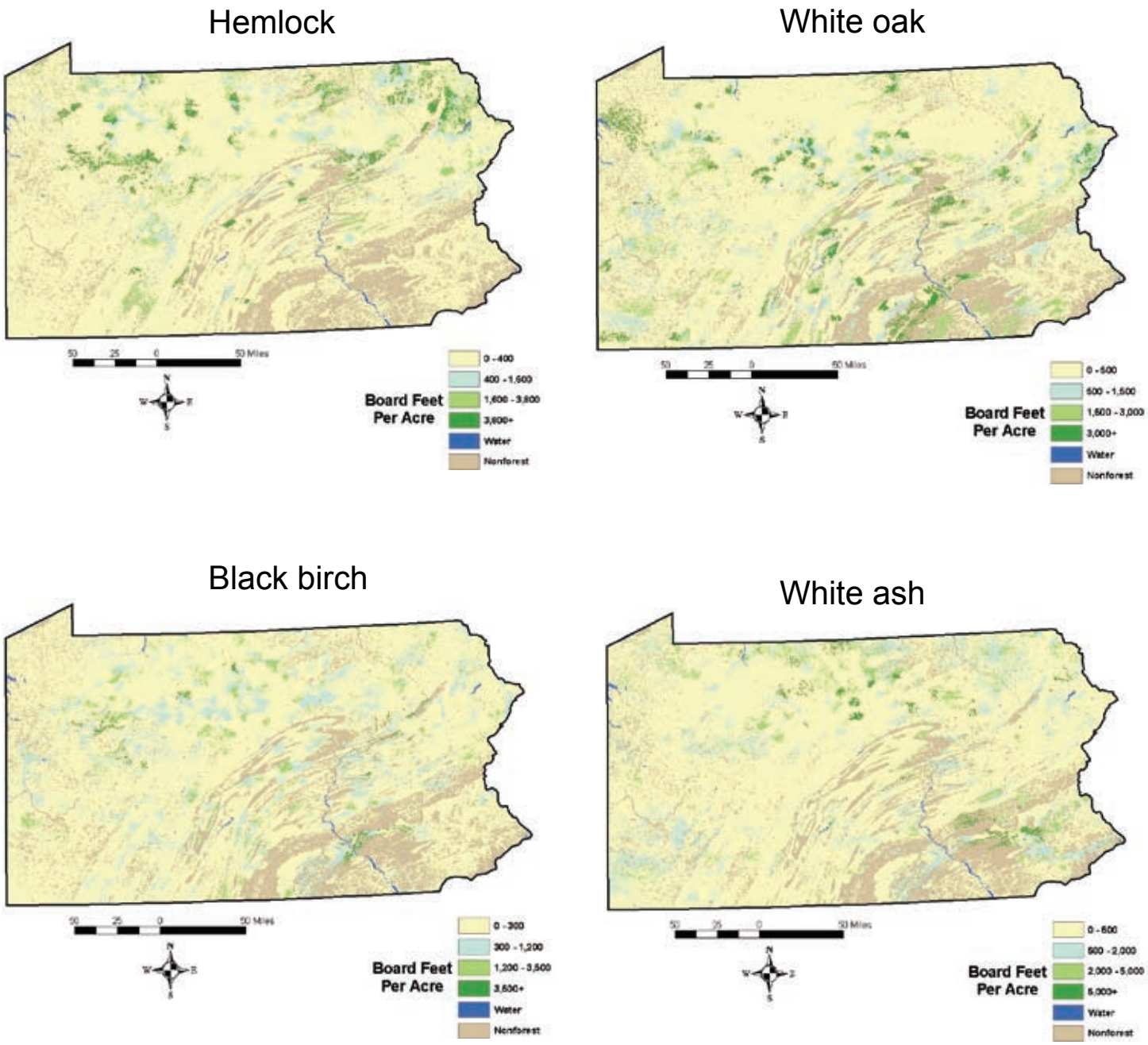

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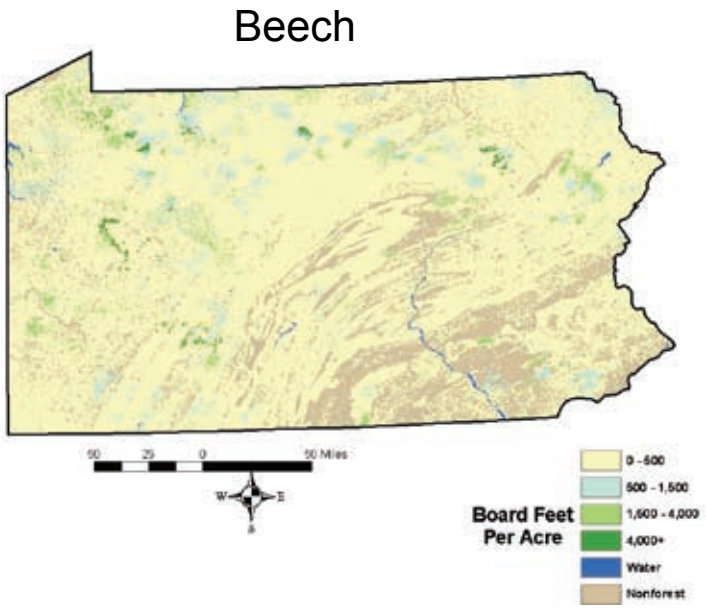

Figure 47.—continued.

Quantities of FWD and CWD in the mixed oak and northern hardwoods forest-type groups, measured in tons per acre, follow similar patterns. Table 2 lists fuel classes in an ascending manner (1-, 10-, 100-, and 1,000-hour), which is based on increasing diameter-class ranges (0.01 to 0.24, 0.25 to 0.9, 1.0 to 2-9, and 3.0+).

Fuel loadings for both forest-type groups also increase with each increase in fuel class (diameter-size class). The forest-type group designated as other displays the only variant in the this pattern. However, in the All Plots column, the original pattern persists.

Northern hardwoods had the largest amount of wood debris (FWD and CWD combined) with nearly 9 tons per acre. Mixed oak had 7.7 tons per acre, and other had 7.2 tons per acre. The largest amount of litter (1.4 tons per acre) was in the mixed oak type, while the northern hardwood type averaged 1 ton per acre. The duff component of DWM contained the most tons per acre of all components. Northern hardwoods contained 8.4 tons per acre, mixed oak 7.2, and other 4.3.

The shrub/herb component is an integrated measurement of percent cover and height representing

Table 2.—Mean fuel loadings and associated standard errors for forest-type groups [a], Pennsylvania, 2001-2004

Down woody	Fuel	Mixed oak		Northern hardwoods		Other		All Plots	
debris component	loading	Tons/acre	SE	Tons/acre	SE	Tons/acre	SE	Tons/acre	SE
FWD	1-hour	0.24	0.03	0.38	0.05	0.22	0.06	0.30	0.03
FWD	10-hour	0.89	0.10	0.93	0.12	0.68	0.18	0.90	0.07
FWD	100-hour	3.10	0.81	2.82	0.35	3.86	2.44	3.03	0.44
CWD	1000-hour	3.42	0.83	4.83	0.86	2.45	1.42	4.00	0.56
Litter		1.40	0.17	1.02	0.14	0.33	0.14	1.18	0.11
Duff		7.19	1.00	8.37	1.29	4.32	2.40	7.52	0.78
Shrub/herb		1.89	0.20	1.67	0.24	2.64	0.59	1.84	0.15

[a] Mixed oak: 71 plots; northern hardwoods: 72 plots; other: 12 plots.

nontree vegetation between the ground and standing trees. The average height for the other type is the tallest at 2.6 feet, followed by mixed oak at 1.9 feet and northern hardwoods at 1.7 feet.

Pennsylvania's northern hardwood forests contain the largest amount of CWD at nearly 5 tons per acre, followed by mixed oak (3.4) and other (2.5). CWD creates numerous ecological niches and serves as habitat for plants, animals, protists, bacteria, and fungi (Harmon and others 1986). The amount of CWD required to maintain a healthy ecosystem in not known (Densmore and others 2004), though large pieces of CWD provide the greatest habitat value (Lofroth 1998). In Pennsylvania, 87 percent of the CWD pieces are dominated by small diameters between 3 and 7.9 inches (Fig. 48). Sixty percent of these pieces are in the more advanced stages of decay (decay classes 4 and 5) (Fig. 49). Only 20 percent of Pennsylvania's CWD pieces were estimated as being freshly fallen or within several years of recruitment.

With respect to stand-size class, the mean volume of CWD is statistically similar among the small, medium, and large stands (Fig. 50). However, the amount of FWD was significantly greater in small- and medium-size stands than in large stands (Fig. 51). The distribution of DWM across Pennsylvania's landscape is shown in Figure 52.

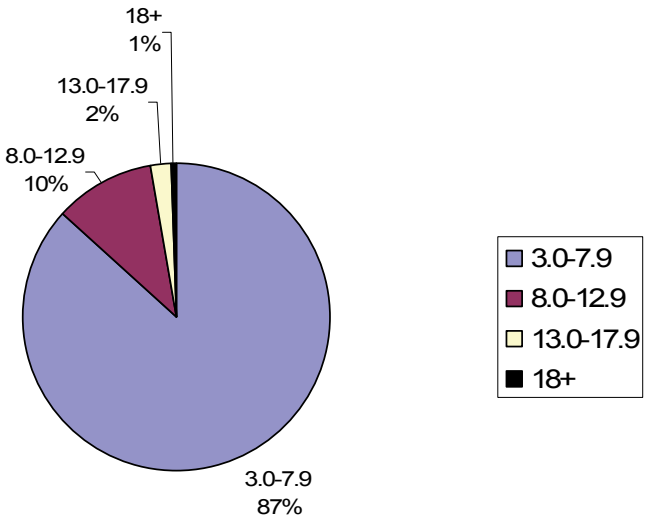

Figure 48.—Percentage of coarse woody debris pieces per acre by transect diameter, Pennsylvania, 2001-04.

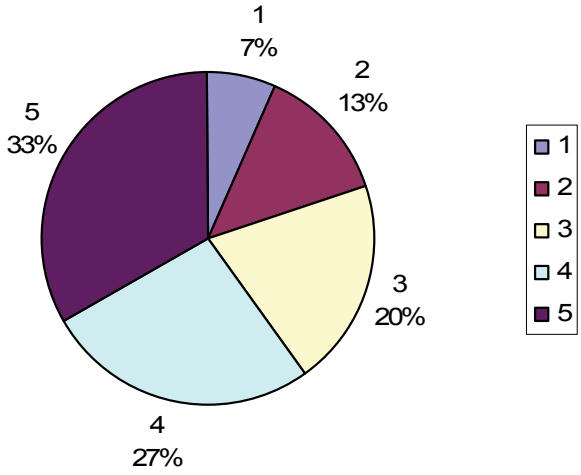

Figure 49.—Percentage of coarse woody debris pieces per acre by decay class, Pennsylvania, 2001-04.

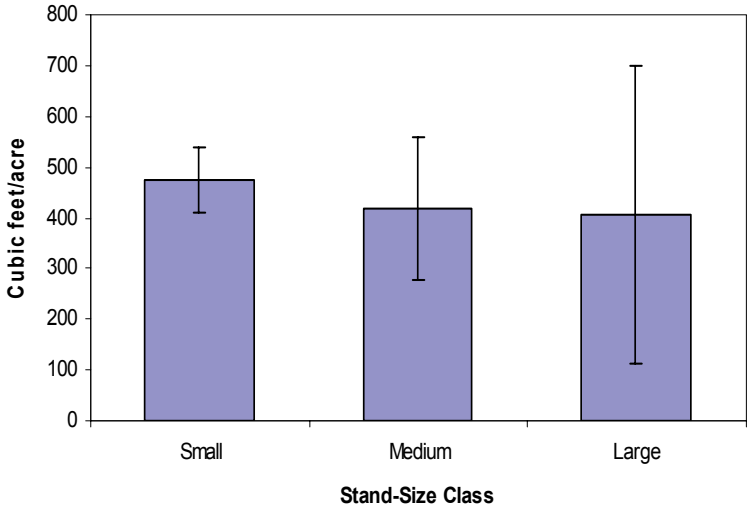

Figure 50.—Distribution of coarse woody debris by stand-size class, Pennsylvania, 2001-04.

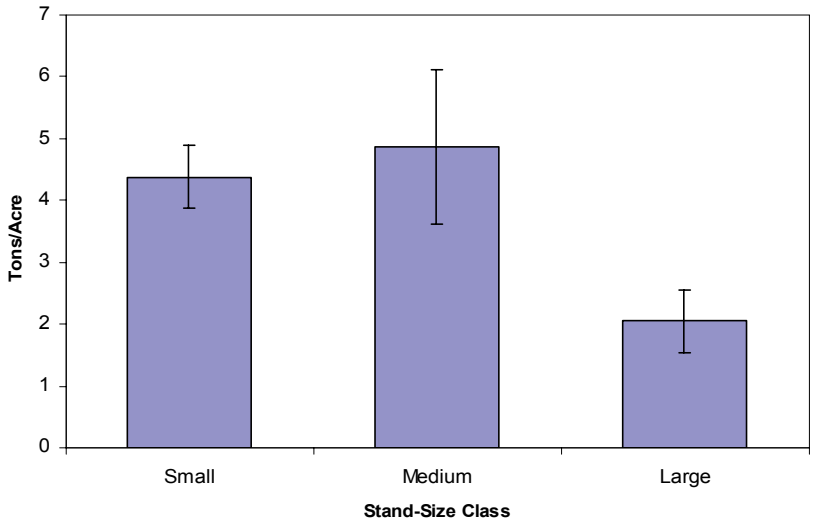

Figure 51.—Distribution of fine woody debris loadings by stand-size class, Pennsylvania, 2001-04.

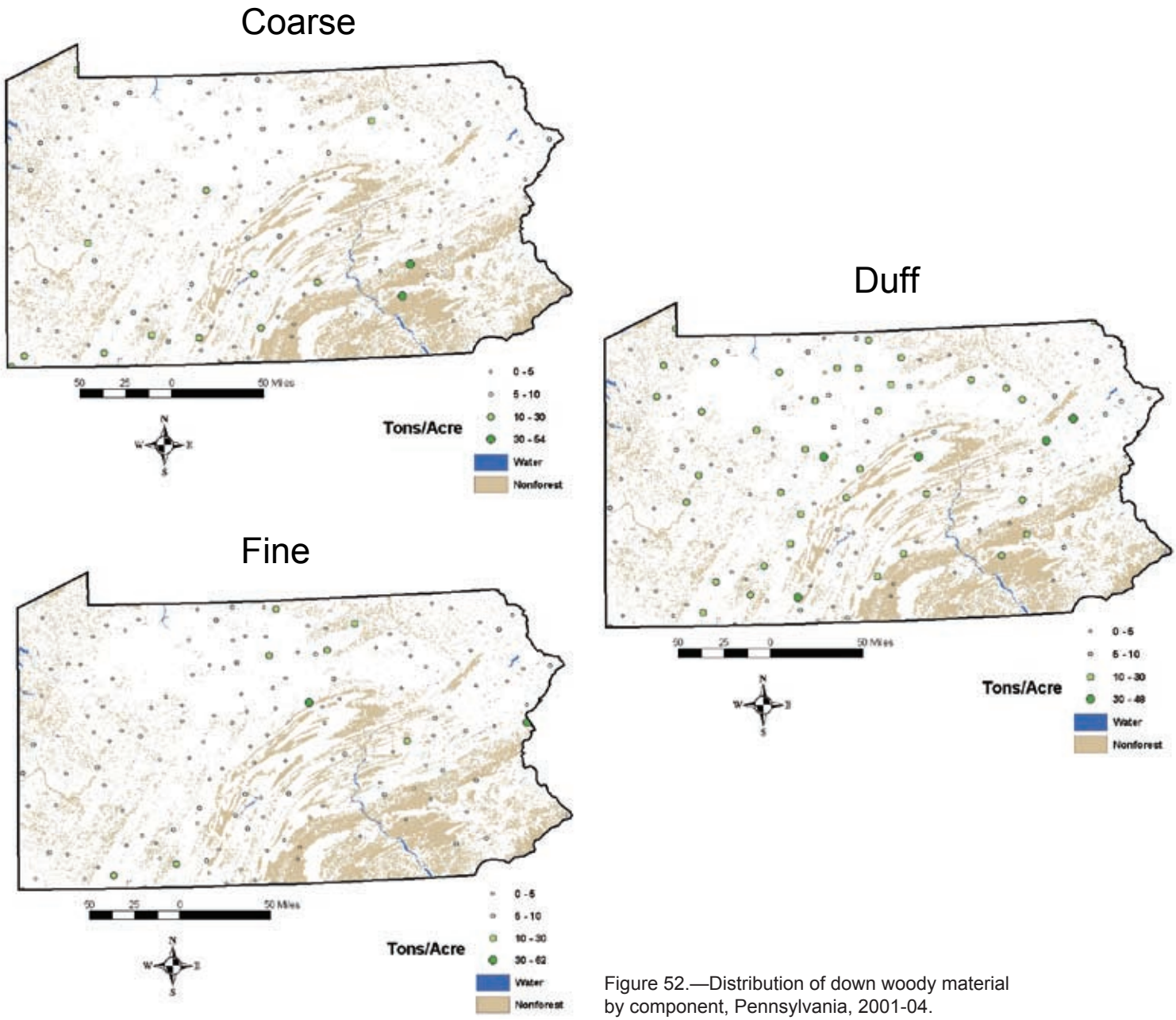

Figure 52.—Distribution of down woody material by component, Pennsylvania, 2001-04.

TIMBER PRODUCTS OUTPUT

The forest products industry in Pennsylvania is an integral part of the State's economy, providing more than 100,000 jobs in the Commonwealth. (Pa. Dep. Conserv. and Nat. Resour. 2004). The industry is fragmented and therefore difficult to track. Small, farm-operated and family-owned mills have traditionally accounted for the largest percentage in terms of numbers of mills, but not the largest percentage in terms of production.

The most comprehensive accounting of sawmills was conducted in 1988 (Wharton and Bearer 1994). By that time there were more than 1,500 operating facilities, most of which produced less than 50,000 board feet per year.

