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Pennsylvania Forests 2019: Summary Report

Citation

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Abstract

This report is the fourth summary of annualized inventory of Pennsylvania with field data collected from 2013 through 2019. Forest land area has decreased since 2014 to 16.6 million acres. Oak/hickory and maple/beech/birch forest-type groups dominate the forested area and large-diameter stands account for 73 percent of timberland. Net volume on timberland is 37.3 billion cubic feet but increases have slowed due to decreased gross growth and increased mortality. Net growth still outpaced harvest removals by a ratio of 2.1:1. Additional information on forest area, land-use change, fragmentation, ownership, species composition, stand structure, volume, growth, removals, mortality, regeneration, invasive plants, forest pests, tree health, forest carbon, and forest economics are also presented. A detailed interactive report is available at https://doi.org/10.2737/NRS-RB-131-INT, and supplemental information, including (1) tables summarizing quality assurance, (2) a core set of tabular estimates for a variety of forest resources, and (3) user and database guides for P2 and P2+ protocols, can be accessed at https://doi.org/10.2737/NRS-RB-131.

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

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Cover photo: Great Island, Clinton County. USDA Forest Service photo by Thomas Albright.

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Foreword

The forests of Pennsylvania are deeply embedded in our State's culture, economy, landscape, and identity. The 16.6 million acres of forests provide clean air and water, recreational opportunities, wood products, energy, plant and wildlife habitat, along with a whole host of other uses and values.

This report summarizes the latest statewide inventory of Pennsylvania forests and is the result of a cooperative effort between the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program and the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry.

An understanding of current conditions and how they are changing over time is of fundamental importance for sustaining the benefits and services provided by Pennsylvania's forests.

This report highlights some encouraging trends for the future of Penn's Woods. It also identifies issues that require vigilant monitoring. Encouraging trends include tree regeneration appears to be stable or slowly improving, net growth is outpacing harvest removal at a little over 2:1, and net volume has increased by 2.2 percent since 2014. Issues of concern include the extent of forest land has been reduced by approximately 300,000 acres to 16.6 million acres, the wildland-urban interface (where the built environment meets forested lands) grew to encompass an additional 1.2 million acres of forest land, and pests and pathogens—old and new—continue to threaten forest health.

I hope that you will explore this report. Then, I hope that you spend some time in the forests of Pennsylvania with a greater understanding of the wonderful resource we call "Penn's Woods."

Ellen M. Shultzabarger

Pennsylvania State Forester

Contents

State forest boundary marker, Bradford County. USDA Forest Service photo by Thomas Albright.

Highlights

On the Plus Side

- Growing-stock volume remains stable as a proportion of all net volume on timberland at 91 percent. Net volume is 2,333 cubic feet per acre, a 4 percent increase since 2014.
- Sawtimber volume on timberland increased to 121.6 billion board feet or 7,609 board feet per acre statewide.
- Net growth outpaces harvest removal volume by a factor of 2.1 to 1.
- Regeneration appears to be stable or slowly improving. High deer browse impacts are less common than in the past, and the proportion of samples adequately stocked with regeneration have increased since 2009 for most species groups in the majority of survey units.

Issues to Watch

- The extent of forest land is 16.6 million acres in 2019, which is a decrease from 16.9 million acres in 2014.
- Nearly half of net loss of forest land is caused by residential and commercial land development.
- The wildland-urban interface grew to encompass an additional 1.2 million acres of forest land between 1990 and 2010.
- Sawtimber sized stands continued to increase to 73 percent of all timberland, leaving small diameter stands as only 7 percent of timberland.
- Nearly half (46 percent) of timberland is aged 80 years or more. Stands 40 years or younger account for only 12 percent of timberland, down from 19 percent in 2004.
- Regeneration challenges, though improving, remain. High deer browse impacts affect 26 percent of sample locations.
- Pests and pathogens, new and old, continue to threaten forest health. Emerald ash borer is still decimating the ash resource. Oak wilt, as of 2021, is found in 37 Pennsylvania counties.

Background

What is FIA?

The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program (FIA) was established by the U.S. Congress to "make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements of the forest and rangelands of the United States" (Forest and Rangeland Renewable Resources Planning Act of 1974). Key definitions, data collection methods (USDA Forest Service 2018), and estimation procedures are summarized in this report.

For more detailed information, see "Statistics and Quality Assurance for the Northern Research Station Forest Inventory and Analysis Program, Version 3" (Gormanson et al. 2023).

Visit the National FIA program website for additional information.

What is this Report?

This report summarizes findings of the 2019 survey of Pennsylvania forest resources. Data for this survey were collected from 2013 through 2019 and are referred to as the 2019 inventory throughout this report. The inventory was conducted by the USDA Forest Service, Forest Inventory and Analysis program in cooperation with the Pennsylvania Department of Conservation and Natural Resources (DCNR). The summary report and additional resource materials are available online at https://doi.org/10.2737/NRS-RB-131.

More detailed results are available in the Pennsylvania Forests 2019: Interactive Report StoryMap collection (Fig. 1). It includes interactive maps, charts, and dashboards that summarize data and illustrate trends, making it easy for readers to compare between inventory periods, geographic locations, or ecological divisions. This document offers a summary of those results.

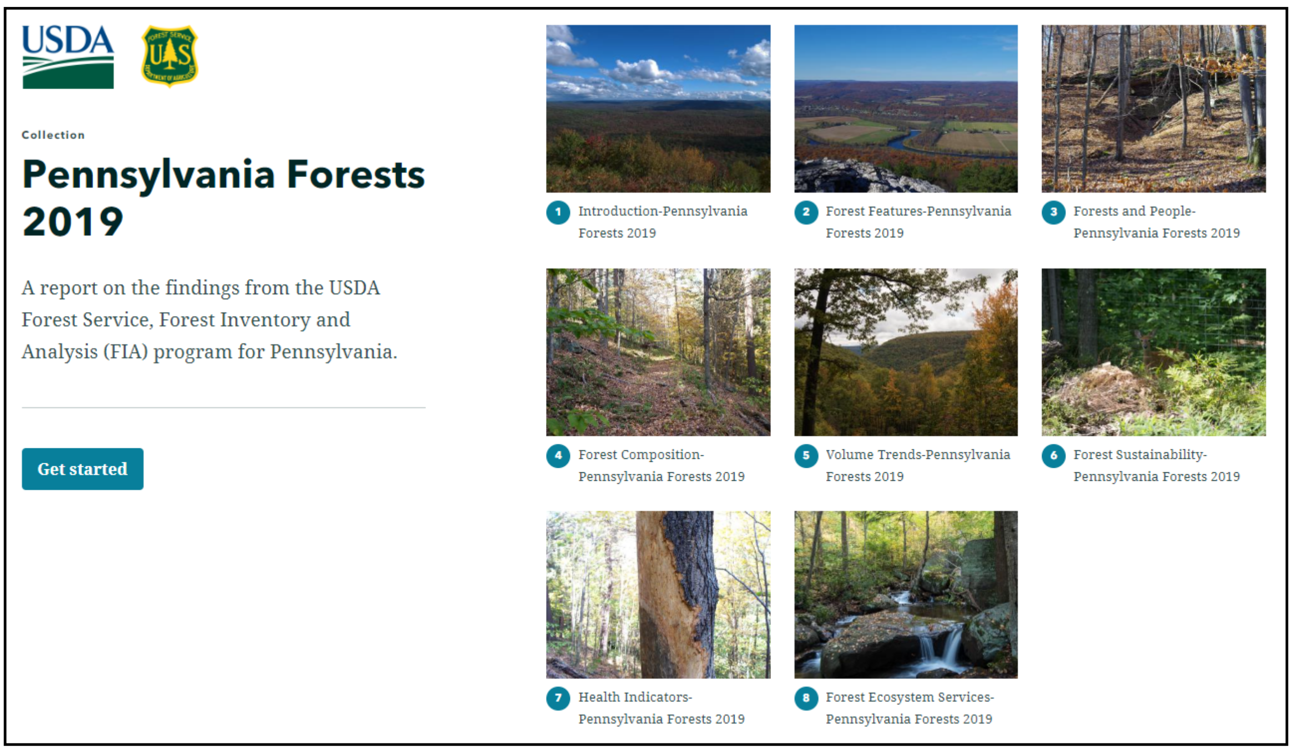

Figure 1.—The Pennsylvania Forests 2019 interactive report contains a series of StoryMaps that focus on different forest aspects. In the interactive report, select "Get started" to enter the collection or click on one of the thumbnail photos to view an individual StoryMap within the collection.