A Billion Board Feet and Beyond

A survey of Pennsylvania's timber industries in 1988 (Wharton and Bearer 1994) showed that the total roundwood volume received by Pennsylvania's primary forest-product-industry had reached nearly 1.5 billion board feet. More than 1 billion board feet of this total were from sawlogs. Pennsylvania consistently exceeds more than a billion board feet of production annually. A study conducted for 1999 (Smith and others 2003a) revealed that the State's sawmill output totaled more than 1.3 billion board feet.

Red maple logs.

The harvest of sawlogs and veneer logs continues to dominate throughout the Commonwealth. About 71 percent of the total roundwood harvest is composed of sawlogs and veneer logs (Murphy 2006). However, there has been a decline in production of sawlogs and veneer logs due largely to a decline in sawlog production (Fig. 54).

The production of veneer from Pennsylvania's timberland has increased in volume or at the very least accounts for a larger share of the market. The increase in veneer logs manufactured within the State has ranged from 31 billion board feet to 127 billion board feet since the late 1980s (Murphy 2006).

Hardwoods Predominate Production

No other state produces more hardwood sawlogs than Pennsylvania. Black cherry and oak, especially select oaks like northern red oak and white oak,

predominate (Fig. 55). Black cherry, soft maples (red maple and similar species), and yellow poplar have increased in production. Other high-volume species in the resource base such as red oak and hard maples (sugar maple and similar species) have declined in importance to Pennsylvania's forest-products industries. The consumption of white oaks has remained relatively constant but the consumption of red oak has declined sharply.

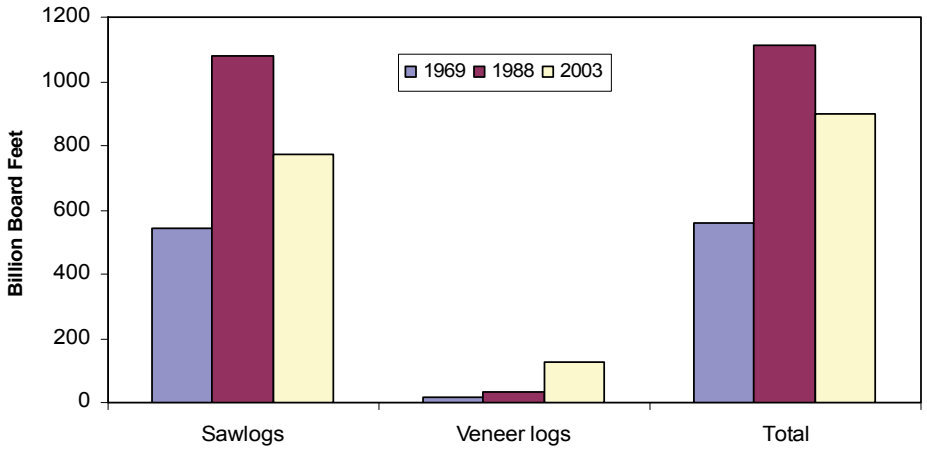

Figure 54.—Sawlog and veneer log production, Pennsylvania, 1969, 1988, and 2003.

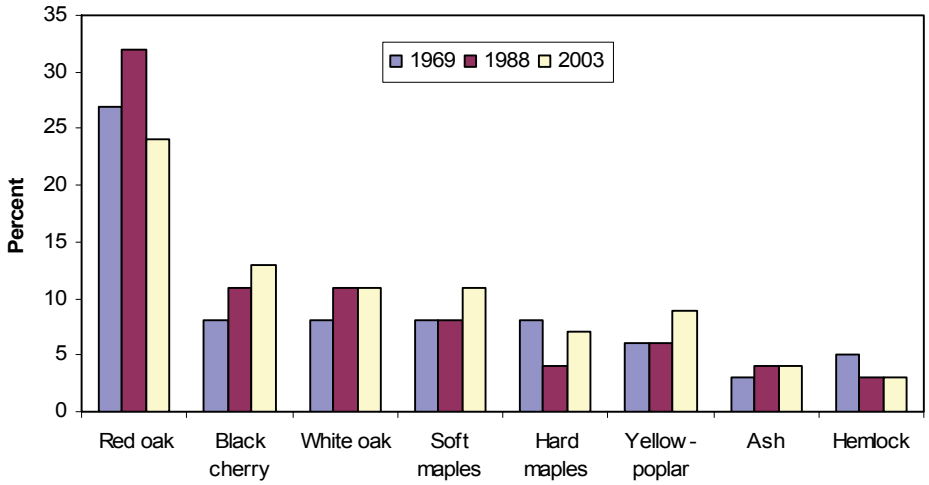

Figure 55.—Percent change in production by species, Pennsylvania, 1969, 1988, and 2003.

Deer fence, Allegheny National Forest.

CHAPTER 4: UNDERSTORY CONDITIONS

The understory is a key component of the forest ecosystem and forest-stand structure (Latham and others 2005). It is the layer of vegetation below the dominant forest canopy layer, and consists of shrubs, grasses, sedges, wildflowers, other herbs, low-canopy trees, saplings, seedlings, fungi, mosses, and lichens. The presence of advance regeneration, that is, trees seedlings and saplings in position to replace high-canopy trees, frequently determines the capacity of the forest to reestablish following disturbance (Marquis 1994).

Measuring variables in the forest understory component is essential to understanding the overall condition of Pennsylvania's forest. The Pennsylvania Regeneration Study (PRS) was developed to address the need for more detailed information on understory status in addition to existing NRS-FIA data. The PRS is the only large-scale regeneration and understory health study that covers the entire Commonwealth in a systematic and consistent fashion.

The PRS was implemented in 2001 following an intensive pilot study to evaluate sampling protocols (McWilliams and others 2002). Measurements are conducted on NRS-FIA sample plots during the leaf-on season (McWilliams and others 2003). To date, 80 percent of PRS data plots have been measured. The data in this initial report provide an important baseline for future understory monitoring.

PRS measurements include a detailed tally of all tree seedlings down to a height of 2 inches and a survey of nontree vegetation. Data are analyzed using silvicultural guidelines for Pennsylvania (Marquis and others 1994). Sample plots are evaluated to gauge the capacity of advance tree seedling and saplings to regenerate the stand. Data on associated understory vegetation provide additional information on understory character and health.

PRS results are divided into five species groups. The high-canopy dominants species group comprises all species that currently contribute at least 2 percent of the total tree biomass in the State and that typically form a high canopy. The all high-canopy group includes all

species with the ability to form a high canopy. The commercially desirable group consists of species that are the most preferred in timber management. The all commercial group includes all commercial species that provide a merchantable crop. The all-tree species group comprises all tree species, including those that do not form a high-canopy forest, e.g., striped maple and dogwood. Nonnative, invasive species also are part of this group.

The only difference between the commercially desirable and high-canopy dominants groups is that black birch and beech are included in the latter group. The impact of these two species on the understory is noticeable in the results.

The percentage of sample plots adequately stocked with advance tree-seedling and sapling regeneration (ATSSR) is shown in Figure 56. Results include sample plots with sufficient sunlight for the establishment and development of advance regeneration (40- to 75-percent stocked). Stands in this stocking range account for 57 percent of Pennsylvania's forests, or about 1,600 samples.

Examining only species capable of producing a high-canopy forest, (high-canopy dominants and all high canopy), 48 percent of the sample plots contained

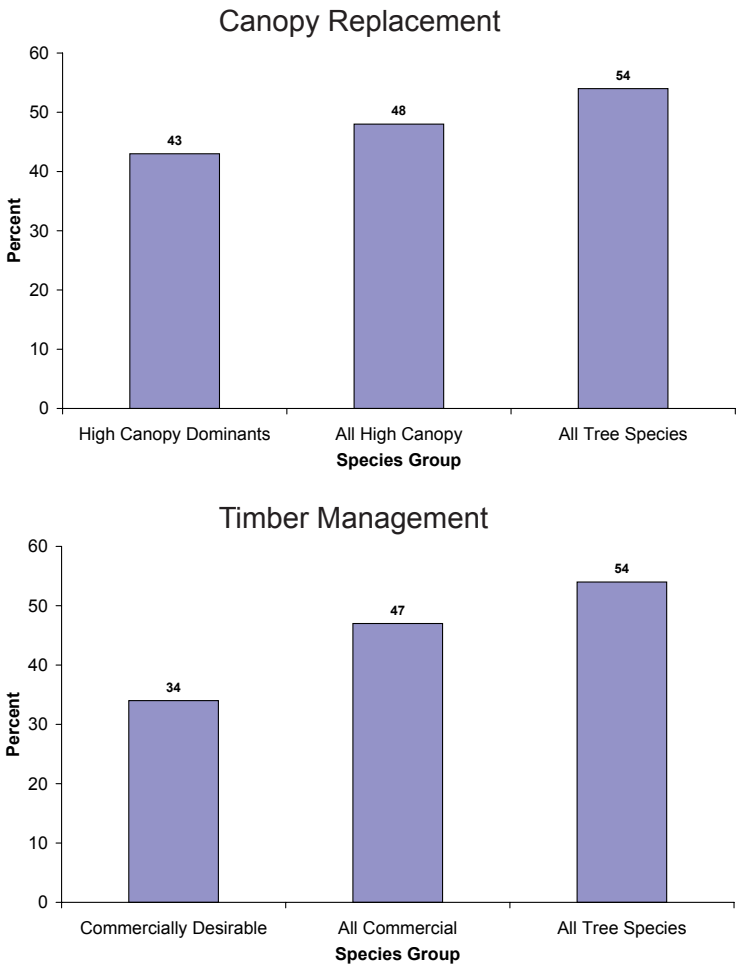

Figure 56.—Percentage of samples adequately stocked with advance tree seedling and sapling regeneration for samples 40- to 75-percent stocked, by species group and subgroup, Pennsylvania, 2004.

Rare wild azalea.

adequate advance regeneration. This means that only about half of the State's forests would regenerate to high-canopy status following significant overstory disturbance.

When all commercial species are examined (commercially desirable and all commercial), results are similar; 47 percent of the sample plots have adequate advance regeneration. When only the most desirable commercial timber species (commercially desirable group) are considered, only about 34 percent of the plots contain adequate advance regeneration.

Results by region for species that lead to canopy replacement are shown in Figure 57. Sample plots with adequate advance regeneration range from 40 to 54 percent. Results for only the most desirable commercial timber species are shown in Figure 58. The percentage of

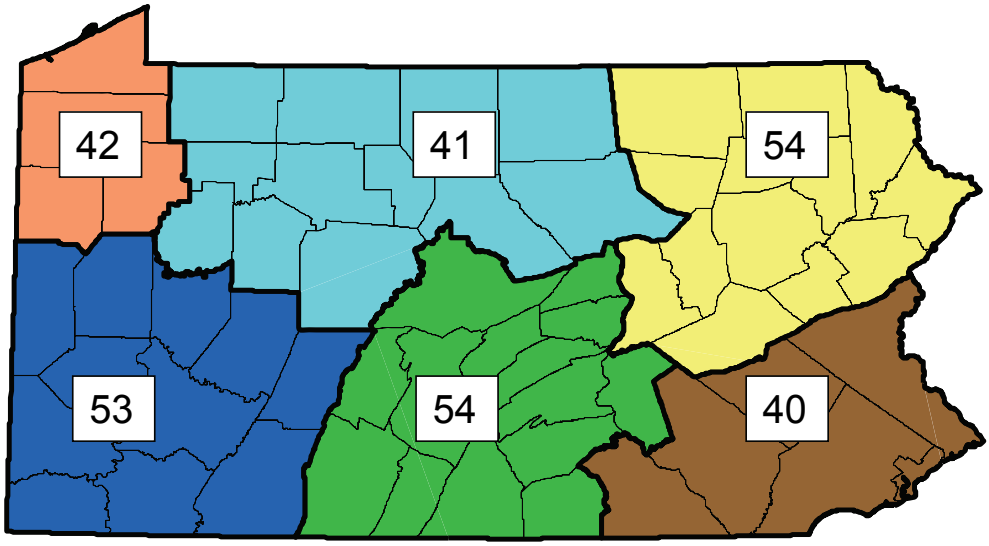

Figure 57.—Percentage of samples adequately stocked with advance tree seedling and sapling regeneration for canopy replacement species and samples 40- to 75-percent stocked, by ecopolitical region, Pennsylvania, 2004.

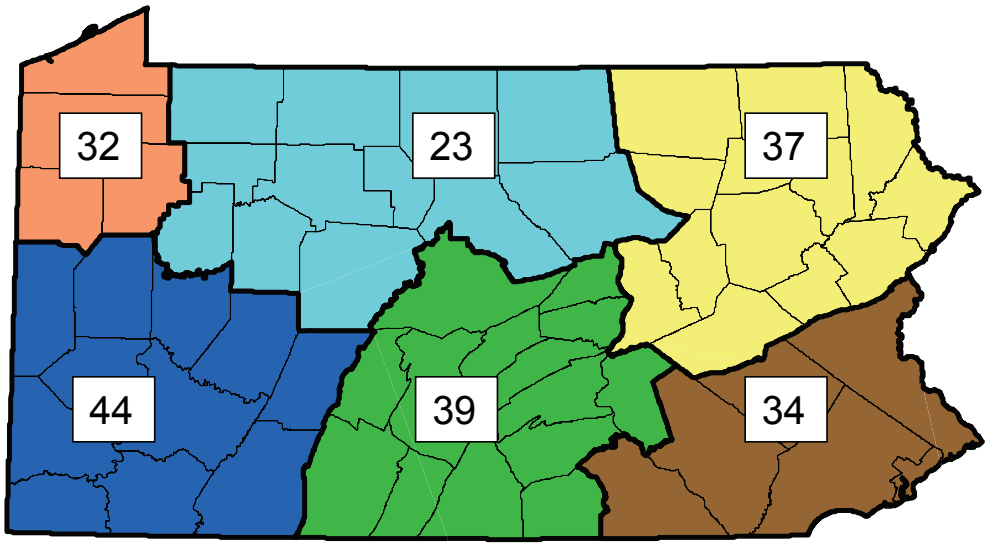

Figure 58.—Percentage of samples adequately stocked with advance tree seedling and sapling regeneration for desirable timber species and samples 40- to 75-percent stocked by ecopolitical region, Pennsylvania, 2004.

sample plots with adequate advance regeneration ranged from 23 percent in the north-central region to 44 percent in the southwestern region.

An important part of the PRS is measuring and monitoring nontree understory vegetation, such as shrubs, ferns, grasses, and other herbs. The understory composition for all stands can be described by ranking species/species groups by their contribution to the total vegetative cover sampled (Fig. 59). Grass/forb and rhizomous fern dominate understory communities, accounting for nearly one-third of the total vegetative cover sampled. Other common species include blueberry, *Rubus* spp., and mountain-laurel. Data collection for these understory communities is in the early phases. Future reports will include more thorough analyses.

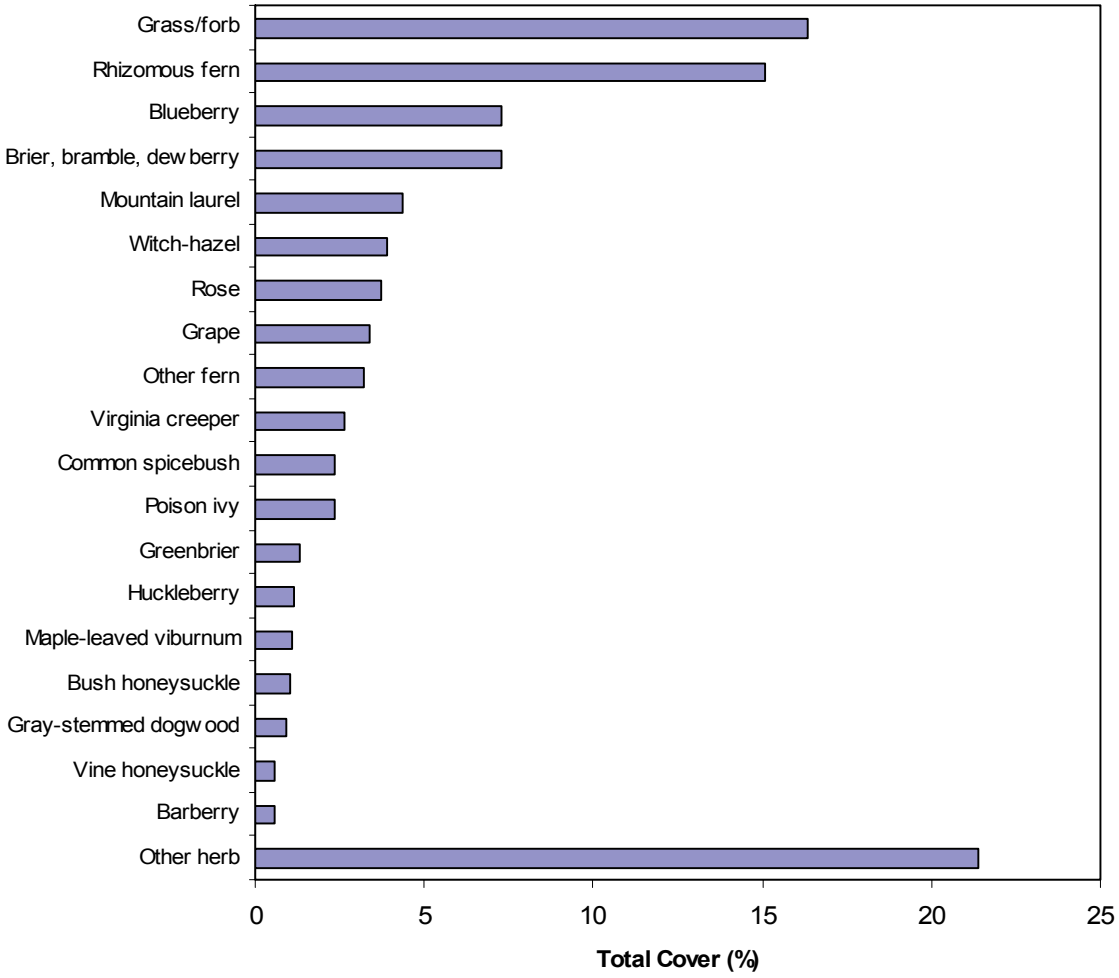

Figure 59.—Percentage of total cover by species/species group for top 20 species/species groups, Pennsylvania, 2004.