Pennsylvania Forest Inventories

FIA has been conducting inventories of Pennsylvania forests since 1955. Prior to 2000, inventories were conducted on a periodic basis or once every 10 to 15 years. Four periodic inventories were completed (1955, 1965, 1978, 1989) and are reported in Ferguson (1958, 1968), Considine and Powell (1980), Alerich (1993), and Widmann (1995). Pennsylvania's inventory moved into the annual system in 2000, wherein a percentage of plots were measured each year and an entire inventory cycle completed every 5 years. Three full-cycle annualized reports were published for 2004 (McWilliams et al. 2007), 2009 (McCaskill et al. 2013), and 2014 (Albright et al. 2017). In 2014, Northern Research Station FIA (NRS-FIA) moved from completing an inventory cycle every 5 years to every 7 years. As such, about 14 percent of sample plots are visited each year in Pennsylvania. FIA maintains a 5-year reporting interval with each report covering a full data cycle. Though the inventory and reporting cycle lengths do not match, each 5-year report is the result of a full inventory cycle of plots of up to 7 years and is identified by the last year in a given full cycle.

The Pennsylvania 2019 inventory consists of 5,059 plots. Of that total, 2,985 contained forest land, 1,501 were sampled but contained no forest land, and 573 were inaccessible due to access prohibitions. Current estimates, such as area and volume, are based on 4,486 sampled plots. Change components, such as land-use change and net growth, are based on 4,204 plots measured at both the latest cycle (2013–2019) and the previous cycle (2008–2013).

Regional Analysis

Previous Pennsylvania FIA reports used six regions developed in conjunction with the Pennsylvania DCNR, Bureau of Forestry for geographical analysis. These regions were custom county groupings that did not leverage the FIA post-stratification system of error reduction. As such, comparison of estimates over time could be problematic. This report will use the FIA inventory units standard for regional analysis across the country. Pennsylvania contains six FIA inventory units (Fig. 2) that are referred to throughout this report as units and inventory units.

Forest Features

Forest Area

The FIA program is, at the broadest scale, a land use assessment. Land is classified as forest, agriculture, developed, water, or other nonforest based generally on its primary use. Forest land is segmented into three subcategories: timberland, reserved forest land, and other forest land. Most forest land in the State also meets the timberland definition. Reserved forest land includes national forest Wilderness Areas, State Parks, state forest Wild Areas, state forest Natural Areas, and some local government parks. Other forest land can be forested bogs or other areas of low productivity and is rare in Pennsylvania.

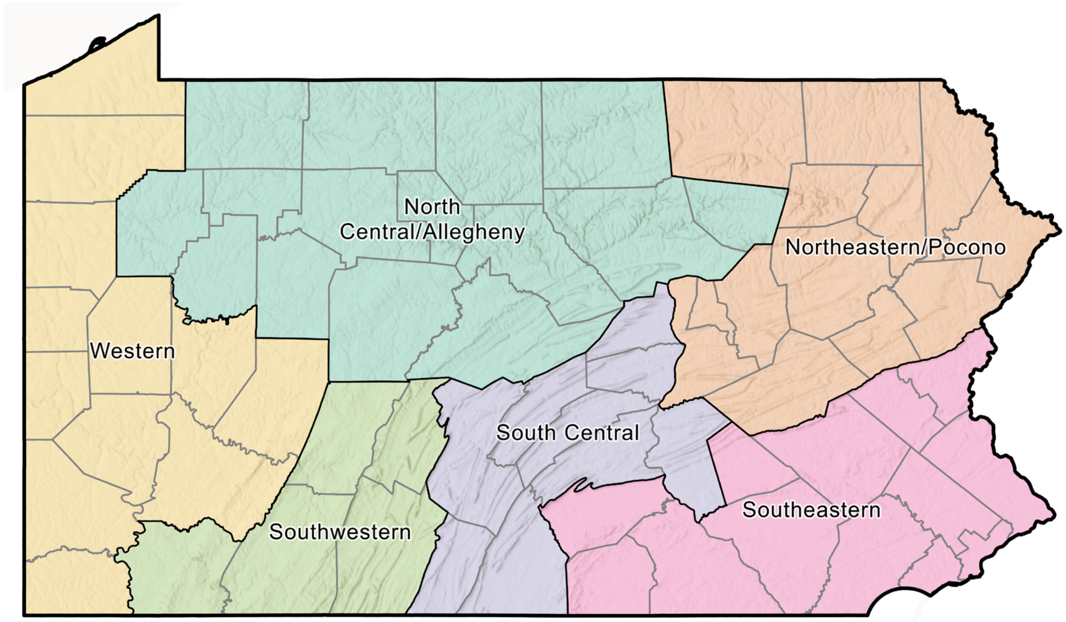

Figure 2.—FIA inventory units, Pennsylvania.

Projection: *Web Mercator WGS 1984. Source USDA Forest Service, Forest Inventory and Analysis program, 2019. Geographic base data are provided by the National Atlas of the USA. FIA data and tools are available online at https://www.fs.usda.gov/research/products/dataandtools/forestinventorydata. Cartography: T.A. Albright, USDA Forest Service, December 2020.*

FIA estimates that forest land occupies 16.6 million acres within Pennsylvania, representing 57.3 percent of all sampled area (including inland water). Timberland, at 16.0 million acres, stands at 96.2 percent of all forest land, a proportion that has remained essentially unchanged for nearly two decades. Reserved areas cover 600,000 forested acres, or 3.7 percent of all forest land, with nearly half of reserved acres falling in the North Central/Allegheny unit. Other forest land is only 27,000 acres. Nonforest land uses cover 12.0 million acres (41.3 percent) and inland water accounts for the remaining 400,000 acres (1.4 percent). The current estimated extent of forest land is a loss of nearly 300,000 acres since 2014. For context, the 2014 estimate was close to the peak forest land extent of 17.1 million acres in 1965, a number that was nearly matched again in 2013 (Fig. 3). Even with an understanding of the difficulties inherent in sampling forest land extent, the 1.7 percent drop over 5 years may cause concern.

The steady upward trend in forest land extent from the beginning of annual inventories in the State through 2013 turned to a downward trend continuing to 2019. This recent decline deserves some attention; however, trends are defined by the timescale of interest. The 2019 estimate is only 0.7 percent less than that reported in 2009. Going back another reporting cycle, the two estimates are even closer, with the latest being within 50,000 acres of the first full-cycle annual estimate in 2004.

While the 5-year trend looks concerning, an understanding of program changes in the past decade alleviates some concern and is discussed next in Land-use Change. Thus, it is helpful to take a wider view of area estimates, comparing data at longer intervals. Ten and 15-year comparisons suggest the forest land extent is relatively stable within Pennsylvania.