Dry oak-heath woodland (Fike 1999).

Gypsy-moth pupae.

CHAPTER 5: FOREST HEALTH

Forest health can be assessed at scales ranging from individual trees to entire landscapes. A healthy forest can renew itself, recover from disturbances, and retain ecological resiliency while meeting the current and future demands of people for products and services (USDA For. Serv. 2003).

The health and condition of forests are influenced by stressors that include drought, flooding, cold temperatures or freeze injury, nutrient deficiencies, soil properties, pollutants, insects and diseases, exotic and invasive species, and human disturbance. This chapter includes results for the forest-health indicators identified by NRS-FIA. Some of the data can serve as a baseline for future monitoring.

Drought, Insects, and Disease

Drought is a significant stressor that frequently precedes or contributes to the onset of major outbreaks of damaging insect pests and diseases. Seasonal or prolonged droughts are common in Pennsylvania. Since the 1989 NRS-FIA inventory, severe droughts have occurred in 1991-92, 1995, 1999, and 2002 (Fig. 60). Alternatively, some of the wettest years on record were in 1994 and 2003-2004. Storm damage due to wind, ice, and excessive precipitation can contribute

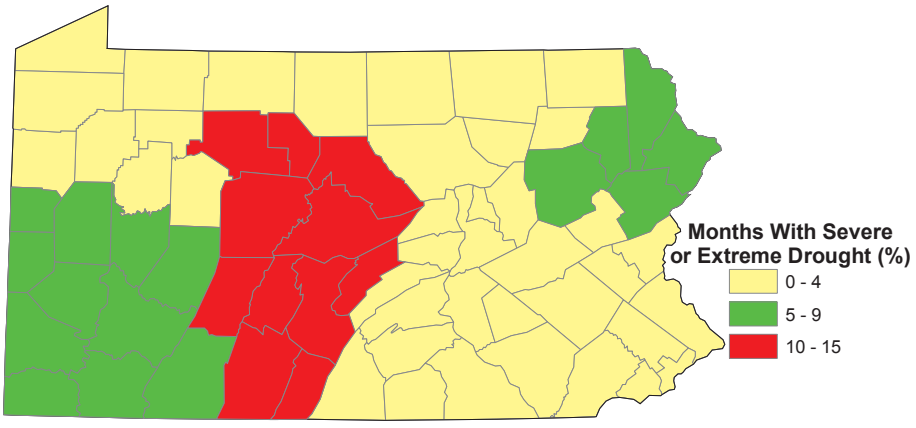

Figure 60.—Drought conditions in Pennsylvania, 1989-2005.
Source: http://www.cpc.noaa.gov/products/monitoring_and_data/drought.shtml

to disease outbreaks, and the initiation and collapse of insect outbreaks, and exacerbate damage associated with droughts.

Exotic insects, diseases, and invasive plant species threaten the productivity and stability of forest ecosystems around the world (Liebhold and others 1995; Vitousak and others 1996; Pimentel and others 2000). Invasions by alien species have resulted in a numerous direct and indirect effects at the community level, including changes in plant species diversity and richness, community structure, vegetation dynamics, and plant-animal interactions (McDonnell and Roy 1997).

Over the last century, Pennsylvania's forests have been damaged by well known exotic and invasive agents such as chestnut blight, gypsy moth, hemlock woolly adelgid, and beech bark disease (Mattson 1997). Insect pests and diseases, both native and exotic, continue to damage and kill trees, though most species have shown a decrease in the percentage of standing dead basal area since 1989 (Table 3), and tree crowns generally are healthy for most species across the State (Table 4). Only beech and eastern hemlock have more than 5 percent of the basal area showing crown dieback of at least 25 percent.

Certain tree species are facing additional risks from newly introduced insects and diseases. The following analysis by species highlights the major insects, diseases, and other stresses that threaten forest health in Pennsylvania.

Oaks

Insect defoliations have played an important role in shaping Pennsylvania's extensive oak forests. Recurring gypsy moth (*Lymantria dispar*) defoliations have affected every region by altering productivity, species composition, and stand structure. Gypsy moth has defoliated millions of acres each decade since 1975, according to the Bureau of Forestry (Figs. 61-62). Many areas, especially those threatened with repeated severe defoliation, were treated with aerial applications

Table 3.—Percentage of dead standing basal area for selected tree species, Pennsylvania, 1989 and 2004

	Dead standing basal area		
Species	1989	2004	Change
	----------*Percent*----------		
Black locust	28.1	24.9	-3.2
Beech	7.3	12.6	5.3
White pine	10.3	10.3	0.0
Chestnut oak	19.0	8.5	-10.5
White ash	12.1	7.1	-5.0
Northern red oak	10.0	6.5	-3.4
Black oak	14.3	6.2	-8.0
Sugar maple	4.8	6.2	1.4
Black birch	8.8	5.5	-3.3
Hemlock	5.0	5.4	0.4
Black cherry	6.1	5.2	-0.9
White ash	4.8	4.4	-0.4
Red maple	4.3	3.6	-.08
Yellow-poplar	1.6	2.1	0.6
Blackgum	2.2	0.9	-1.3

Table 4.—Percentage of basal area by crown-dieback category for selected tree species, Pennsylvania, 2004

	Basal area			
	0-20%	25-45%	50-95%	100%
Species	dieback	dieback	dieback	dieback
Beech	92.4	2.3	5.3	0.0
Hemlock	94.9	1.2	3.9	0.0
Black oak	95.5	4.1	0.4	0.0
White ash	95.6	3.9	0.5	0.0
Red maple	97.8	1.3	0.8	0.1
Black locust	98.2	1.2	0.6	0.0
Black cherry	98.5	0.8	0.6	0.0
White pine	98.7	1.3	0.0	0.0
White oak	98.8	0.0	1.2	0.0
Northern red oak	99.1	0.9	0.0	0.0
Sugar maple	99.2	0.7	0.2	0.0
Chestnut oak	99.4	0.4	0.2	0.0
Black birch	99.6	0.0	0.2	0.0
Yellow-poplar	100.0	0.0	0.0	0.0
Blackgum	100.0	0.0	0.0	0.0

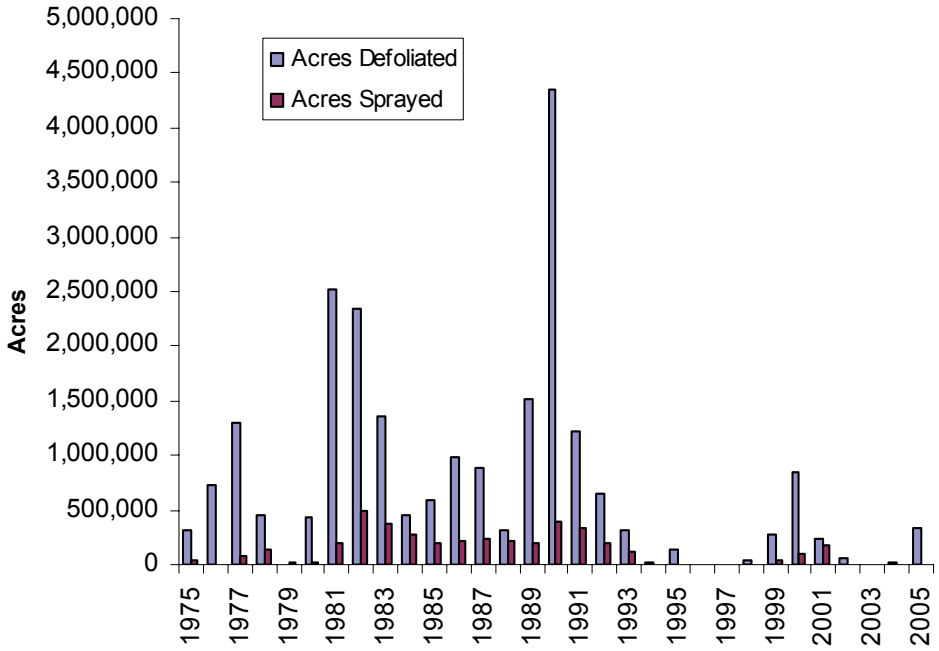

Figure 61.—Number of acres defoliated by and sprayed for gypsy moth, Pennsylvania, 1975-2005.

of insecticide, often the biological insecticide *Bacillus thuringiensis,* to avoid higher rates of tree mortality and decline. The influence of gypsy moth on oak mortality is evident from mapped estimates of percent standing dead basal area for each oak species (Fig. 63).

Widespread gypsy moth outbreaks in the 1970s and 1980's are reflected in the mean percentage of standing dead basal area from the 1989 inventory results. These percentages decreased in the current inventory and likely correspond with the decrease in gypsy moth defoliation, salvage harvesting, and natural tree fall.

Also causing significant defoliation are periodic outbreaks of oak leaftier (*Croesia semipurpurana*), oak leafroller (*Archips semiferana*), orange striped oak worm (*Anisota senatoria*), and walking stick (*Diapheromera femorata*).

A potential threat to the oak resource in Pennsylvania is sudden oak death (SOD) caused by the pathogen *Phytophthora ramorum*. Over the past 10 years, certain oak species in California and Oregon have been dying as a result of *P. ramorum*, which also causes leaf blight and shoot dieback on many other woody and nonwoody plant species. Surveys of nurseries and general forest communities were conducted in Pennsylvania in 2003-06 as part of efforts to detect *P. ramorum*. This pathogen has since been transported to several eastern states via infected ornamental nursery stock, specifically camellias, the source of inoculum from which introduced Rhododendron cultivars, native *Rhododendron,* and other susceptible horticultural and native hosts may be exposed. In 2006, several rhododendron plants exhibiting blight symptoms associated with *P. ramorum* were detected in a nursery in southeastern Pennsylvania. The infected and exposed plant materials were destroyed and a monitoring program near the infected nursery location was established. Should *P. ramorum* become established, the oak resource in association with understory hosts such as *Rhododendron*, *Vaccinium*, and *Kalmia* will be at risk. The occurrence of oak overstory, understory hosts, and their co-location are shown in Figure 64.

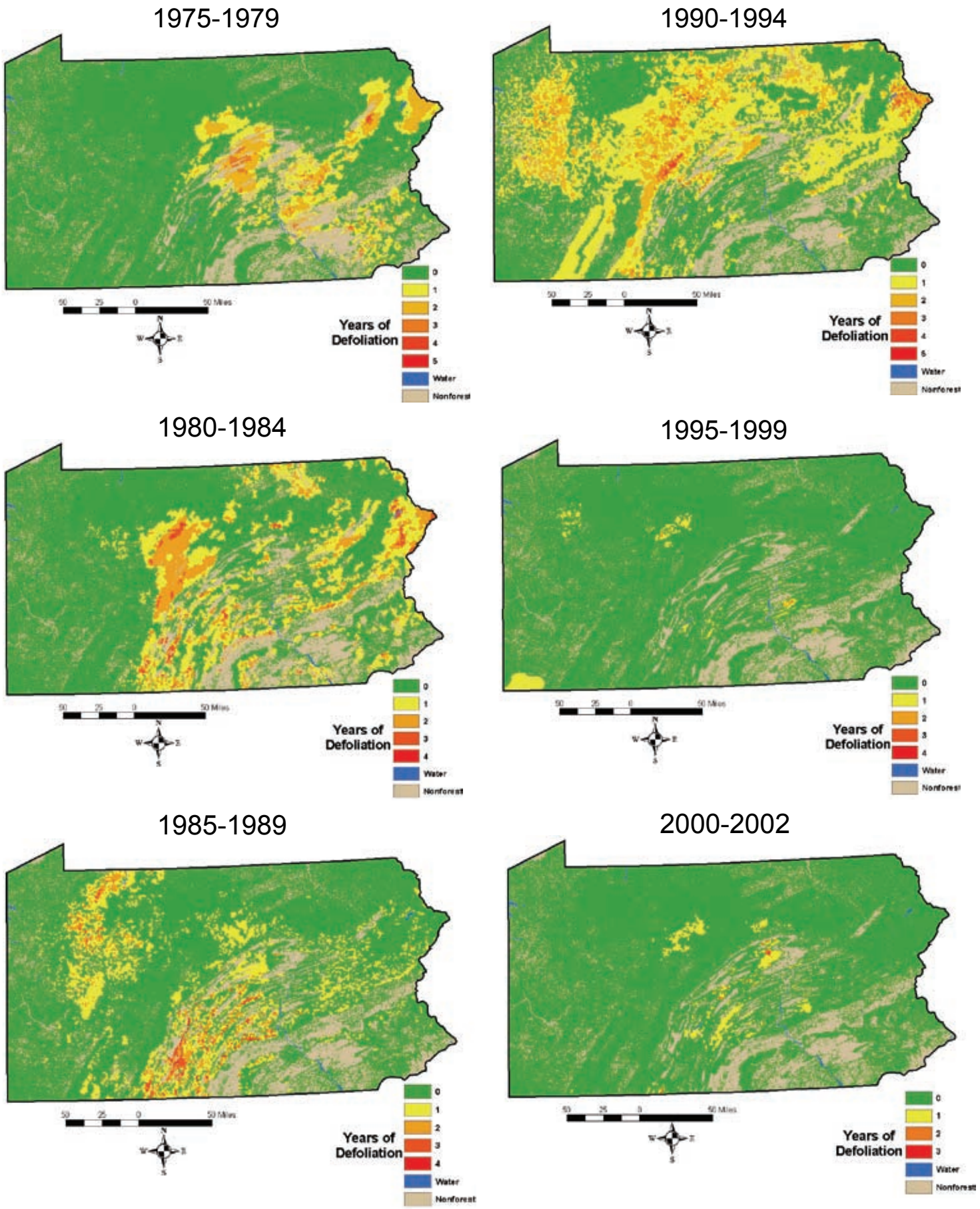

Figure 62.—Frequency of gypsy moth defoliation, Pennsylvania, 1975-2002.

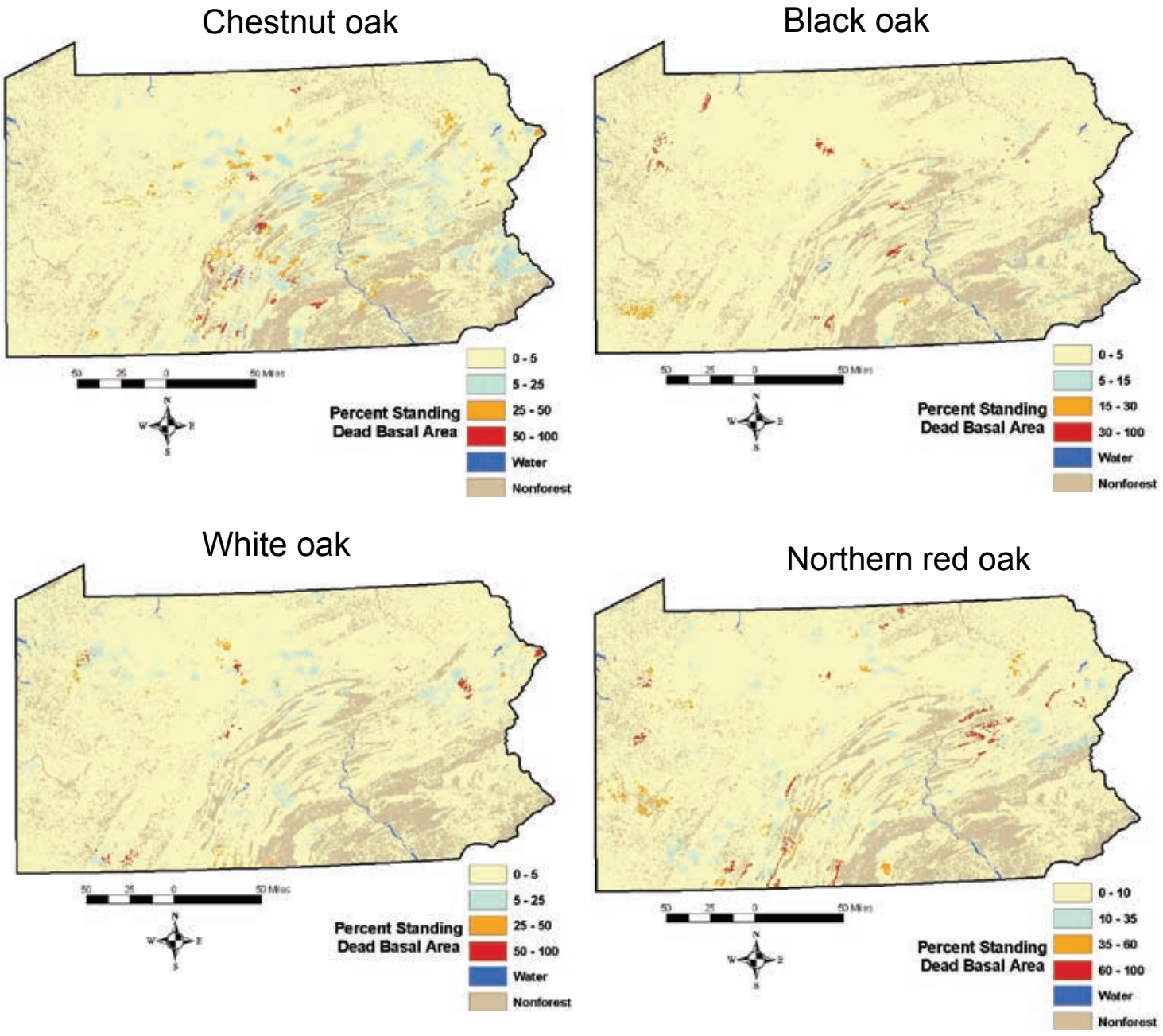

Figure 63.—Percent standing dead basal area, Pennsylvania, 2004.

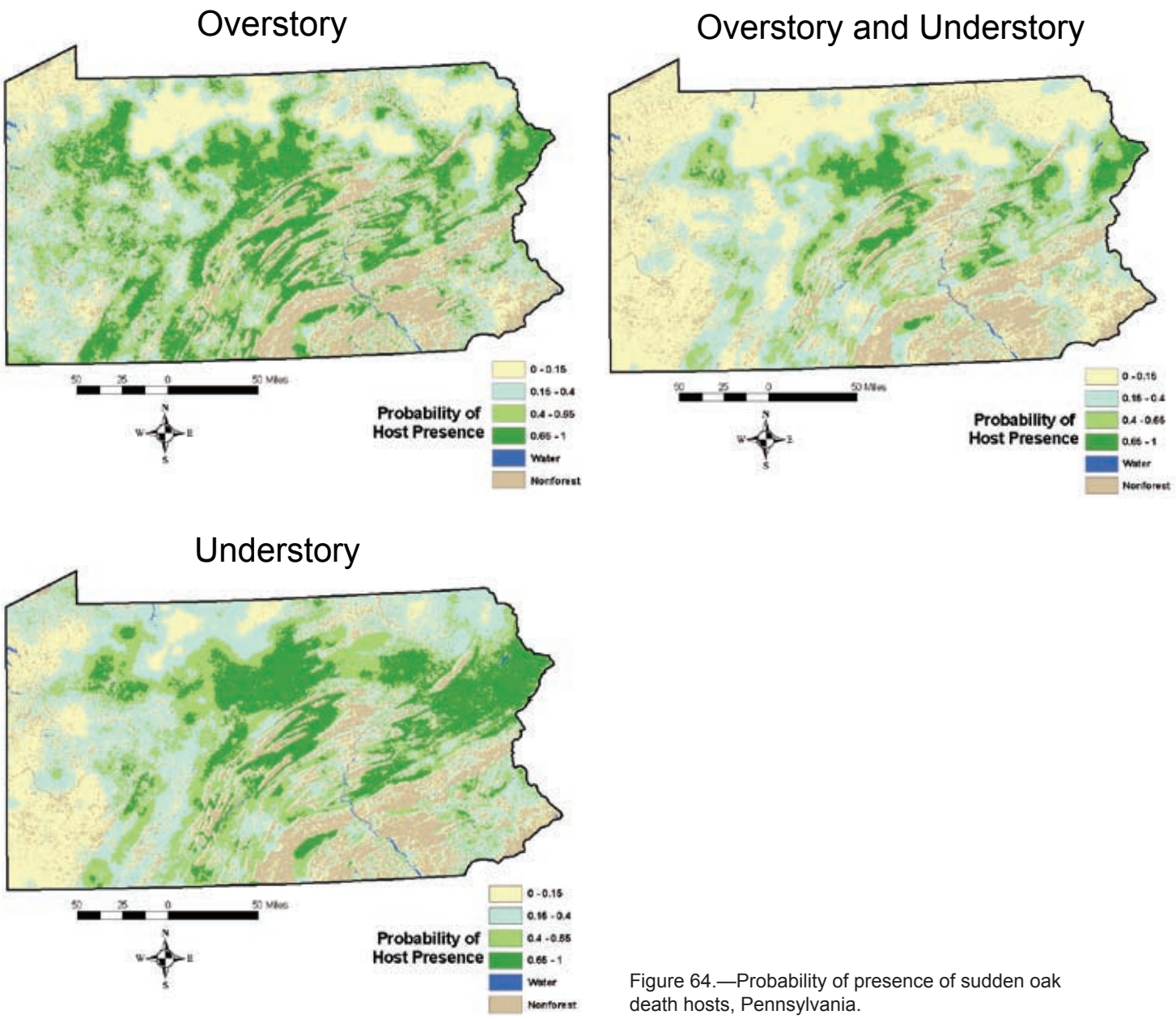

Figure 64.—Probability of presence of sudden oak death hosts, Pennsylvania.

Beech

Beech bark disease (BBD), which continues to spread slowly throughout Pennsylvania's forests is an insect-fungus complex involving the beech scale insect (*Cryptococcus fagisuga*) and the exotic canker fungus *Neonectria coccinea* var. *faginata* or the native *Neonectria galligena*. The scale insect creates small wounds in bark tissue that serve as entry points for the fungal pathogens. Small cankers may coalesce over time. As cankers become more numerous, the host tree is weakened and declines, and may die.

Three phases of BBD are recognized: 1) the advancing front, or areas recently invaded by scale populations; 2) the killing front, or areas where fungal invasion has occurred (typically 3 to 5 years after the scale insects appear but sometimes as long as 20 years) and tree mortality begins, and 3) the aftermath forest, or areas where the disease is endemic (Shigo 1972, Houston 1994).

In Pennsylvania, beech scale was first observed in 1958 at Promised Land State Park near Gouldsboro, PA. In 1969, bark cankers caused by *N. coccinea* were detected

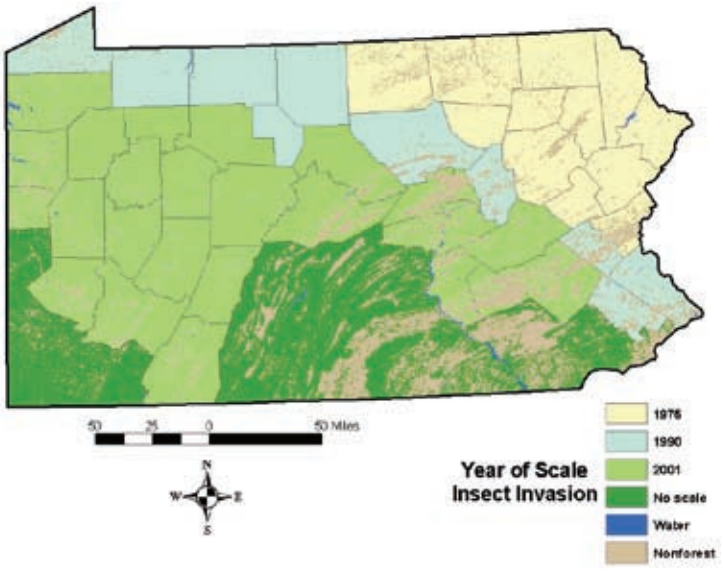

Figure 65.—Spread of the advancing front of beech-bark disease in Pennsylvania.

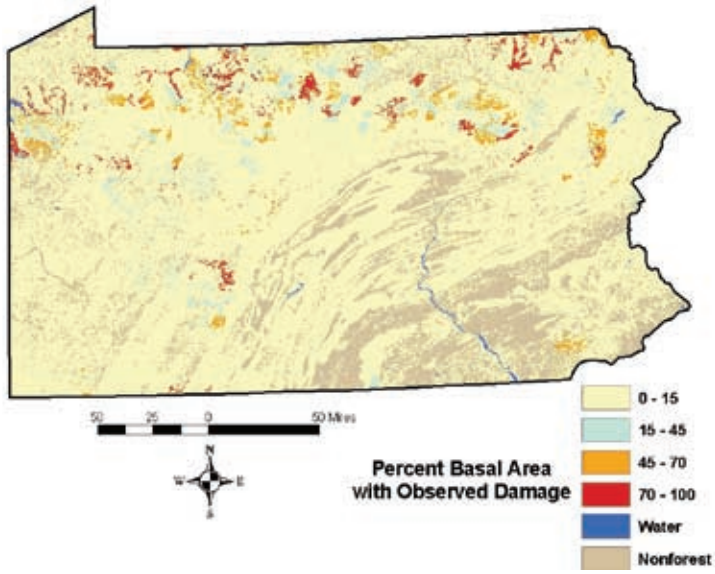

Figure 66.—Percentage of beech basal area with observed damage, Pennsylvania, 2004.

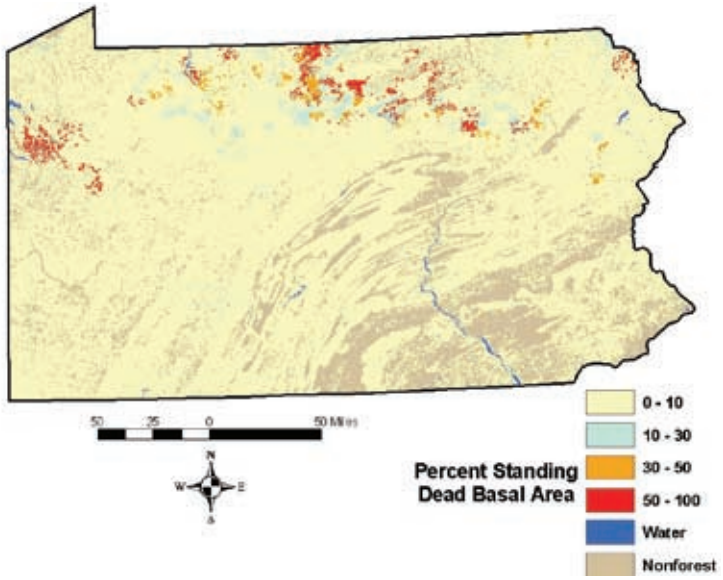

Figure 67.—Percentage of standing dead beech basal area, Pennsylvania, 2004.

west of the park. The advancing front has continued across the northern tier counties and is proceeding slowly in a southerly migration (Fig. 65). The killing front has advanced similarly as there are significant amounts of damaged and standing dead beech in much of the northern portion of the State. In fact, the amount of standing dead beech basal area has increased by 5 percent since the 1989 inventory. In the aftermath forest, many areas exhibit excessive root sprouting that creates a beech brush understory.

Other major stress factors associated with beech include the combined effects of drought and defoliation by elm spanworm (*Ennomos subsignanus*), gypsy moth, and fall cankerworm (*Asophila pomentania*). In the early and mid-1990s, these stressors along with BBD caused significant tree damage and mortality in the northern-tier counties (Figs. 66-67).

Sugar Maple

Since the mid-1990s, forest tent caterpillar (*Malacosoma americanum)*, fall cankerworm (*Alsophila pometaria*), and related insects have defoliated sugar maple to varying degrees across the Commonwealth. Cool, moist conditions in 1994 resulted in an outbreak of anthracnose (*Discula campestris*) on sugar maples and red maples previously damaged by the forest tent caterpillar and elm spanworm, respectively. Many trees that were defoliated by an insect pest in the spring of 1994 were severely damaged by anthracnose during the refoliation phase. The affected trees showed high levels of crown dieback and many died within 5 years.

A decline in the health of sugar maple stands throughout the unglaciated region of the Allegheny Plateau has been documented since the late 1970s. Researchers have been examining a variety of stress factors associated with the decline. Stressors that have been identified include poor availability of select base cations (e.g., calcium, aluminum, and manganese) in soil solution, excessive amounts of antagonistic cations (aluminum and manganese) that increase availability under acid soil conditions, and defoliation insects (Long and others 1997, Horsley and others 2000, 2002, Bailey and others 2004, 2005, Hallet and others 2006).

There are numerous damaged and standing dead sugar maple across the northern tier of Pennsylvania (Figs. 68-69). The percentage of standing dead sugar maple has increased slightly since the 1989 inventory. However, despite substantial decline in this species, many live sugar maple trees are healthy with little crown dieback.

Eastern hemlock

Many hemlock stands across Pennsylvania are vulnerable to two important insect pests. Elongate hemlock scale (*Fiorinia externa*), an exotic pest introduced from Japan and first observed in the Eastern United States in 1908, and hemlock woolly adelgid (HWA) (*Adelges tsugae*), an exotic pest introduced from Asia and first reported in the United States in 1951, cause significant foliage damage to

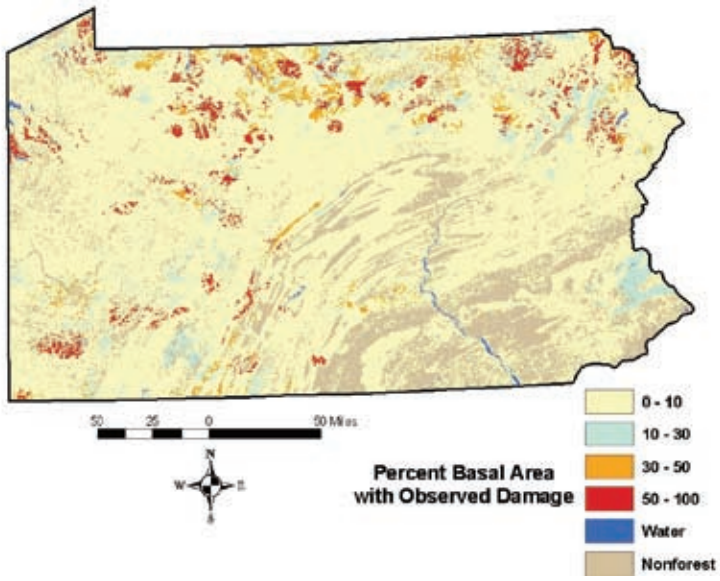

Figure 68.—Percentage of sugar maple basal area with observed damage, Pennsylvania, 2004.

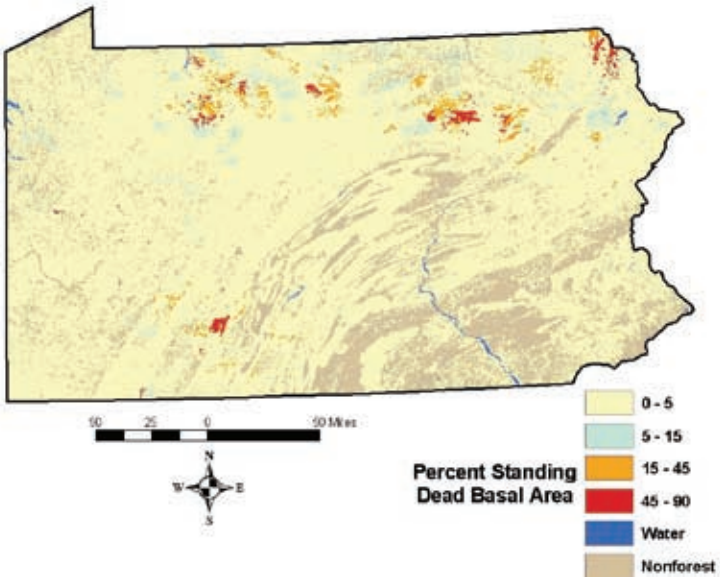

Figure 69.—Percentage of standing dead sugar maple, Pennsylvania, 2004.

Hemlock woolly adelgid. Forestry images.org. Pennsylvania Department of Conservation and Natural Resources.

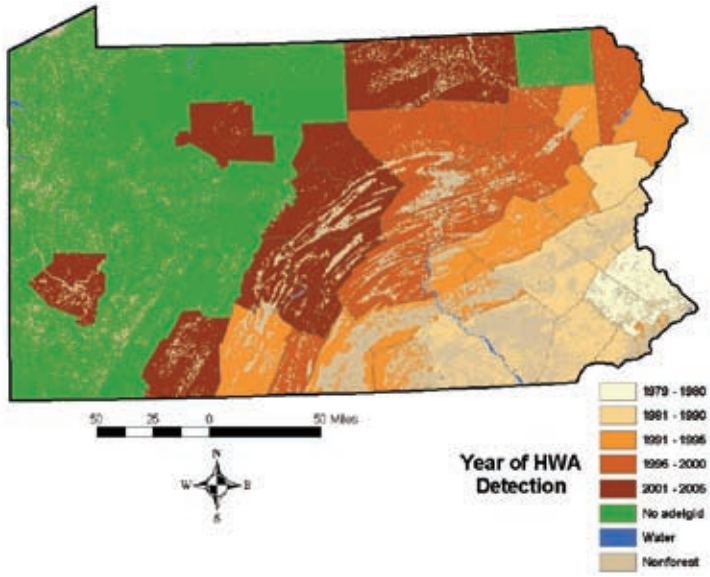

Figure 70.—Spread of hemlock woolly adelgid (HWA), Pennsylvania.

Emerald ash borer. Forestry images.org. David Cappaert.

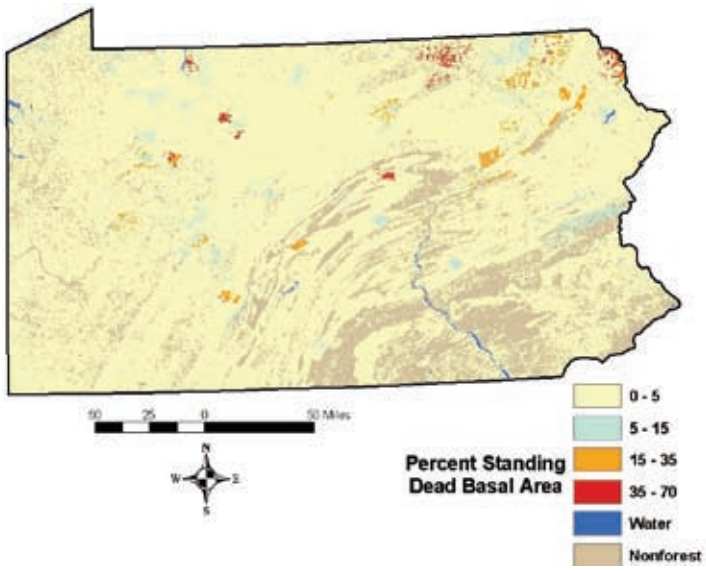

Figure 71.—Percentage of standing dead eastern hemlock, Pennsylvania, 2004.

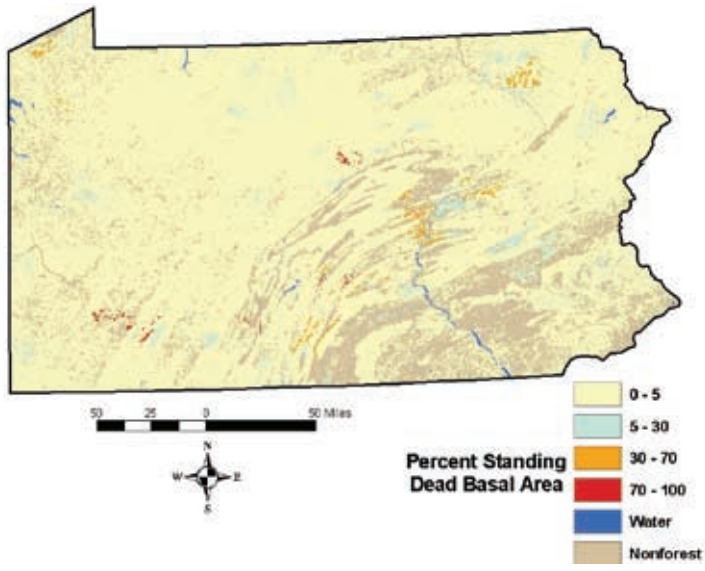

Figure 72.—Percentage of standing dead white ash, Pennsylvania, 2004.

hemlocks of all ages. In recent years, drought, insect infestations, and a needle blight disease (*Fabrella tsugae*) have been associated with needle cast, poor crown conditions, and tree mortality.