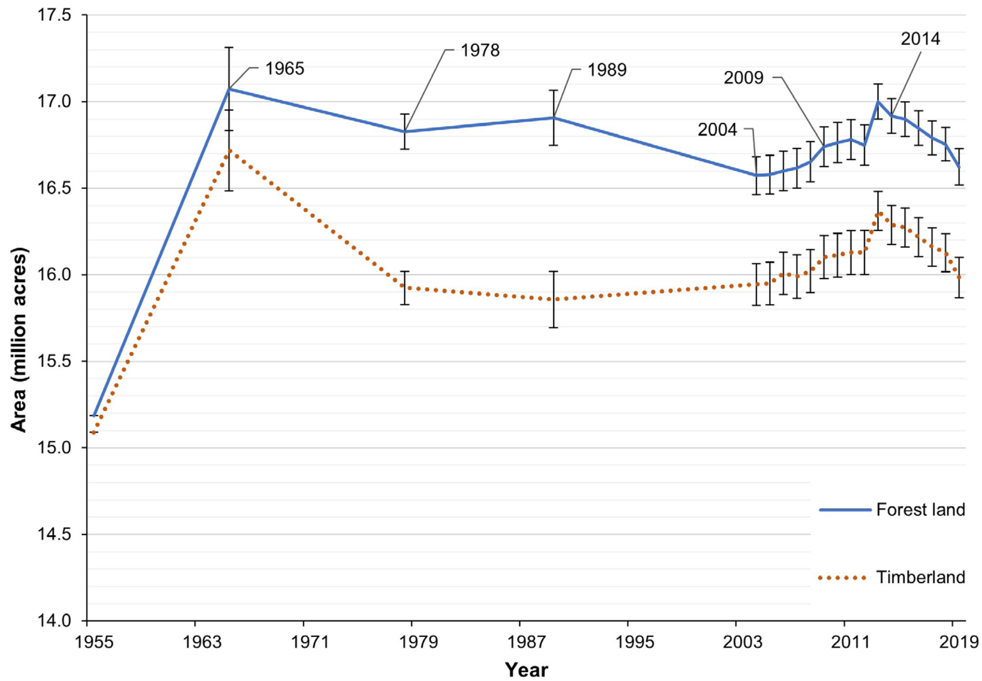

Figure 3.—Forest land and timberland area by inventory year, Pennsylvania. Error bars represent a 68 percent confidence level.

Land-use Change

Current estimates quantifying the extent of land uses utilize all sampled plot locations and account for the effects of nonresponse. Such estimates are useful for long-term trend analysis but should be used with an understanding of the changes in FIA protocols over time. Land-use change analysis makes use of two successive visits to the same sample location and compares land uses at time 1 and time 2. In this way, it is possible to eliminate most of the incidental influences on area estimation inherent in sampling and focus on change itself. Land-use change analysis can help contextualize the dynamics affecting the extent of forest land across the State.

The vast majority (98 percent) of forest land measured in the previous cycle remained as such when revisited. Areas changing land use are a small but important portion of the overall resource as understanding the trends can help to identify pressures on forest resources. Overall, there was 388,000 acres of gross forest land loss that was partially offset by 193,000 acres of gross forest gain, resulting in a net loss of 195,000 acres (Fig. 4). Note that this represents only about two-thirds of the estimated loss derived from comparisons of forest land in 2014 and 2019. The majority of the 100,000-acre discrepancy can be attributed to slight changes in the post-sampling stratification process. All inventory units of the State had a net loss of forest land with Western, Northeastern, and Southeastern seeing losses around 2 percent of regional forest land. Effects were lowest in the South Central and North Central/Allegheny units at 0.1 percent and 0.4 percent losses, respectively.

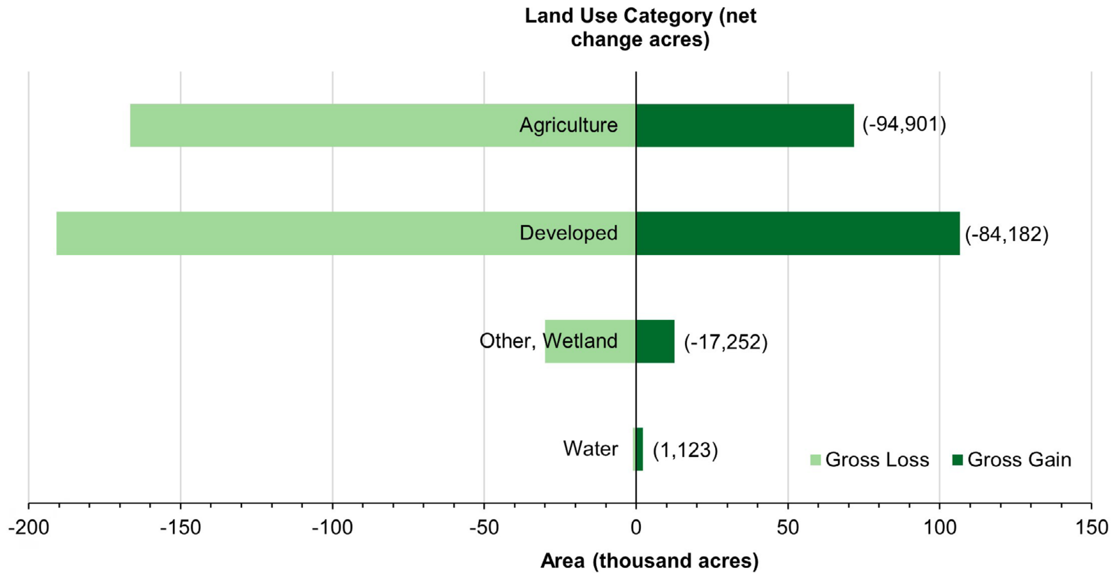

Figure 4.—Gross loss and gross gain of forest land area by land use category with net change acres in parentheses, Pennsylvania, 2019.

Nearly half of the gross forest loss went to developed land uses, both residential and commercial, along with associated rights-of-way. Agriculture accounted for another 43 percent of gross loss. Water and other nonforest uses accounted for only 31,000 acres of forest loss (8 percent). Gains of newly qualifying forest land came from land uses previously classified as developed (55 percent), agricultural (37 percent), and water/other (8 percent). While the shift from developed land uses to forest land may seem surprising, it is not at all uncommon. Small changes in maintenance lines, changes in ownership, or both can result in areas meeting minimum forest land size and canopy cover thresholds. However, the large proportion of forest loss to agricultural uses, including idle farmland, deserves a closer look.

An in-depth analysis of the 359 revisited sample locations that exhibited a change in extent of forest land found that in 29 samples, the change was related to a fundamental change in the FIA definition of forest land in 2013. Beginning in that year, forest land became defined by a minimum canopy cover level of 10 percent, rather than the previous threshold of 10 percent stocking. Though the change may seem insignificant, the results were quite consequential. The sample locations affected collectively represent an estimated loss of 114,000 acres of forest land, 59 percent of the 195,000-acre net loss total. Land previously qualifying as forest is now categorized as idle farmland (50,000 acres), mining (36,000 acres), and others. This is possible because of the differences in assessing relative stocking levels, which defined forest land in the past, and the new canopy cover method. Relative stocking uses the diameter of the largest tree stem in the questionable condition as well as the species and diameter of sampled stems to assign a stocking value to each sampled stem (USDA Forest Service 2010). Canopy cover assessments determine whether the condition in question has 10 percent or more of its area covered by tree canopy. While this is a much simpler, repeatable, and transparent method, the result was many marginally stocked lands throughout the State failing to meet the new canopy threshold. As stated, effects were concentrated in agricultural and mining land, primarily in sparsely stocked agricultural fields left fallow for 3 or more years and reclaimed surface mined areas of similar character. These effects ranged from 0.2 percent of a given inventory unit's total forest land in the North Central/Allegheny and Southeastern units to 1.5 percent in the Western unit. No forest land in the South Central unit was affected.

There is little doubt that forest land throughout the Commonwealth has decreased, though the extent of loss is still in question. The latest estimate of forest land suggests there has been a 300,000-acre loss of forest since 2014. However, looking at changes in land use at the same location between visits reveals a 195,000-acre loss. Being aware of changes in the inventory and estimation methods leads to an understanding that a majority of the loss due to land-use change was in fact loss brought about by a change in the FIA definition of forest land. Nevertheless, 16.6 million acres remains the best available estimate of forest land extent within the State. Though this represents a substantial loss in the last 5 years, it is also nearly equal to the estimates from the mid-2000s, suggesting an inherent stability in the forest land base. Analysis of land-use change data adds credence to such a conclusion. Continued analysis with an eye toward FIA program refinements affecting estimates will likely clarify trends as time goes on.