HWA has the greatest potential to cause significant mortality and threaten the sustainability of hemlock species. It was first detected in Pennsylvania in 1979 in Montgomery County and has since spread westward across the State (Fig. 70). Concentrations of mortality are evident across the northern half of the Commonwealth (Fig. 71).

Ash

The two major ash diseases in Pennsylvania are ash yellows (a *Phytoplasma* bacteria) and ash decline (a complex). Along with drought, these likely are responsible for most of the standing dead ash in the State (Fig. 72). A significant threat to all ash species in Pennsylvania is posed by the emerald ash borer (EAB) (*Agrilus planipennis*), an exotic insect pest first detected in Butler County in 2007. Monitoring plots were established in western Pennsylvania in 2005 and will detect the eventual spread of this pest, which causes ash mortality in both urban and forested landscapes.

Exotic-Invasive Plants

The range of exotic-invasive plants continues to expand across Pennsylvania. Much like other exotic-invasive organisms, these plants typically have some advantage over native plants, e.g., prolific seed production and dispersal. Native forest ecosystems have limited ability to compete with these invaders, which affect both canopy-dominant species and understory plant communities. Of primary concern is the impact of exotic-invasive plants on native forest composition, health, structure, function, resource productivity, and overall sustainability. These plants are especially threatening because little is known about the complex interactions between introduced invasive species and native systems, and because both data sources and monitoring are minimal to date.

Japanese stiltgrass, Valley Forge National Park.

In 2003, NRS-FIA added a list of exotic-invasive plants for collection on Pennsylvania Regeneration Study samples[1] to gain a better understanding of their distribution and impact on the forest ecosystem. The list was compiled by researchers with the Forest Service, Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry, The Nature Conservancy, Morris Arboretum, Pennsylvania State University, Pennsylvania Biodiversity Partnership, and Allegheny National Forest. The exotic-invasive plant survey covers 19 shrubs, 8 vines, 12 forbs and grasses (Fig. 73) along with Norway maple, tree-of-heaven, and other tree species.

Shrubs	Vines	Forbes and Grasses
Japanese barberry	Fiveleaf akebia	Garlic mustard
European barberry	Porcelain-berry	Spotted knapweed
Russian olive	Oriental bittersweet	Canada thistle
Autumn olive	English ivy	Bull thistle
Winged Euonymous	Japanese honeysuckle	Crown-vetch
Border privet	Mile-a-minute vine	Giant hogweed
Common privet	Kudzu	Purple loosestrife
Bell's honeysuckle	Common periwinkle	Japanese stilt grass
Amur honeysuckle		Reed canary grass
Morrow's honeysuckle		Common reed
Standish honeysuckle		Japanese knotweed
Tartarian honeysuckle		Giant knotweed
Common buckthorn		
Glossy buckthorn		
Multiflora rose		
Wineberry		
Japanese spiraea		
Linden viburnam		
Guelder rose		

Figure 73.—List of exotic-invasive shrubs, vines, and forbes/grasses sampled.

The exotic-invasive survey includes more than 500 sample plots across Pennsylvania. As additional data are collected, future reports will address questions related to the distribution of exotic-invasive plants species and their impact on the State's forests.

Tree-of-heaven under an oak canopy.

[1]Northeast invasive plants identification field guide (a compilation of online fact sheets), on file at Northern Research Station, Forest Inventory and Analysis, Newtown Square, PA.

Abundant understory exotics include multiflora rose, Russian/autumn olive, garlic mustard, Japanese stiltgrass, and bush honeysuckles. Data from established tree-inventory plots show that tree-of-heaven has expanded to the point where there is an average of one stem for every forested acre in the State. Tree-of-heaven stems have increased by about 80 percent since 1989. The distribution of tree-of-heaven based on detection at sample plots is shown in Figure 74. This species is most common in regions where the density of human population is high.

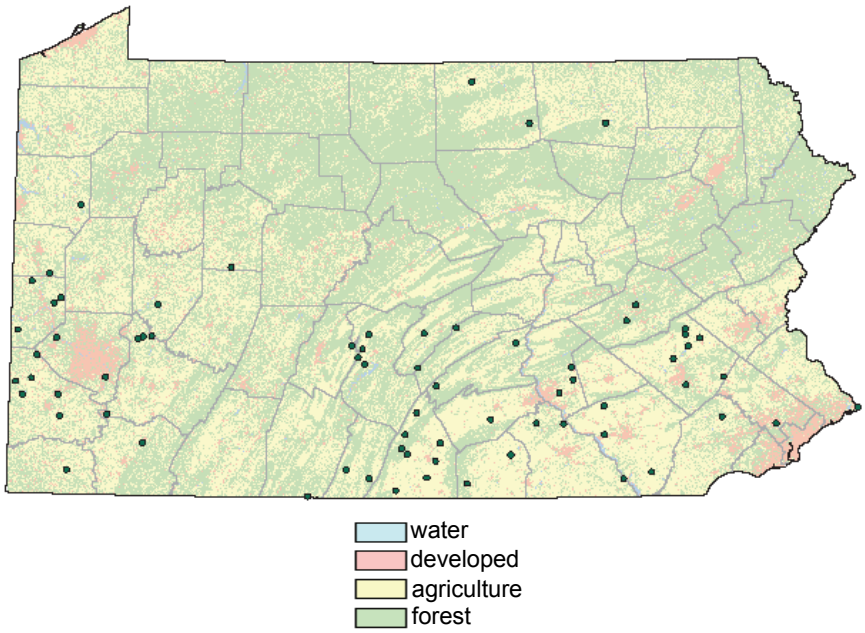

Figure 74.—Phase 2 sample plots with at least one tree-of-heaven, Pennsylvania, 2004.

Forest Soils

Soil is an important component of forest ecosystems and significantly influences productivity and species composition (Pritchett and others 2000). Forest soils are highly variable in physical and chemical properties. This is reflected in the variability of forest vegetation across the landscape. Inventorying and assessing forest soils provide critical baseline information on forest health and productivity and provide an opportunity to detect changes in soil nutrition.

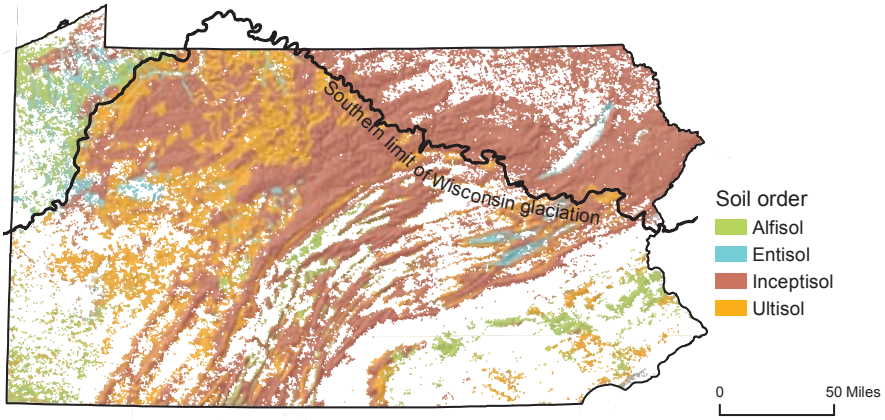

Figure 75.—Soil orders and limit of glaciation, Pennsylvania.

Pennsylvania's forests are largely underlain by inceptisols, ultisols, alfisols, and entisols (Fig. 75). Inceptisols are a diverse soil occurring across a range of climates and vegetative communities. They are characterized by the combination of water available to plants and the development of one or more soil horizons, but lack the noticeable movement of soil material, e.g., clay. Ultisols are characterized by the presence of an illuvial clay horizon and low base status. Both of these properties result from the movement of water through the soil profile, so these highly weathered soils with low native fertility typically are found in stable, older, unglaciated environments. Ultisols generally form under forests (Brady 1990).

Alfisols are fertile soils generally with an illuvial clay horizon and a base status that is medium to high (USDA Nat. Resour. Conserv. Serv. 1999). Most alfisols developed under deciduous forest (Brady 1990). Entisols are characterized by the absence of soil horizons, which may be the result of insufficient time for soil development or resistant parent material (USDA Nat. Resour. Conserv. Serv. 1999).

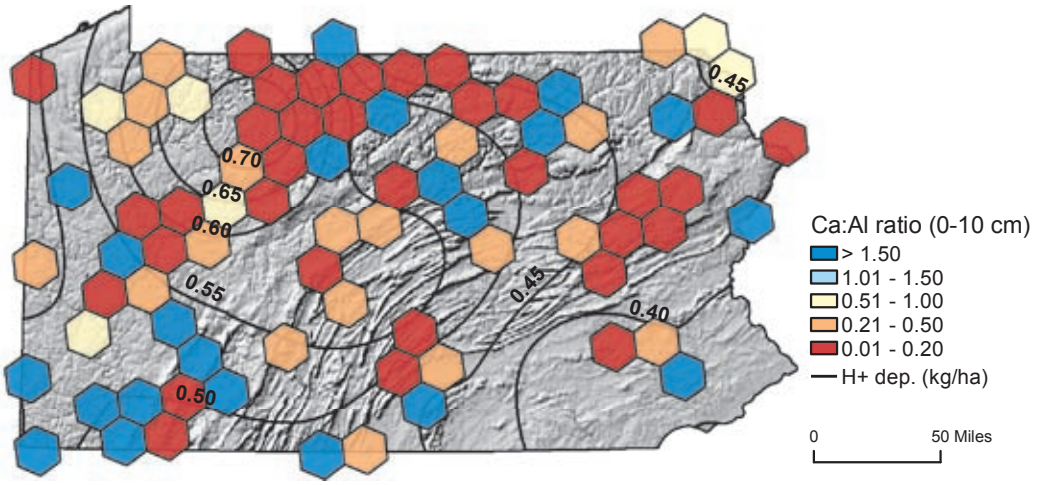

Figure 76.—Calcium:aluminum ratios, Pennsylvania, 2001-03. (Source: National Atlas of the USA; National Atmospheric Deposition Program; USDA Forest Service; U.S. Geological Survey)

Calcium/aluminum ratios closely follow observed patterns of acid deposition (Fig. 76). Pennsylvania receives some of the highest levels of acid deposition of any state, though there has been a downward trend over the past 10 years (Nat. Atmos. Deposition Prog. 2007) (Fig. 77). The deposition is heaviest in western Pennsylvania where much of the electricity is generated by coal-fired power plants (Fig. 78). An essential macronutrient, calcium is particularly important for plant structure (Marschner 1986). Acid deposition alters the interactions between critical soil minerals and has been linked to calcium leaching (Driscoll and others 2001). Toxic in high concentrations, aluminum is increasingly mobilized in these environments (Driscoll and others 2001, McBride 1994). The inhibition of root growth is one of the initial responses to aluminum toxicity (Marschner 1986). The lower the calcium/aluminum ratio (Fig. 76), the higher the amount of aluminum that is in the soil and thus a higher probability of tree stress or toxicity.

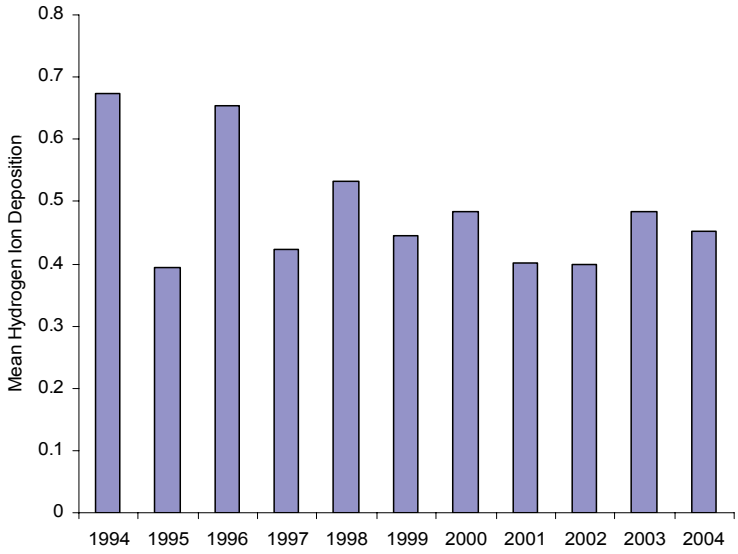

Figure 77.—Mean hydrogen wet deposition by year, Pennsylvania, 1994 to 2004.

The Soil Quality Index (SQI) combines the distinct physical and chemical properties of the soil into a single, integrative assessment.[2] Particular chemical or physical properties of the soil may be important for specific forest assessments, but the SQI combines 19 properties into a single value that describes overall soil health. As such, it facilitates the documentation of trends in forest health. Soil quality is average to above average in the unglaciated northeast and the developed alfisols of the southwest (Fig. 79). This is particularly apparent in the deeper soil (10 to 20 cm).

Lichens

Monitoring lichen communities can aid in assessing the impact of air pollution and identifying trends in biodiversity. There is a close relationship between lichen communities and air pollution, particularly acidifying

[2]Amacher, M.C.; O'Neill, K.P. Soil vital signs: a new index for assessing forest soil health. In preparation.

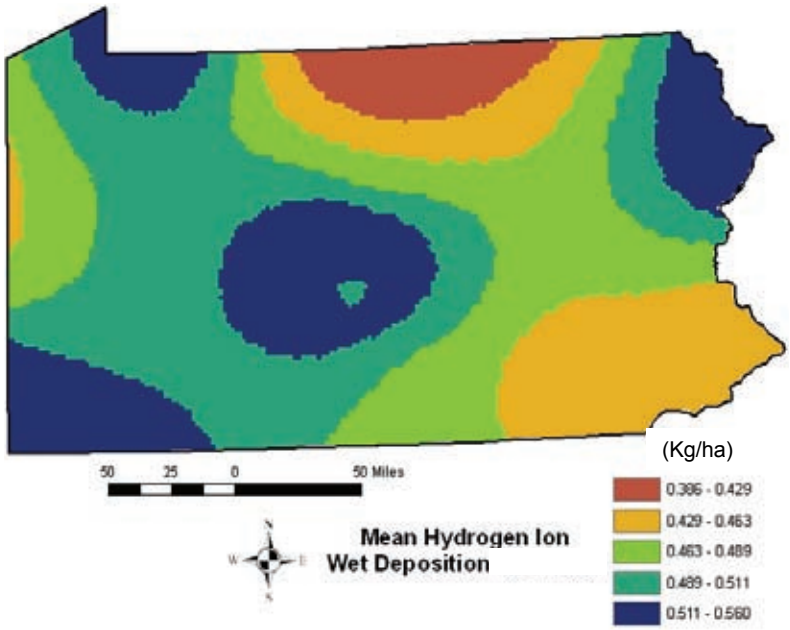

Figure 78.—Mean hydrogen wet deposition, Pennsylvania, 1994 to 2004.

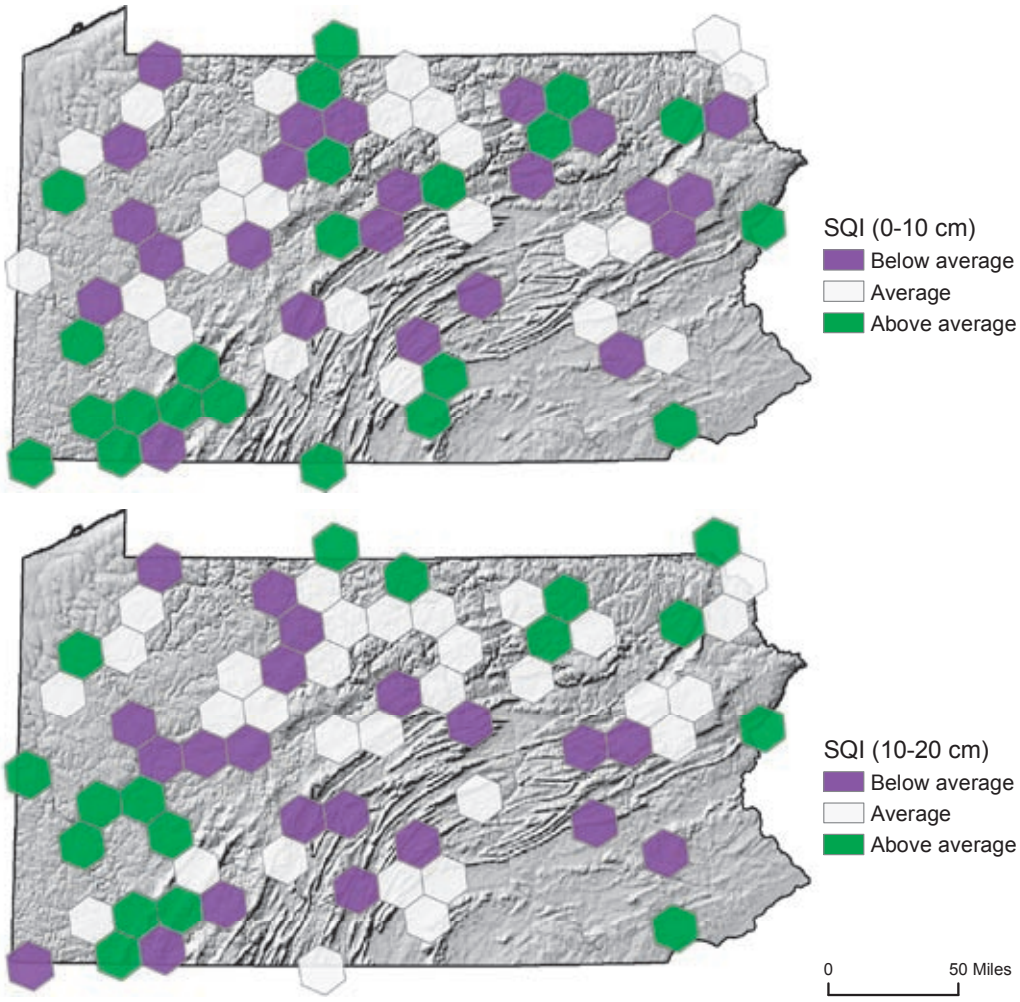

Figure 79.—Soil quality index (SQI) patterns, Pennsylvania, 2001-03.

Table 5.—Summary table for lichen communities, Pennsylvania, 2000-03

Number of plots surveyed	141
Number of plots by species richness category	
0-6 species (low)	80
7-15 species (medium)	60
16-25 species (high)	1
Median	6
Range of species richness score by plot (low-high)	1-22
Average species richness score per plot (alpha diversity)	6.3
Standard deviation of species richness score per plot	3.2
Species turnover rate (beta diversity)	16.7
Total number of species per area (gamma diversity)	81

Note: Beta diversity is calculated as gamma diversity divided by alpha diversity.

or fertilizing nitrogen- and sulfur-based pollutants. Lichens are ideal as indicators of air quality because they rely on the atmosphere for nutrition (McCune 2000).

Eighty-one lichen species in 34 genera were sampled on plots in Pennsylvania (Table 5). Although lichens are found on many substrates, e.g., rocks, sampling was restricted to standing trees or recently fallen branches and twigs. The most common lichen genera, *Punctelia* and *Physcia*, were present on nearly 15 percent of the plots (Table 6). Of the species sampled, the most (14) were in the genus *Cladonia*.

Species diversity is used to describe the number of different species present in an area and the distribution of individuals among species. The easiest way to measure species diversity is to count the number of species at a site. The resulting value, species richness, does not provide a complete picture of diversity in an ecosystem because it ignores abundance. Richness values were low to medium across Pennsylvania. Mean species richness of the mixed oak forest-type group was slightly higher than that of the northern hardwoods group; the mean for both groups was considerably higher than for softwood types (Table 7).

Table 6.—Percentage of specimens and number of species for lichen genera sampled, Pennsylvania, 2000-03

Genus	All specimens	All species
Punctelia	14.7	5
Physcia	14.6	6
Phaeophyscia	12.6	3
Cladonia	12.2	14
Parmelia	11.8	4
Flavoparmelia	11.1	3
Myelochroa	4.3	4
Cetraria	3.4	2
Melanelia	2.5	2
Hypogymnia	2.4	2
Candelaria	1.8	2
Parmotrema	1.4	4
Flavopuctelia	1.0	2
Pyxine	0.9	2
Imshaugia	0.7	1
Physconia	0.5	1
Hypotrachyna	0.4	2
Parmelinopsis	0.4	2
Bulbthrix	0.3	1
Heterodermia	0.3	3
Physciela	0.3	1
Usnea	0.3	2
Anaptychia	0.2	1
Bryoria	0.2	1
Canoparmelia	0.2	1
Hypocenomyce	0.2	1
Lobaria	0.2	2
Evernia	0.1	1
Hyperphyscia	0.1	1
Menegazzia	0.1	1
Parmeliopsis	0.1	1
Pseudevernia	0.1	1
Rimelia	0.1	1
Umbilicaria	0.1	1
Total	100.0	81

Table 7.—Number of FIA Phase 3 plots and richness and diversity scores for lichen species by broad forest-type group, Pennsylvania, 2000-03

Broad forest-type group	Number of plots	Richness	Diversity
Softwoods	12	4.1	1.3
Mixed oak	63	6.9	1.8
Northern hardwoods	62	6.3	1.7

Lichen species richness also increased with stand size (Table 8). The mean number of lichen species was lowest for small stands and higher for large stands, which reflects the lag time for lichen recolonization after harvest or disturbance. The spatial distribution of lichen species-richness scores are shown in Figure 80. Species richness generally is higher in central Pennsylvania. The richness and diversity scores reported here will serve as baseline estimates for future monitoring at the state and regional levels.

Due to the sensitivity of many lichen species to airborne pollution, it is useful to examine levels of acid deposition. Showman and Long (1992) reported that mean species richness for lichens was significantly lower in areas where sulfate deposition is high than in low-deposition areas as found in north-central Pennsylvania. Levels of sulfate deposition have been relatively high in the Commonwealth and surrounding states in recent years (Fig. 81). Estimated lichen species richness in the Northeastern United States in 2000-03 and the location of pollution-sensitive lichen species in Pennsylvania are shown in Figures 82 and 83, respectively.

Ground-Level Ozone Injury

Ozone (O_3) biomonitoring is used to monitor the potential impact of tropospheric O_3 (smog) on forests. O_3 pollution is a byproduct of industrial processes that facilitate the production and accumulation of O_3 which forms when nitrogen oxides and volatile organic compounds react in the presence of sunlight (Brace and others 1999). Ground-level O_3 pollution might reduce tree growth, alter species composition, and predispose trees to attack by insects and disease.

Certain plant species exhibit visible, easily diagnosed foliar symptoms of O_3 stress and thus are as important indicators of O_3 pollution. A national system of monitoring sites is used to asses the impact of O_3 on forests (Smith and others 2003b).[3] These sites are not

[3]Smith, G.C.; Smith, W.D.; Coulston, J.W. Statistics band sampling and estimation document; ozone indicator. In preparation.

Table 8.—Number of FIA Phase 3 plots and richness and diversity scores for lichen species by stand-size class, Pennsylvania, 2000-03

Stand-size class	Number of plots	Richness	Diversity
Small	12	4.1	1.3
Medium	63	6.9	1.8
Large	62	6.3	1.7

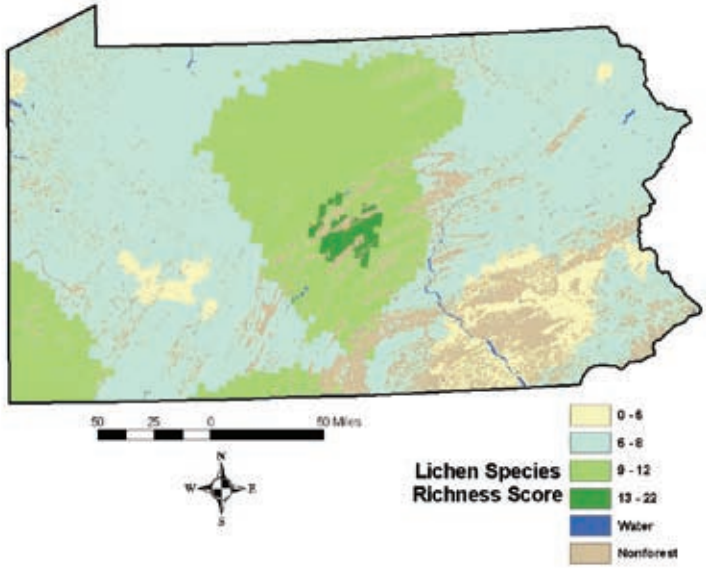

Figure 80.—Estimated lichen species richness, Pennsylvania, 2000-03.

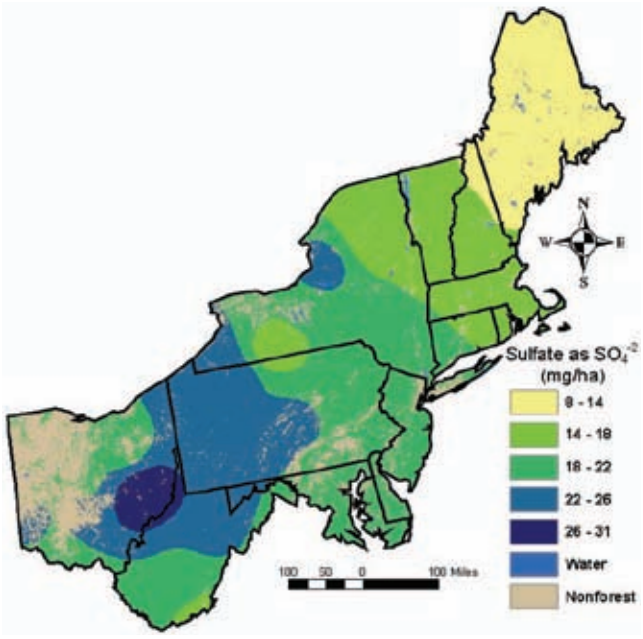

Figure 81.—Mean sulfate ion wet deposition, 1994 to 2002, Northeastern United States (source: USDA Forest Atmospheric Deposition Program).

co-located with NRS-FIA samples. O_3 plots are chosen for ease of access and optimal size, species, and plant counts. As such, O_3 plots do not have set boundaries and vary in size. At each plot, 10 to 30 individual plants of three or more indicator species are evaluated for O_3 injury. Each plant is rated for the proportion of leaves with O_3 injury and the mean severity of symptoms, using break points that correspond to the human eye's ability to distinguish differences. A biosite index is calculated based on amount and severity ratings.

O_3 plot data from 1998 to 2004 (Table 9) show a high degree of year-to-year variation. Twenty-eight percent of the sampled plants showed symptoms of O_3 injury in 1998, though most of the injury was on less than 25 percent of the foliage. By contrast, less than 10 percent of the sampled plants showed symptoms in 2002, and less than 5 percent showed symptoms in 1999, 2001, 2003, and 2004. It should be noted that O_3 injury is influenced by soil moisture. Moist conditions facilitate the entry of O_3 into leaves during the growing period; dry conditions tend to block O_3 entry into leaves.

The number of plants sampled by species is shown in Table 10. Blackberry had the highest occurrences of O_3 damage, with 55 percent of sampled plants showing symptoms of damage in 1998 versus less than 25 percent in other years. Nearly 30 percent of the black cherry plants sampled showed injury symptoms in 1998, but less than 10 percent showed symptoms between

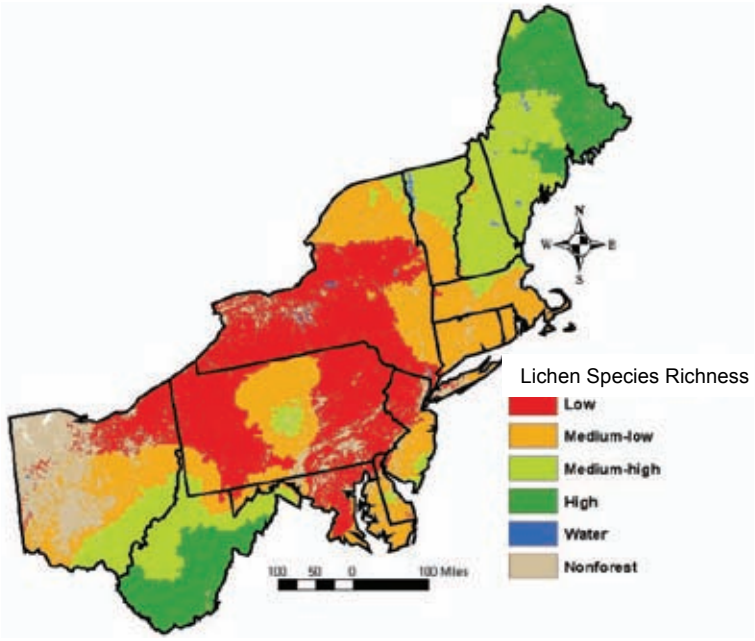

Figure 82.—Estimated lichen species richness, Northeastern United States, 2000-2003.

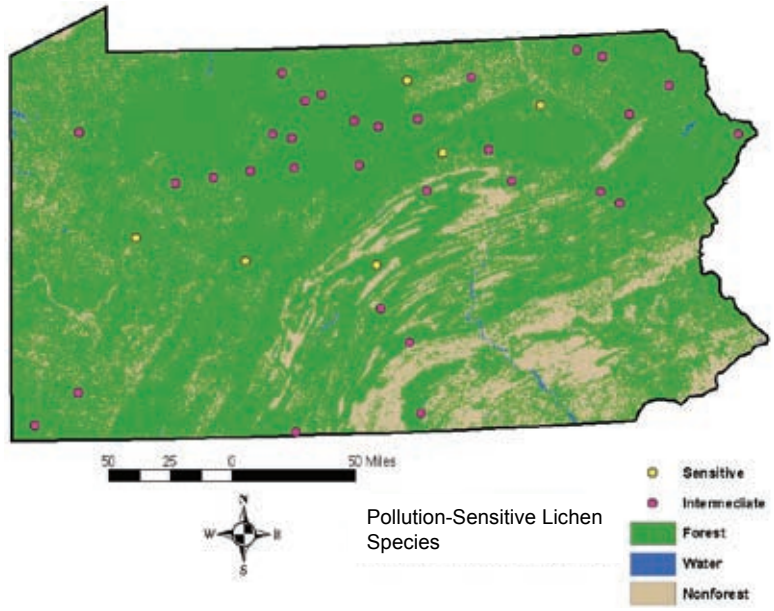

Figure 83.—Presence of pollution-sensitive lichen species, Pennsylvania, 2004.

Table 9.—Percentage of sampled plants with ozone injury, Pennsylvania, 1998-2004

Year	No. plots evaluated	No. plots sampled	Sampled plants (%)					
			No injury	1-6% leaf injury	7-25% leaf injury	26-50% leaf injury	51-75% leaf injury	76+% leaf injury
1998	96	2,285	71.6	7.4	8.6	6.4	3.7	2.4
1999	122	6,719	98.0	0.5	0.9	0.4	0.1	0.1
2000	95	7,117	89.5	3.3	3.2	1.7	1.6	0.7
2001	98	10,487	96.4	0.8	1.1	1.0	0.6	0.2
2002	40	5,040	92.1	1.7	2.9	1.9	1.2	0.2
2003	42	10,372	98.2	0.8	0.8	0.1	0.1	0.0
2004	40	4,493	96.3	2.5	0.6	0.3	0.2	0.0

Note: Rows and columns may not add to 100 due to rounding.

Table 10.—Number of plant specimens examined (percentage injured in parentheses), by selected species, Pennsylvania, 1998-2004

Species	1998	1999	2000	2001	2002	2003	2004
Big leaf aster	0 (0)	218 (0)	13 (0)	105 (0)	0 (0)	180 (0)	30 (0)
Black cherry	254 (29)	1,117 (2)	1,207 (6)	2,041 (3)	1,093 (7)	2,216 (1)	960 (3)
Blackberry	717 (54)	842 (6)	1,303 (25)	1,763 (13)	974 (20)	2,028 (1)	937 (4)
Milkweed	837 (13)	1,810 (1)	1,640 (8)	1,900 (1)	824 (10)	1,970 (4)	738 (13)
Pin cherry	16 (0)	19 (0)	0 (0)	25 (0)	30 (0)	124 (0)	30 (0)
Sassafras	39 (0)	452 (0)	661 (7)	1,034 (0)	412 (0)	980 (0)	432 (1)
Spreading dogbane	286 (0)	1,456 (0)	1,024 (2)	1,830 (0)	692 (6)	1,056 (2)	360 (0)
White ash	88 (36)	775 (0)	975 (8)	1,383 (3)	875 (1)	1,434 (1)	789 (1)
Yellow-poplar	48 (19)	60 (0)	294 (1)	406 (0)	140 (1)	384 (1)	217 (4)

1999 and 2004. Damage was minimal to other species sampled except in 1998 when more than one-third of the sampled white ash and nearly 20 percent of the yellow-poplar showed injury symptoms. Even for species with high occurrences of O_3 injury, severity was low.

A large portion of Pennsylvania, particularly in the central part of the State, has a moderate to high risk of O_3 damage. The biosite index in Figure 84 was created using block kriging, a geospatial mapping procedure, to determine which tree species in the Northeastern United States are sensitive to O_3 (Coulston and others 2003).

A typical pattern of O_3 in summer for the Northeastern United States is shown in Figure 85 (USDA For. Serv. 2002a). The term SUM06 is defined as the sum of all valid hourly O_3 concentrations that equal or exceed 0.06 part per million. Controlled studies have found that high O_3 levels (shown in orange and red) can lead to measurable growth suppression in sensitive tree species (Chappelka and Samuelson 1998). Smith and others (2003) reported that even when ambient O_3 exposures are high, the percentage of injured plants can be reduced sharply in dry years. Differences in the amount of O_3 injury between years are more likely due to precipitation levels than to ambient O_3 exposure levels.

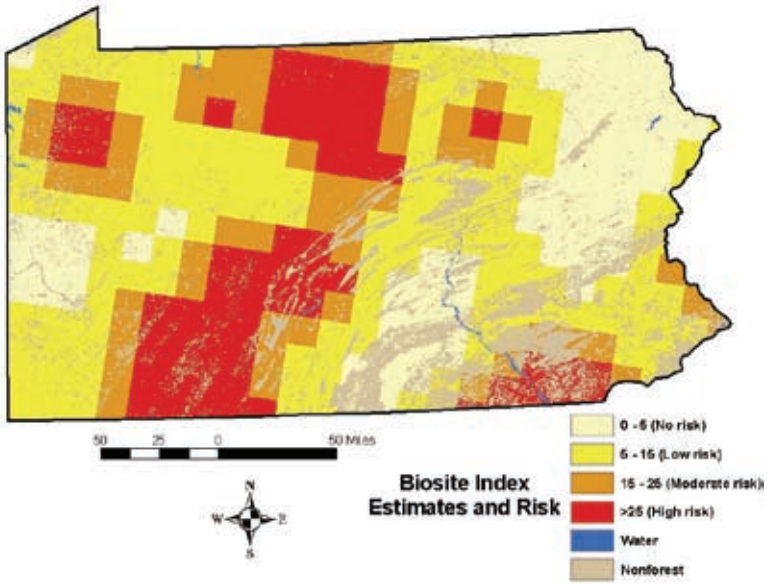

Figure 84.—Estimated surface of ozone biosite index, Pennsylvania (Coulston and others 2003).