Urbanization and Fragmentation

The wildland-urban interface (WUI) is the zone where human development meets or intermingles with undeveloped wildland vegetation, and it is the fastest growing land use type in the conterminous United States (Mockrin et al. 2019, Radeloff et al. 2018). Although the term was originally created to identify the area where wildfires pose the greatest risk to people, the WUI is associated with a variety of consequential human-environment conflicts. The 2018 report from the Mid-Atlantic Climate Change Response Framework on Mid-Atlantic forest ecosystem vulnerability (Butler-Leopold et al. 2018) identified fragmentation and land-use change as one of the top seven current major stressors and threats to forest ecosystems, and three of the other threats—invasion by nonnative species, forest diseases and insect pests, and herbivory—are also heavily influenced by forest fragmentation and urbanization.

By 2020, 5.0 million acres of forest land in the State has been in WUI conditions for at least 30 years, with an additional 1.2 million acres of forest land crossing into the WUI category between 1990 and 2010. The 6.2 million-acre total represents 36 percent of all forest land. Seventeen counties had 10 percent or more of their forest land converted to WUI conditions over the two decades (Fig. 5).

There are well-documented negative effects of residential development on forest land and a large proportion of forest land occurring in WUI conditions. Thus, it matters how those residential areas are managed and what strategies are pursued to reduce the effects of those residential land uses on surrounding forest land (Kramer 2013).

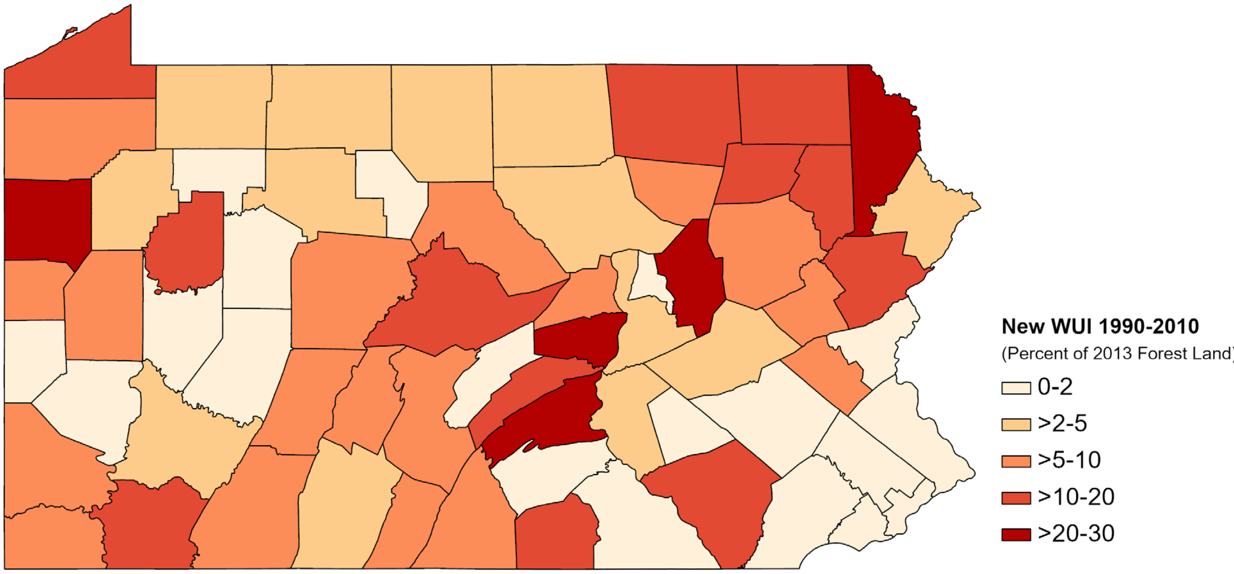

Figure 5.—Proportion of forest land changing status between 1990 and 2010.

Projection: Web Mercator WGS 1984. Source USDA Forest Service, Forest Inventory and Analysis program, 2019; Wildland-Urban Interface 2010 (Radeloff et al. 2017). Geographic base data are provided by the National Atlas of the USA. FIA data and tools are available online at https://www.fs.usda.gov/research/products/dataandtools/forestinventorydata. Cartography: T.A. Albright, USDA Forest Service, April 2021.

Forests and People

Forest Ownership

To a large extent, the quantity and quality of forest resources are determined by landowners, including recreational opportunities, timber supply, and wildlife habitat. By understanding the priorities of forest landowners, the forest conservation community can better help owners meet their needs, and in so doing, help conserve the forests of Pennsylvania for future generations.

The National Woodland Owner Survey (NWOS) of the FIA program studies private forest owners' attitudes, management objectives, and concerns with a focus on the families, individuals, and other unincorporated groups collectively referred to as "family forest ownerships." The NWOS results reported here are from studies completed in 2006 (Butler 2008), 2013 (Butler et al. 2016), and 2018 (Butler et al. 2021).

Sixty-nine percent of Pennsylvania forest land is privately owned (Fig. 6). The vast majority of this private land, an estimated 8.4 million acres, are family forests. Corporate ownerships have an estimated 2.4 million acres across the State and other private owners, including conservation organizations and unincorporated clubs and partnerships, own an estimated 698,000 acres. Federal, state, and local governments are responsible for 31 percent of forest land in the State. Much of the 655,000 acres of federal forest land is in the Allegheny National Forest. The 3.9 million acres of state-owned forest land are controlled by a combination of the Department of Conservation and Natural Resources (as state

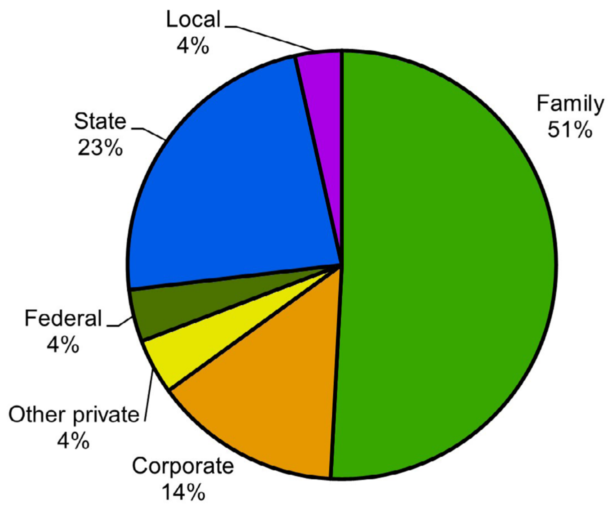

Figure 6.—Forest land proportion by owner class, Pennsylvania, 2019.

forests and state parks) as well as the Pennsylvania Game Commission. County and other local governments own an estimated 586,000 acres of these forested acres. The area of forest land by ownership class has remained relatively constant since 2009, with the largest change being a 320,000-acre loss of family forest land.

Just over half (51 percent) of all forest land in Pennsylvania is owned by family forest owners. As of 2018, there are an estimated 163,000 family forest ownerships with 10 or more acres that collectively hold 7.5 million acres of forest land in the State. An estimated 75 percent of these family forest ownerships own less than 50 acres of forest land, but 66 percent of the family forest land is in holdings of 50 or more acres. The average size of family forest holdings is 46 acres in 2018, a slight increase from the 2013 and 2006 averages of 45 and 44 acres, respectively.

The majority of family forest landowners surveyed have environmental concerns with implications for resource management. Half are concerned about invasive plants, two-thirds have concern about water pollution, and over 80 percent are concerned about unwanted insects and disease. However, fewer owners pursued management practices aimed at addressing these concerns. For example, 13 percent of the family forest ownerships, who control 25 percent of the family forest land, have received advice in the last 5 years, proportions that remain relatively unchanged from 2013. Only 6 percent of the family forest ownerships, who control 15 percent of the family forest land, have a written forest management plan. Participation in preferential property tax programs is very common with 51 percent of the family forest ownerships, who control 63 percent of the family forest land, reporting participation. Eight percent of the family forest ownerships, who control 14 percent of the family forest land, report participating in a certification program. In terms of both ownerships and acreage, 10 percent or less have participated in a cost-share program or have a conservation easement.