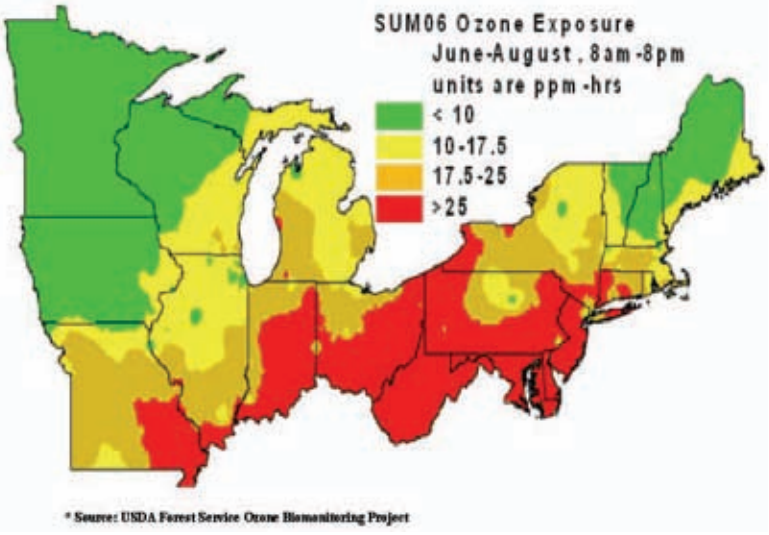

Figure 85.—Typical ozone exposure rates in the Northeastern United States (source: USDA Forest Service, Biomonitoring Project).

FOREST CARBON

Forest land accounts for a significant portion of carbon (C) sequestered in terrestrial ecosystems. The net accumulation of C in forests partially mitigates the increase in carbon dioxide in the atmosphere. The exchange of C between the atmosphere and forests is affected by photosynthesis, growth, mortality, decomposition, disturbances such as fires or pest outbreaks, weather, and edaphic processes, as well as anthropogenic activities such as harvesting, thinning, clearing, and replanting.

Carbon is sequestered in growing trees, principally as wood (as cellulose, hemicellulose, and lignin) in the tree bole. Accrual in forest ecosystems also depends on the accumulation of C in dead wood, litter, and soil organic matter. When wood is harvested and removed from the forest, not all C flows immediately to the atmosphere. The portion of harvested C sequestered in long-lasting wood products or landfills may not be released to the atmosphere for years or even decades. Thus, C stored in harvested wood products is an important part of complete accounting of forest C.

Carbon Estimates

Estimates are first developed as stocks, or total mass of C for a defined area and component of the forest ecosystem. Six ecosystem C pools and two pools of C remaining in harvested wood products are used to segment estimates. Forest structure provides a convenient modeling framework for assigning C to distinct forest-ecosystem pools: live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic C. These pools are consistent with guidelines developed by the Intergovernmental Panel on Climate Change. The fate of C in harvested wood is summarized as C remaining in products in use or in landfills.

American chestnut down woody material.

With the exception of soils, forest-ecosystem C stocks are based on the individual C pool estimators in FORCARB2, a forest C accounting model (Heath and others 2003, Smith and others 2004, 2007). FORCARB2 is essentially a national empirical simulation and C accounting model that produces stand level inventory-based estimates of C stocks.

Estimates of C sequestered in wood products depend on information on the quantities of wood harvested and processed every year. Each end-use product can be characterized according to its expected lifespan and ultimate disposal of the product. Carbon that does not remain in products in use or in landfills is emitted to the atmosphere. The amount of C emitted depends on the initial quantity harvested, characteristics of the wood products, and time since harvest and initial processing.

Thus, C stocks and net annual flux of C in wood products are subject to continuous change over time.

Carbon Stocks

The distribution of C stocks by ecosystem pool for 1989 and 2004 is shown in Figure 86. Live trees and forest floor/soils account for 48 percent and 45 percent of total C, respectively. Standing dead, downed dead, and understory vegetation make up the remaining C stocks. Average C density for live trees on forest land in the Northeastern United States and Pennsylvania is shown in Figure 87.

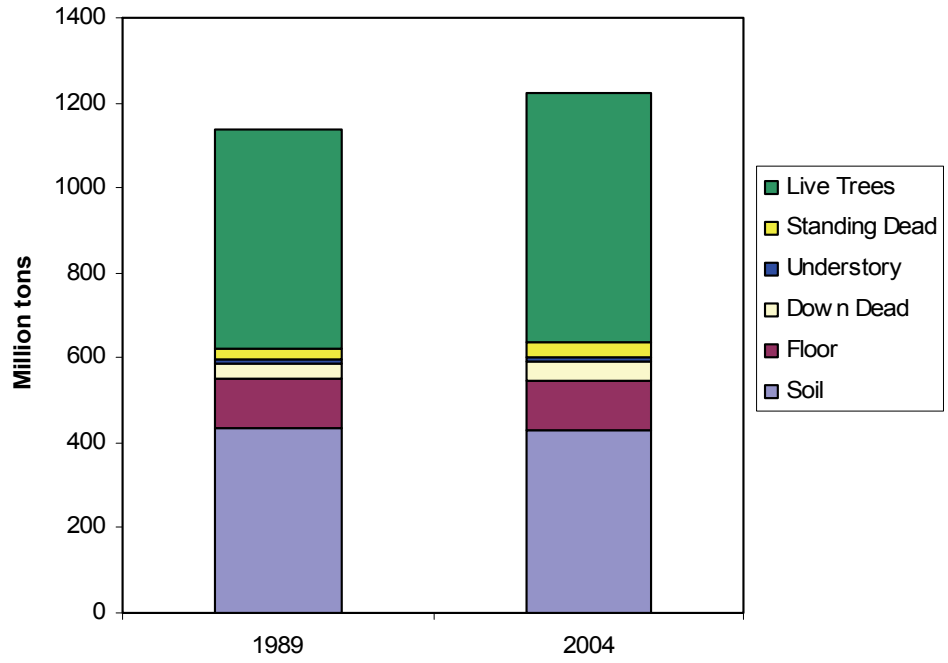

Figure 86.—Carbon (total tons) by forest ecosystem pool, Pennsylvania, 1990 and 2004.

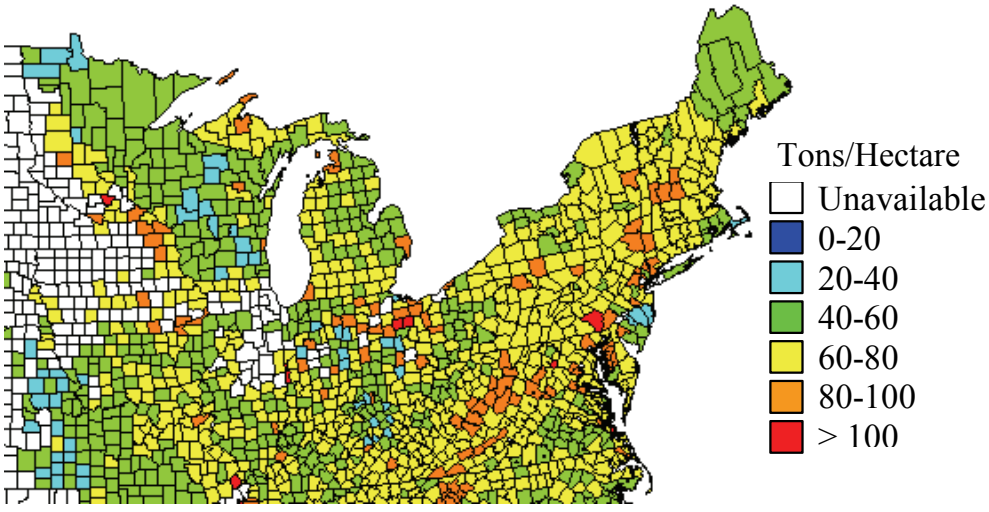

Figure 87.—Carbon density for live trees on forest land by county, Northeastern United States.

Oak regeneration within a deer fence.

CHAPTER 6: SUSTAINABILITY ISSUES AND KNOWLEDGE GAPS

This report has focused on a range of data and indicators concerning the condition of Pennsylvania's forests. This chapter highlights key findings related to forest sustainability and also identifies important knowledge gaps associated with the existing NRS-FIA inventory data. This information is provided to aid management and policy decisions, and to improve and enhance future analyses.

Changing Forest Land Base

Although Pennsylvania's forest-land base is stable at 16.6 million acres, the impact of urbanization, parcelization, and fragmentation poses a serious threat to forest sustainability in certain regions of the Commonwealth. Since 1989, the State has lost 663,000 acres of forest land, with nearly two-thirds of this loss—or 28,000 acres a year—to some type of development. Urbanization, parcelization, and fragmentation generally result in permanent changes to the landscape that adversely affect forest character, biodiversity, ecosystem function, and resource availability.

The statewide forest-land base appears stable because nearly 350,000 acres of agricultural land shifted into it. This block of land periodically shifts back and forth between forest and nonforest. Often, abandoned pasture with sufficient stocking of young tree needs only be mowed to be reclassified as pasture in a subsequent inventory. This conversion of land from agricultural to forest (and vice versa) makes it difficult to fully understand and illustrate real gains and losses in forest land. Additional regional analyses in future reports will help to pinpoint changes occurring in the forest-land base.

Forest Ownership

Private entities and individuals own 71 percent of Pennsylvania's forests. Major public owners include the Department of Conservation and Natural Resources, the Game Commission, and the Forest Service (Allegheny National Forest). Families and individual owners account for more than half of Pennsylvania's forest-land base, making them an important component of future policies and outreach efforts. Families and individuals value their forests for many reasons. They own relatively small tracts of land, and often do not seek formal or planned assistance from resource professionals when making decisions about their properties. This lack of

management planning is especially troublesome because many privately owned forests are becoming financially mature, a stage when numerous management options are available. Without effective planning, many of the opportunities to improve forest conditions or ensure adequate regeneration are lost when the trees are harvested. Another important consideration of family and individual owners is that 18 percent have indicated that they plan to sell their forest land or pass it on to heirs within 5 years. This is important because harvesting and other decisions often are made at the time of or shortly following the transfer.

The Forest's Changing Structure and Composition

Pennsylvania's forests are aging as evidenced by increases in the percentage of stands dominated by large trees and a slowing in increases in inventory volume. Although information on harvest levels is not yet available from the inventory, decreases in the fully and overstocked stands indicate expanding harvest levels. There is a clear difference between conditions on public and private forest land as the shifts in stocking levels are most evident on private lands.

Changes in species composition and stand structure also point to aging forests in Pennsylvania. The number of smaller trees is decreasing while the number of large trees is increasing. This trend is apparent across all regions. Relative differences between species indicate that hemlock, sugar maple, and the oaks will be less prominent in the future. Although increases in red maple inventory have slowed, red maple will continue to dominate for many years. Black birch is now positioned to become one of the dominant species as its influence on species composition and stand structure will increase in coming years.

Pennsylvania now supports the highest sawtimber volume since the turn of the century. High volumes (averages in excess of 5,000 board feet per acre), high quality (over half the inventory in tree grades 1 or 2), and high global demand for the State's hardwoods make harvesting financially attractive in many areas. Landowner decisions must consider residual stand conditions and regeneration for the next forest as trees are harvested.

Forest Health

Exotic diseases and insects are very serious threats to Pennsylvania's forests. Oaks continue to be at risk from gypsy moth and SOD could devastate oaks because understory hosts are prevalent in mixed-oak forests. The killing front of BBD continues to expand and combined with other stressors could increase beech mortality. Threats to the oaks and beech are especially important because they are the most important sources of hard mast for wildlife. HWA is beginning to affect the hemlock resource, so continued monitoring will be critical to research and management efforts aimed at understanding and ameliorating the impact of this insect pest. The emerald ash borer has entered the State and should be considered a serious threat to the ash resource. The Asian long-horned beetle is another exotic pest that could cause considerable harm to the maple resource should it enter the State. Many native diseases and pests could cause severe defoliation and mortality as intense outbreaks in local areas, or when they occur in conjunction with other stressors, e.g., drought and acidic precipitation.

Information on the occurrence and spread of introduced exotic-invasive plants is just becoming available but it is clear from the existing sample that these plants pose a threat to Pennsylvania's forests. Exotic-invasive plants occur in all of the major life forms—trees, shrubs, vines, herbs, etc. As such, this issue has moved from a concern over single-species invasion to forest-community invasions, particularly in urbanized areas. Understory species appearing in the inventory include multiflora rose, Russian/autumn olive, garlic mustard, Japanese stiltgrass, and the bush honeysuckles. Tree-of-heaven has expanded in more urbanized areas and is positioned to replace native species following stand disturbance.

Information on soil conditions shows that this critical feature of the forest ecosystem has been affected by acid deposition. Historical information reveals high levels of acid deposition in the western half and northeastern corner of Pennsylvania. Low calcium/aluminum ratios were found across the northern-tier counties. This means aluminum toxicity likely is affecting healthy root development and thus, overall forest productivity.

Additional research is needed to determine the impacts of varying levels of acid deposition on the forest as well as interactions with disturbances such as timber harvesting and deer browsing.

Stump from previous logging.

Lack of Forest Regeneration

The most disturbing finding from the forest inventory is the general lack of understory plants and tree regeneration across much of Pennsylvania. Understory plant communities are particularly problematic north of Interstate 80. Fencing to account for deer browsing and herbicide applications to control competing vegetation often are necessary to ensure the establishment and growth of tree seedlings. Changes in soil chemistry due to acid precipitation and other potential influences such as invasive species increase the complexity of understanding soil-plant-deer interactions. Harvesting trees without considering the complex suite of soil-plant-deer interactions could significantly affect the future composition of plant species as well as tree stocking levels in Pennsylvania's forests.

Sustainability Issues Summary

Forests offer a wide array of resources, uses, and values to Pennsylvanians. The current forest originated about 100 years ago following large-scale harvests at the turn of the last century. Trees in the forest have grown to the point where stands of large trees predominate and inventory volume growth is beginning to slow. Although forests are both gained and lost through agricultural land conversions, Pennsylvania loses about 28,000 acres of forest each year to development. The most glaring issue, a general lack of understory plants and trees over large areas, requires expensive management options and is certain to dramatically affect forest composition and health if not addressed. The array of exotic plants, diseases, and insects constitute a significant threat especially when considered along with native stressors and other disturbances. There is considerable evidence that managing for a more even distribution of forest land by seral stage could improve the overall health and resiliency of the future forest. There is scant information on the compositional and structural development of Pennsylvania's forests during the first half of the century, and little is known about how today's stands will evolve. The opportunity to study reference stands in various seral stages will aid in understanding forest dynamics, and developing late-succession forests for the major forest community types would fill an important scientific void. The challenge lies in understanding and overcoming the various threats and their interactions on forest development. Forest managers and policymakers are at a critical juncture in planning Pennsylvania's future forests.

Knowledge Gaps

The following knowledge gaps are hindering efforts to manage Pennsylvania's forest resource effectively. Filling these gaps will greatly aid scientists, landowners, and policymakers plan for and manage the Commonwealth's future forests.

- The current NRS-FIA annual inventory has not provided statistically reliable estimates of change components, e.g., net growth, removals, and mortality. This report has included numerous surrogate indicators but there is no substitute

for understanding harvest levels in relation to growth and mortality rates. Estimates of components of change will greatly increase our ability to gauge sustainability.

- Improving and expanding the suite of resources that NRS-FIA addresses will further aid in understanding the real wealth of Pennsylvania's complex forest. Carbon storage has become an important measure of the forest's role in climate change. Other examples include nontraditional forest products, contributions to water quality, and relationships between forests and human health and well-being.
- Wood resource availability is another gap that needs to be filled. The complexity of this issue will require integrating physical, biological, economic, legal, and social considerations.
- Once the gaps related to change components and wood resource availability are filled, there will be a valuable opportunity to examine prospective future trajectories. Application of projection models could aid in understanding how the forest can be managed to meet the many goals and objectives of Pennsylvania's residents.
- Additional information is needed to fully understand the complex interrelationships that underlie forest-ecosystem processes. For example, it is apparent that acid deposition is affecting soil chemistry; however, the impact on native plant communities, forest pests/diseases, and invasive plants is not fully understood. Understanding how these interrelationships affect future forest conditions will enable scientists, landowners, and policymakers to make more informed decisions.

Gaps in our knowledge, e.g. a lack of statistically sound information on net growth, removals, and mortality, will be filled as the NRS-FIA annual inventory progresses through the second 5-year cycle. Additional research on wood availability, ecosystem services, and resource projection models also will aid in understanding resource dynamics.

Bald eagle.

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Forester measuring tree height.

APPENDIX

Annual Inventory Overview

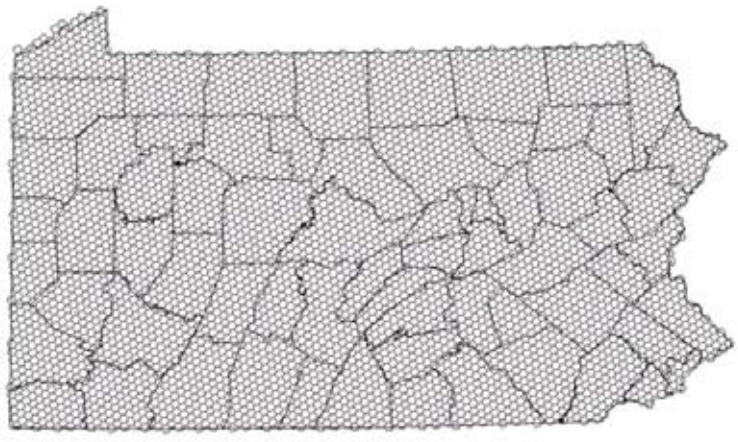
The annual inventory system combines features of the periodic system with a new systematic grid of sample plots and incorporates forest-health parameters. The inventory consists of three phases.

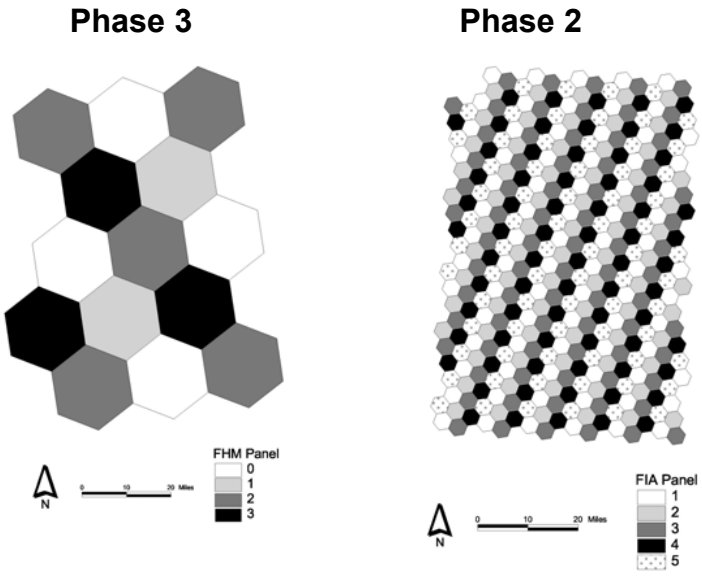
Phase 1

Phase 1 procedures reduce variance associated with estimates of forest-land area. A statistical estimation technique is used to classify digital satellite imagery and stratify the land base as forest or nonforest to assign a representative acreage to each sample plot. Source data are from Landsat Thematic Mapper (30-m resolution) imagery that ranged from 1999 to 2001. An image filtering technique is used to classify individual pixels using the 5- by 5-pixel region that surrounds each pixel that contains the sample plot. The resulting 26 classes are collapsed for each estimation unit (county or supercounty; the latter is a combination of small counties). Stratified estimation is applied by assigning each plot to one of these collapsed strata and by calculating the area of each collapsed stratum in each estimation unit. Stratified estimation produces more precise estimates than simple random sampling.

Phase 2

Field measurements are conducted at sample locations distributed systematically about every 3 miles across the landscape. Sample locations are situated within individual cells of a national hexagonal grid laid across Pennsylvania. Each Phase 2 sample represents about 6,000 acres depending on the Phase 1 stratification of forest land. The new national design also incorporates a change to a four-subplot cluster (USDA For. Serv. 2002). At each location, a suite of variables is measured that characterizes the land and trees associated with the sample (Fig. 88). Each year, 20 percent of the sample locations are measured, that is, it takes 5 years to complete the inventory. Each year's sample is referred to as an "inventory panel." The overall design is referred to as an "interpenetrating design" because no two cells are adjacent to one another within each inventory panel. As a result, each panel provides an unbiased representation of conditions across the State. Each completed panel





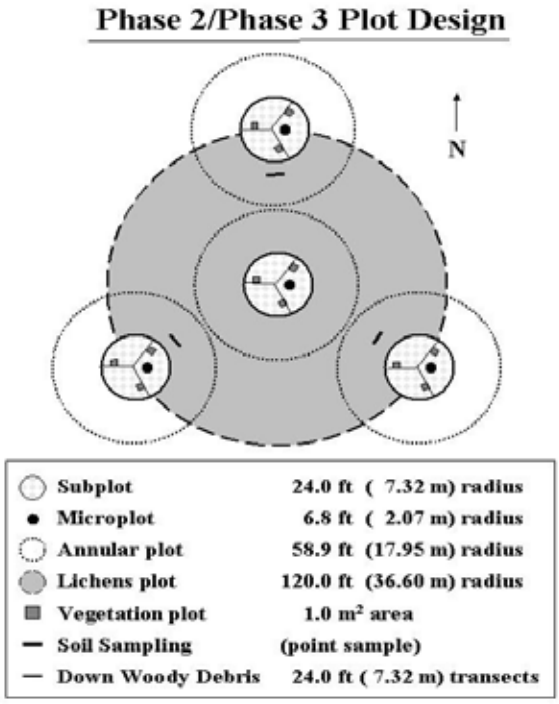


Figure 88.—Phase 2 and 3 sample-plot design, Pennsylvania, 2000-04.

is combined with existing panels to produce the most precise estimates possible. This report is based on the first five panels measured in Pennsylvania using the new annual inventory protocols. After the next panel is complete, the set of panels used for estimation "moves" to the most recent five panels (2nd through 6th year). The moving average approach ensures that the most current and complete inventory data are used.

Phase 3

More extensive forest-health measurements are collected during a 10-week period in summer on a subset of Phase 2 sample locations. The measurements are grouped into six general categories of indicators: crown condition, understory vegetation, down woody material, soil condition, lichen communities, and ozone damage. The intensity of the Phase 3 sample is one sample location per 96,000 acres of land. The relatively small number of Phase 3 samples does not provide detailed analyses in some cases. For example, breaking down tree damage for a particular species by region reduces the number of samples and yields a high sampling error (SE).

Statistical Significance

This report contains a wealth of statistical estimates that are compared over time and among numerous variables. Changes in estimates are discussed in terms of direction and magnitude. All mention of "significant" changes are based on comparing 95-percent confidence intervals for the various estimates. If confidence intervals overlap, there has been no real change in a statistical sense. When confidence intervals do not overlap, significant change has occurred.

Definition of Terms

Basal area . The cross-sectional area of a tree stem at breast height, expressed in square feet.

Board foot. A unit of lumber measurement 1 foot long, 1 foot wide, and 1 inch thick, or its equivalent. International ¼ inch rule is used as the USDA Forest Service standard log rule in the Eastern United States.

Commercial species. Tree species currently or prospectively suitable for industrial wood products; excludes species of typically small size, poor form, or inferior quality, e.g., hawthorn and sumac.

Condition. A delineation of a land area based on land use, forest type, stand size, regeneration status, reserved status, tree density, and owner class.

Cropland. Land that currently supports agricultural crops including silage and feed grains, bare farm fields resulting from cultivation or harvest, and maintained orchards. Includes cropland used for cover crops and soil improvement.

Cull tree. A rough tree or a rotten tree.

Diameter at breast height (d.b.h.). The diameter outside bark of a standing tree measured at 4-1/2 feet above the ground.

Dry ton. A unit of measure of dry weight equivalent to 2,000 pounds or 907.1848 kilograms.

Dry weight. The weight of wood and bark as it would be if it had been oven dried; usually expressed in pounds or tons.

Forest land. Land that is at least 10 percent stocked with trees of any size, or that formerly had such tree cover and is not currently developed for a nonforest use. The minimum area for classification of forest land is 1 acre. The components that make up forest land are timberland and all noncommercial forest land.

Forest type. A classification of forest land based on the species that form a plurality of live-tree stocking.

Forest-type group. A combination of forest types that share closely associated species or site requirements are combined into forest-type groups.

Growing-stock trees. Live trees of commercial species classified as large or medium size; that is, live trees of commercial species except rough and rotten trees.

Growing-stock volume. Net volume, in cubic feet, of growing-stock trees 5.0 inches and larger in from a 1-foot stump to a minimum 4.0-inch top diameter outside bark of the central stem, or to the point at which the central stem breaks into limbs. Net volume equals gross volume less deduction for cull.

Hardwoods. Dicotyledonous trees, usually broad-leaved and deciduous.

International 1/4-inch rule. A log rule or formula for estimating the board-foot volume of logs. The mathematical formula is:

Board-foot volume = $(0.22D^2 - 0.71D)(0.904762)$

for 4-foot sections, where D = diameter inside bark at the small end of the log section. This rule is used as the USDA Forest Service standard log rule in the Eastern United States.

Land area. (a) Bureau of Census: The area of dry land and land temporarily or partly covered by water, such as marshes, swamps, and river flood plains; streams, sloughs, estuaries, and canals less than 200 feet wide; and lakes, reservoirs, and ponds less than 4.5 acres in area; (b) Forest Inventory and Analysis: same as (a) except that the minimum width of streams, etc. is 120 feet, and the minimum size of lakes, etc. is 1 acre.

Land use. A classification of land that indicates the primary use at the time of inventory. Major categories are forest land and nonforest land.

Large-size stand. A stand-size class of forest land that is at least 10 percent stocked with live trees of which half or more of such stocking is in medium- or large-size trees or both, and in which the stocking of large trees is at least equal to that of medium trees.

Large-size tree. A live tree of commercial species at least 9.0 inches d.b.h. for softwoods or 11.0 inches d.b.h. for hardwoods.

Live tree. Live trees at least 1.0-inches d.b.h. and larger, including growing-stock, rough, and rotten.

Medium-size stand. A stand-size class of forest land that is at least 10 percent stocked with live trees of which half or more of such stocking is in medium or large-size trees or both, and in which the stocking of medium trees exceeds that of large trees.

Medium-size tree. A live tree of commercial species meeting regional specifications of soundness and form and at least 5.0 inches d.b.h. but smaller than a large tree (9.0 inches d.b.h. for softwoods and 11.0 inches d.b.h. for hardwoods)

Merchantable stem. The main stem of the tree between a 1-foot stump height and a 4-inch top diameter (outside the bark), including the wood and bark.

Mortality. The estimated net volume of trees at the previous inventory that died from natural causes before the current inventory (divided by the number of growing seasons between surveys to produce average annual mortality).

Net dry weight. The dry weight of woody material less the weight of all unsound (rotten) material.

Net growth. The change, resulting from natural causes, in volume during the period between surveys (divided by the number of growing seasons to produce average annual net growth). Components of net growth are ingrowth plus accretion, minus mortality, minus cull increment, plus cull decrement.

Noncensus water. Streams/rivers 120 to 200 feet wide and bodies of water 1 to 4.5 acres in size. The Bureau of the Census classifies such water as land.

Noncommercial species. Tree of typically small size, poor form, or inferior quality that usually are unsuitable for industrial wood products.

Nonforest land. Land that has never supported forests, or land formerly forested but now in nonforest use, e.g., cropland, pasture, residential areas, marshes, swamps, highways, industrial or commercial sites, or noncensus water.

Nonsalvable dead tree. A dead tree with most or all of its bark missing that is at least 5.0 inches d.b.h. and at least 4.5 feet tall.

Nonstocked area. A stand-size class of forest land that is less than 10 percent stocked with live trees.

Pasture land. Includes pasture land other than cropland and woodland pasture. It can include lands that have had lime fertilizer or seed applied, or that had been improved by irrigation, drainage, or control of weeds and brush.

Relative stand density. A stocking classification procedure that reflects species, stage of development, and the characteristics of the trees present in a stand.

Removals. The net volume harvested or killed in logging, cultural operations (such as timber stand improvement) or land clearing, and the net volume neither harvested nor killed but now growing on land that was reclassified from timberland to noncommercial forest land or nonforest land during the period between surveys. This volume is divided by the number of growing seasons to produce average annual removals.

Reserved productive forest land. Forest land sufficiently productive to qualify as timberland but withdrawn from timber utilization through statute or administrative designation; land exclusively used for Christmas tree production.

Rotten tree. A live tree of commercial species that does not contain at least one 12-foot sawlog or two noncontiguous sawlogs, each 8 feet or longer, now or prospectively, and does not meet regional specifications for freedom from defect primarily because of rot; that is, more than 50 percent of the cull volume in the tree is rotten.

Rough tree. The same as a rotten tree except that a rough tree does not meet regional specifications for freedom from defect primarily because of roughness or poor form; also a live tree of noncommercial species.

Salvable dead tree. A tree at least 5.0 inches d.b.h. that has died recently and still has intact bark; may be standing, fallen, windthrown, knocked down, or broken off.

Sampling error. A measure of the reliability of an estimate, expressed as a percentage of the estimate. The sampling errors given in this report are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. Indicated in statistical tables as SE.

Sapling. All live trees 1.0 to 4.9 inches d.b.h.

Sapling/seedling stand. A stand-size class of forest land that is at least 10 percent stocked with live trees of which half or more of such stocking is in saplings or seedlings, or both.

Sawlog. A log meeting regional standards of diameter, length, and freedom from defect, including a minimum 8-foot length and a minimum top diameter inside bark of 6 inches for softwoods and 8 inches for hardwoods (see specifications under Tree-Grade Classification).

Sawlog portion. The part of the bole of a large tree between the stump and the sawlog top.

Sawlog top. The point on the bole of a large-size tree above which a sawlog cannot be produced. The minimum sawlog top is 7.0 inches diameter outside bark (d.o.b.) for softwoods and 9.0 inches d.o.b. for hardwoods.

Sawtimber volume. Net volume in board feet (International 1/4-inch rule) of sawlogs in large trees. Net volume equals gross volume less deductions for rot, sweep, and other defects that affect use for lumber.

SE. See Sampling error.

Seedling. A live tree at least 6.0 inches tall for softwoods and 12.0 inches for hardwoods.

Seral stage. A series of ecological communities formed in ecological succession.

Small-size tree. A live tree of commercial species less than 5.0 inches d.b.h.

Small-size stand. A stand-size class of forest land that is at least 10 percent stocked with live trees of which stocking of small-size trees exceeds medium- and large-size trees.

Snag. Standing dead tree with most or all of its bark missing that is at least 5.0 inches d.b.h. and at least 4.5 feet tall (does not include salvable dead).

Softwoods. Coniferous trees, usually evergreen and having needles or scalelike leaves.

Sound-wood volume. Tree volume of the central stem from a 1-foot stump to a minimum top diameter outside bark or a point at which the stem breaks into limbs. Sound cull portions are included and rotten cull portions are excluded; most often expressed in cubic feet for live trees.

Stand. A group of forest trees growing on forest land.

Stand origin. An indication of how the measured stand originated: 100 percent natural, 100 percent artificial, or a combination of both.

Stand-size class. A classification of forest land based on the size class of the stocking of live trees in the area. Stands are classified as small (previously referred to as sapling/seedling), medium (poletimber), and large (sawtimber).

State lands. Lands owned by the state or leased to the state for 50 years or more.

Stocking. The degree of occupancy of land by trees relative to the growth potential utilized by a site. It is expressed as a percent of the "normal" value presented in yield tables and stocking quides. Two categories of stocking are traditionally used in FIA reports: live-tree and growing-stock trees. The relationships between the classes and the percentage of the stocking standard are: nonstocked (0 to 9), poorly stocked (10 to 34), moderately stocked (35 to 59), fully stocked (60 to 100), and overstocked (100+).

Stump. The main stem of a tree from ground level to 1 foot above ground level, including the wood and bark.

Timberland. Forest land producing or capable of producing crops of industrial wood (more than 20 cubic feet per acre per year) and not withdrawn from timber utilization by statute or administrative designation. The statutes and designations apply to publicly owned land only. Timberland was formerly known as commercial forest land. Timberland may be "nonstocked" so long as no natural condition or human activity prevents or inhibits the establishment of tree seedlings.

Timberland includes the following components:

a) Rural. The historical and traditional acreage classified as timberland in previous inventories.

b) Other forest land. Defines a subset of forest land that is producing, or capable of producing, crops of industrial wood, but is associated with or part of a nonforest land use. In the past, these areas would have been treated as inclusions in the nonforest land use because they were considered part of a development. The minimum area for classification as other forest land is 1 acre. These strips of timber must have a crown width of at least 120 feet. Examples of land that could be classified as other forest land are forested portions of city parks, forested land in highway medians and rights-of-way, forested areas between ski runs, and forested areas within golf courses. Generally, although surrounded by nonforest development, these areas have not been developed and exhibit natural, undisturbed understories.

c) Urban timberland. A subset of forest land that now is grouped into timberland. Includes land that except for its location would be classified as rural timberland. This land is nearly (surrounded on three sides) or completely surrounded by urban development, whether commercial, industrial, or residential. This land meets all the criteria for timberland, that is, at least 1 acre capable of producing at least 20 cubic feet per acre per year of industrial wood, is not developed for other than timber production, and is not reserved by a public agency. It is highly unlikely that such land would be used for timber products on a continuing basis. Such land may be held for future development, or scheduled for development. (The timber that is present may be utilized only at the time of development.) The land may be undeveloped due to periodic flooding, low wet sites, steep slopes, or their proximity to industrial facilities that are unsuitable for residential development. Forested areas within city parks are not urban forest land; it may be other forest land if all requirements are met. City parks cannot be classified as urban timberland as it is currently defined.

Timber products. Roundwood (round timber) products and manufacturing plant by-products harvested from growing-stock trees on timberland, from other sources, e.g., cull trees, salvable dead trees, limbs, tops, and saplings, and from trees on noncommercial forest and nonforest lands.

Timber removals. The volume of trees removed from the inventory for roundwood products, plus logging residues, volume destroyed during land clearing, and volume of standing trees on land that was reclassified from timberland to noncommercial forest land.

Top. The wood and bark of a tree above the merchantable height (or above the point on the stem 4.0 inches in diameter outside bark); generally includes the uppermost stem, branches, and twigs but excludes the foliage.

Tree class. A classification of the quality or condition of trees for sawlog production. Tree class for large trees is

based on current condition. Tree class for medium trees is a prospective determination--a forecast of potential quality when they become large (11.0 inches d.b.h. for hardwoods, 9.0 inches d.b.h. for softwoods).

Tree grade. A classification of large-tree quality based on guidelines for tree grades for hardwoods, white pine, and southern pine. (note: red pine was graded using the guidelines for southern pine).

Trees. A woody perennial plant, typically large, with a single well-defined stem carrying a more or less definite crown; sometimes defined as attaining a minimum diameter of 3 inches (7.6 cm) and a minimum height of 15 feet (4.6 m) at maturity.

Unproductive forest land. Forest land that is incapable of producing 20 cubic feet per acre per year of industrial wood under natural conditions.

Upper stem portion. That part of the main stem or fork of a large tree above the sawlog top to a diameter of 4.0 inches outside bark, or the point at which the main stem or fork breaks into limbs.

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Pennsylvania's forest-land base is stable, covering 16.6 million acres or 58 percent of the land area. Sawtimber volume totals 88.9 billion board feet, an average of about 5,000 board feet per acre. Currently, only half of the forest land that should have advance tree seedling and sapling regeneration is adequately stocked with high-canopy species, and only one-third has adequate regeneration for commercially desirable timber species. Several exotic diseases and insects threaten the health of Pennsylvania's forests. Stressors such as drought, acidic deposition, and ground-level ozone pollution are adversely affecting the State's forests.

KEY WORDS: forest inventory, forest health, sustainability, tree regeneration

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