The fate of the forests lies primarily in the hands of those who own and control the land. It is therefore critical to understand forest owners and what policies and programs can help them conserve the forests for current and future generations.

Forest Composition

Forest Composition

FIA characterizes the composition of a forest by forest-type groups, which can be further broken down into individual forest types. Tree species that generally coexist in a stand make up forest types, and similar forest types are collectively known as forest-type groups. Composition can be described further by the count or proportion of species in certain size classes. Size classes include seedlings (less than 1.0 inch d.b.h. and at least 12.0 inches in length for hardwoods or 6.0 inches in length for softwoods), saplings (1.0 to 4.9 inches d.b.h.), trees greater than or equal to 5.0 inches, and sawtimber-size trees (at least 9.0 inches in softwoods and 11.0 inches in hardwoods).

In the 2019 inventory, 102 tree species having a d.b.h. of at least 1.0 inch were identified on FIA plots across Pennsylvania. Fifty-nine forest types in 15 forest-type groups were found throughout the State. The overwhelming majority of forest land (95 percent) was occupied by hardwood forest types. Forest types in the oak/hickory group covered 9.0 million acres, or 54 percent of all forest land. The maple/beech/birch forest-type group accounted for an additional 31 percent of forested area at 5.2 million acres, down from 5.5 million acres in 2004. Other hardwoods, a group that is nearly 50 percent sweet birch by basal area, was the only other forest-type group to break the 500,000-acre threshold at 677,000 acres, or 4 percent of forest land. This group has gained 150,000 acres of forest land area in the last 15 years and nearly half of its total area is in the North Central inventory unit.

Though the number of tree species found in the State represents an incredibly rich diversity of trees, many species exist in relatively small proportions. Only 17 species of trees have at least 1 percent of the 2.6 billion total stems 5.0 inches or greater at d.b.h., accounting for 85 percent of stems and demonstrating a loss of species diversity since 2004 when 19 species each met the same threshold. The 10 most abundant species remain the same as the 2004 list; however, changes for individual species has shifted the order. Red maple is still the most abundant tree by far at 587 million stems, or 23 percent of all trees at least 5.0 inches (Fig. 7). Black cherry still occupies the number two spot at 231 million trees. A steady increase in the estimate for the number of sweet birch totaling 31 percent since 2004 to 193 million stems puts that species as the third most abundant species, up from number six in 2004. Sugar maple stayed in the number four position by abundance at 182 million individuals, but a 16 percent decrease in chestnut oak numbers resulted in the species dropping from the number three spot in 2004 to the fifth position in 2019.

Species diversity is an important component of forest health. The resiliency of the resource in the face of changing conditions as well as insect and disease outbreaks depends heavily on the variety of trees composing a forest. Pennsylvania remains one of the most species rich states outside the southern United States in terms of forest composition. However, it is becoming increasingly clear that some of that diversity is being lost as forests age and mature across the State and fewer species represent at least 1 percent of total abundance, at least in the overstory.

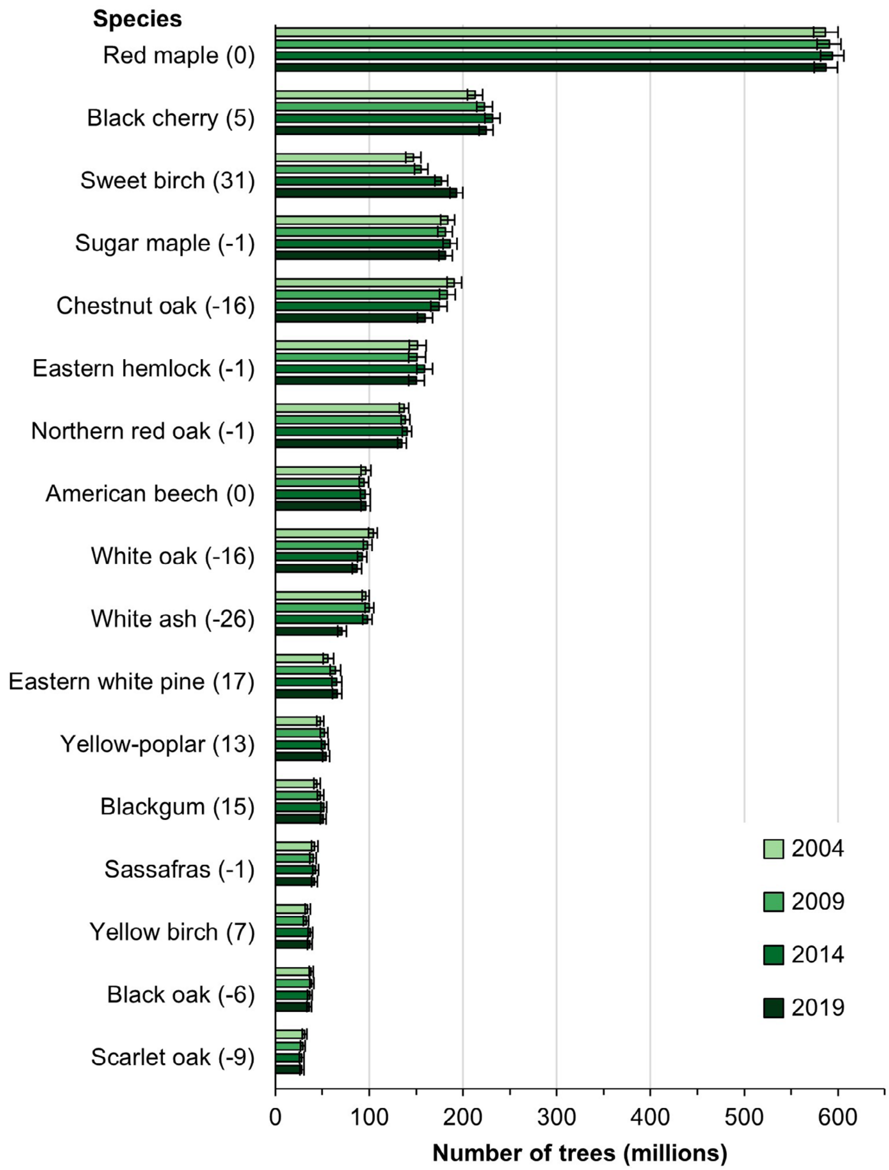

Figure 7.—Number of trees at least 5.0 inches d.b.h. on forest land for species composing at least 1 percent of total number of trees, by species and inventory year, with percentage change between 2004 and 2019 in parentheses, Pennsylvania. Error bars represent a 68 percent confidence interval.

Though the richness of species for seedlings and saplings has continued, composition shifts that appear to be underway are likely to continue. Less desirable species such as sweet birch, American beech, and eastern hophornbeam have proliferated in the understory while major timber species like black cherry, sugar maple, and northern red oak have lost some prominence in regeneration components at both the seedling and sapling level.

Some evidence of shifting composition is already apparent in the forest land area by forest type and forest-type group results. The rise of sweet birch into a more prominent high canopy tree has led directly to the increasing proportion of forested area categorized into the other hardwoods group. Additionally, the effects of sweet birch proliferation have not been confined to just this group. Nine forest-type groups across the State have seen an increase in the proportion of total stems for this single species to the point that over 10 percent of trees found in oak/hickory stands are sweet birch.

Stand Structure

Descriptions of forested lands necessitate characterizing the trees that compose the stands. Stands are categorized by the size of trees representing the majority of the forested condition. These stand sizes are: large diameter (minimum 11.0 inches d.b.h. for hardwoods and 9.0 inches d.b.h. for softwoods), medium diameter (5.0 to 10.9 inches d.b.h. for hardwoods and 5.0 to 8.9 inches d.b.h. for softwoods), and small diameter (less than 5.0 inches d.b.h.). These classes are generally indicative of the developmental stage of the resource and are also referred to as sawtimber, poletimber, and seedling/sapling, respectively.

Pennsylvania timberland has been trending toward larger stand sizes for decades. The earliest FIA inventory of the State in 1955 found roughly one-quarter of the timberland area was in each of the sawtimber and seedling/sapling stand sizes (Fig. 8). By the end of the first full annual cycle in 2004, small-diameter stands had dropped to 11 percent of all timberland and 58 percent of the area was in sawtimber. The latest results show nearly three-quarters (73 percent) of all timberland acreage was sawtimber-sized. Only 7 percent of timberland was occupied by seedling/sapling stands in 2019. Differences in current stand-size class distribution by major ownership group are negligible.

Similarly, stand ages have been moving toward older classes. A steady decline in the timberland area 80 years or younger has been observed since 2004 (Fig. 9). In 2019, stand-age class 81 to 100 years became the dominant class of timberland, occupying 31 percent of total area. An additional 15 percent of timberland is in the over 100-year age class. Between 2004 and 2019, timberland in the 0 to 20 and 21 to 40-year age classes each dropped 3 percentage points, ending at 4 percent and 8 percent of total timberland, respectively. The combined loss from the two youngest classes totals over 1 million acres of timberland in 15 years.

A decades long march of Pennsylvania timberland toward forests dominated by larger and older trees has led to an imbalance of resources. The lack of age and stand-size class diversity has far reaching implications for timber resources, wildlife, and the surrounding environment. A steady decrease in the area of young and small-diameter stands suggests most management activities are of an intensity below the level necessary to initiate a new stand. A sustainable flow of timber resources is dependent on consistent turnover of lands to younger age classes to combat the mortality and quality degradations inherent in overmature forests. Furthermore, maintaining a portion of the resource in early successional conditions is crucial for wildlife species dependent on young forests.

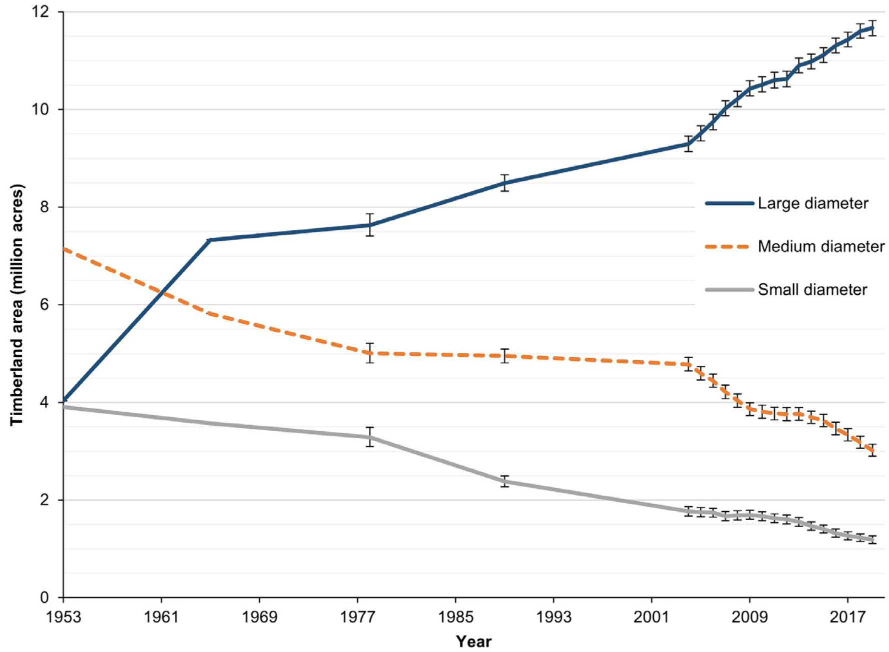

Figure 8.—Area of timberland by stand-size class and inventory year, Pennsylvania, 1955 to 2019. Error bars represent a 68 percent confidence interval.

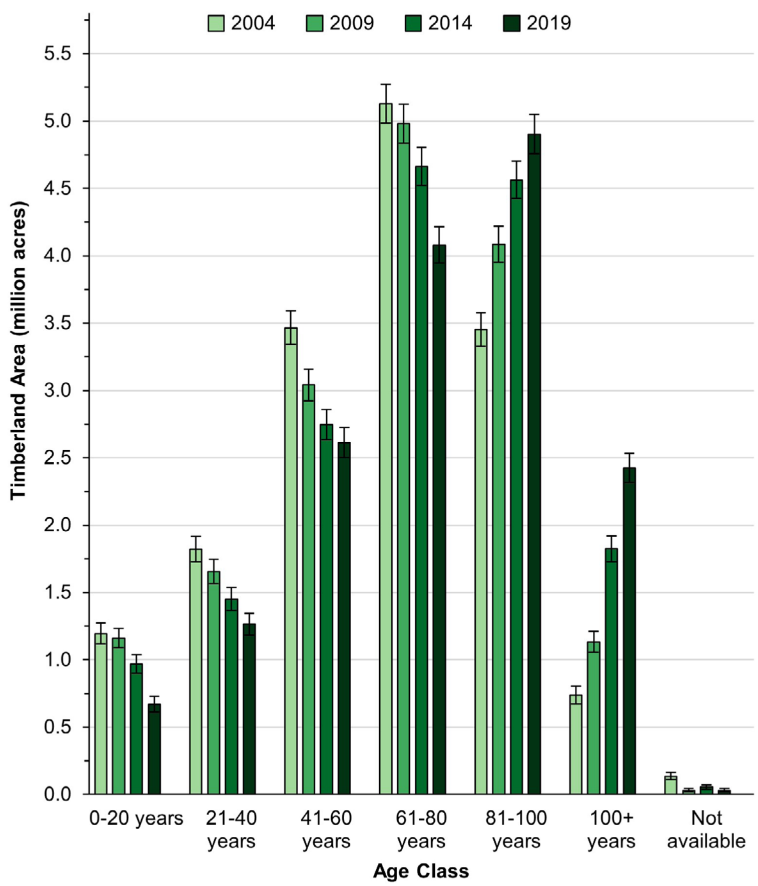

Figure 9.—Timberland area by stand-age class and inventory year, Pennsylvania. Error bars represent a 68 percent confidence interval.

Volume Trends

Volume on Timberland

Volume estimates provide the opportunity to evaluate trends in the wood resource, potential uses of that wood, and its economic value. FIA reports tree volume as sound and net volume of live trees and growing-stock trees (cubic feet), sawtimber trees (board feet, International ¼-inch rule), and biomass (dry tons).

Volumes are calculated for all trees at least 5.0 inches in diameter and are reported in various categories. The sound volume of live trees makes deductions only for rotten and missing wood (rotten cull). Net sound-wood volume, also referred to as net volume, is sound volume with additional deductions for tree form, including sweep, crooks, and forks (sound cull). It includes qualifying sections of cull trees (trees with more than two-thirds cull due to rot and form or those of a noncommercial species). Growing-stock volume includes trees of commercial species with less than two-thirds cull. Sawtimber is the volume in the saw-log portion of growing-stock trees. The minimum d.b.h. for sawtimber trees is 11.0 inches for hardwood species and 9.0 inches for softwood species. The requirements to qualify as growing stock make growing stock and sawtimber the most restrictive and subjective of the volume measures.

Pennsylvania forest land contains an estimated 44.5 billion cubic feet of sound wood, up from 43.5 billion cubic feet in 2014. A relatively small proportion (4.4 percent) of this volume is found on reserved and other forest land, leaving 42.5 billion cubic feet on timberland, and thus theoretically available for use. As a proportion of all net volume on timberland, growing stock is 91 percent (Fig. 10). Rough cull trees account for 7 percent of net volume and rotten cull trees are 2 percent. The portion of timberland net volume that is growing stock has declined due to an increase in the amount of cull since 2004. However, the growing-stock proportion was stable over the last 5 years.

Net volume for 2019 totals 37.3 billion cubic feet, and growth slowed recently, with the 2.2 percent increase since 2014 falling within the bounds of sampling error. Previous increases were 5.7 percent from 2004 to 2009 and 6.6 percent from 2009 to 2014. The recent slowdown in net volume growth was substantially impacted by the reduced estimate of timberland area as per acre volume increased 4.0 percent over the last 5 years as compared to 4.7 percent and 5.4 percent, respectively, in the first and second annual remeasurement periods (Fig. 11). All per acre volume changes at the statewide level since 2004 have been greater than sampling error. In 2019, per acre net volumes ranged from 2,090 cubic feet per acre in the South Central inventory unit to 2,878 cubic feet per acre in the Southeastern unit with a statewide average of 2,333 cubic feet per acre. Net volume per acre also varied across timberland ownerships from 2,285 cubic feet per acre on private land to 3,022 cubic feet per acre on National Forest land. Increases in volume per acre have appeared to level off for most ownerships with the notable exception of private timberland, which has shown a steady rise over the past 15 years.

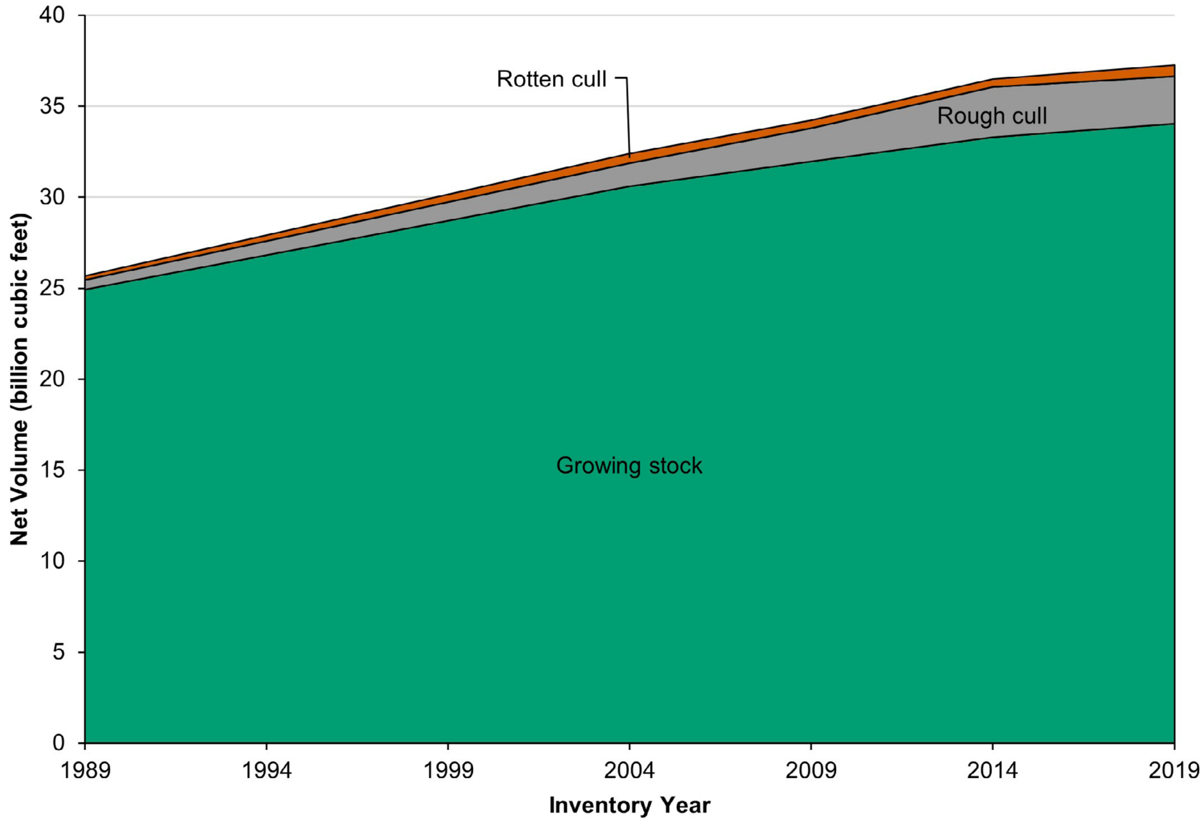

Figure 10.—Net volume on timberland by tree class and inventory year, Pennsylvania.

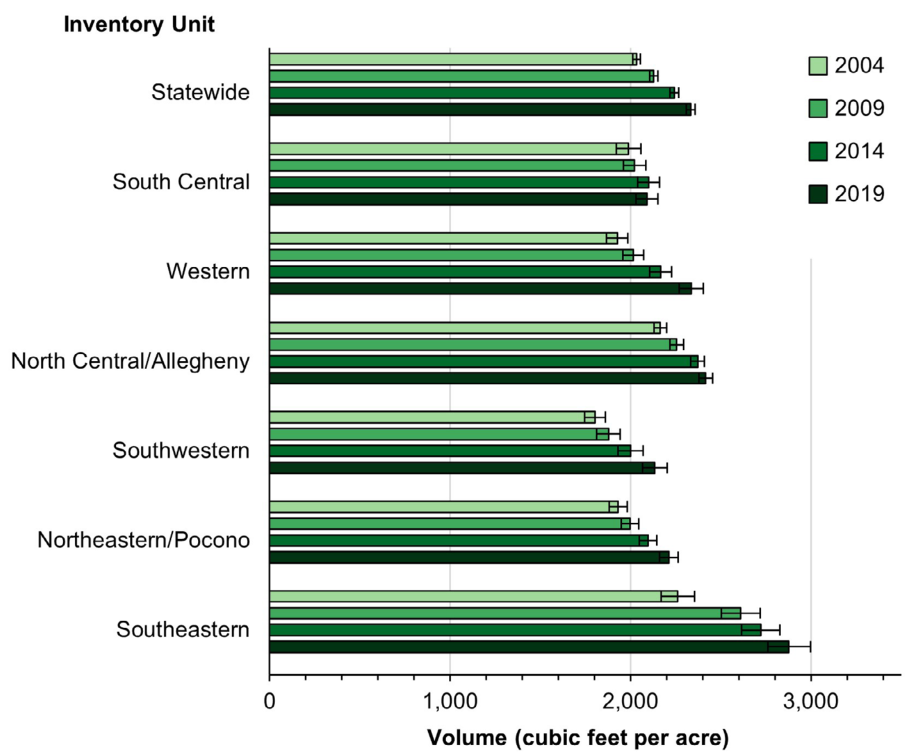

Figure 11.—Net volume per acre of timberland by inventory unit and inventory year, Pennsylvania. Error bars represent a 68 percent confidence interval.

Sawtimber volume reached 121.6 billion board feet, or 7,609 board feet per acre of timberland. The sawtimber volume per acre estimate represents an 8 percent increase since 2014 and a 31 percent increase since 2004. Per acre volumes vary across the regions of the State with 6,380 board feet per acre in the Southwestern unit to 11,150 board feet per acre in the Southeastern unit.

The same list of species composing at least 1 percent of net and growing-stock volume holds for sawtimber volume, though in a different order (Fig. 12). Red maple, northern red oak, black cherry, sugar maple, and yellow-poplar are the five species with the highest sawtimber volumes, having 15-year rates of change ranging from 28 percent in black cherry to 48 percent in yellow-poplar. As a proportion of overall sawtimber volume, most species maintained levels of prominence similar to 2004, with some notable exceptions. Red maple, northern red oak, yellow-poplar, and eastern white pine all increased in proportion of total sawtimber to some degree while chestnut oak, white oak, eastern hemlock, white ash, and American beech decreased.

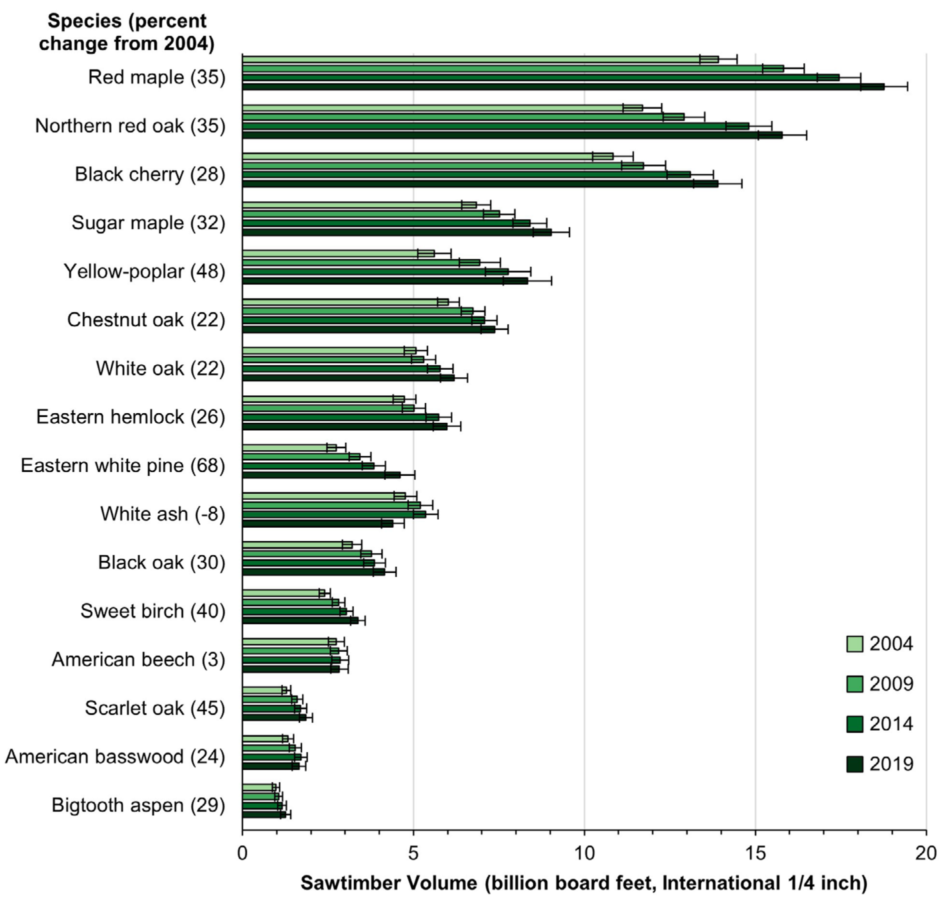

Figure 12.—Sawtimber volume on timberland for species having at least 1 percent of total sawtimber volume on timberland, by species and inventory year, with percent change between 2004 and 2019 in parentheses, Pennsylvania. Error bars represent a 68 percent confidence interval.

As the timber resources of the State continue to mature, all measures of volume have also continued to increase despite the recent downturn in the estimate for the extent of forest land and timberland. That decrease in forested area has led to a slowdown in the rate of volume increases; however, analyzing volumes on a per acre basis over time reveals relatively steady growth. The proportion of volume accounted for by the top 16 species has stayed stable at 88 percent of net volume and 89 percent of growing-stock volume but has increased 1 point to 91 percent in sawtimber. This relative stability suggests a measure of resilience to stressors that will help ensure the State maintains both its dominance as the number one hardwood timber state, and a steady flow of products contributing to the State's economy.

Further encouragement can be taken from the analysis of volume change by component. The increasing portion of sound volume attributed to sound cull (form defect) and cull trees noted in previous reports appears to have slowed. Increases for sound volume, net volume, and growing-stock net volume between 2014 and 2019 were all around 2 percent. This, combined with the slight bump up in proportion of net volume attributed to growing stock statewide, may warrant some cautious optimism about the future of Penn's Woods.

Growth, Removals, Mortality

A forest's ability to provide continuous forest products and ecological services is determined by processes of change within the forest itself. These processes can be evaluated by analyzing growth, removals, and mortality across the resource. Growth is expressed on both a gross and net basis. Gross growth is all volume growth on trees already in the inventory (accretion) and growth due to trees coming into the sample for the first time (ingrowth). Estimates of mortality express the volume in trees that have died between plot visits. Removals fall into two general categories: harvest removals are trees removed due to harvest activities, and other removals refers to trees lost due to a change in land use. Finally, net growth is calculated by subtracting mortality from gross growth, and net change is an expression of net growth minus removals. All change components are expressed on an average annual basis.

Gross growth on timberland totaled 1.1 billion cubic feet per year in 2019, down 4.4 percent from 2009 (Fig. 13). Annual mortality increased 34 percent since 2009 to 410 million cubic feet per year. The effect of increasing mortality can be seen in the significant drop in net growth, which decreased 18 percent since 2009 and 14 percent since 2014 to 691 million cubic feet per year. Annual harvest removals decreased 20 percent since 2009 to 321 million cubic feet per year but were nearly equal to the 2014 estimate. Other removals were estimated to be 15 million cubic feet per year, making total removals (harvest and other removals) 337 million cubic feet per year, down from 433 million in 2009. Lower removals mitigated the effects of decreased net growth on the estimate of net change to a degree. Net change was 355 million cubic feet per year on timberland in 2019, 14 percent lower than in 2009, but still within the bounds of sampling error.

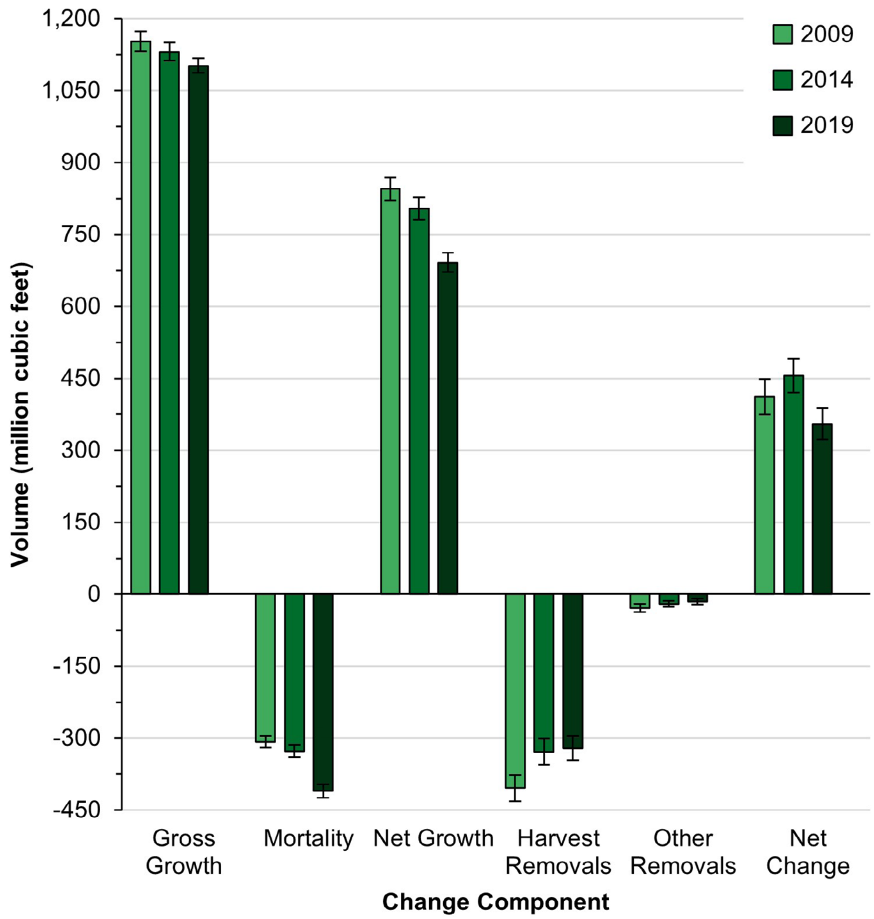

Figure 13.—Annual change component volume on timberland (including land-use change), by component and inventory year, Pennsylvania. Error bars represent a 68 percent confidence interval.

Evaluating mortality in a species relative to its gross growth allows for an assessment of the health of a species. When annual mortality exceeds 60 percent of annual gross growth, a species may be experiencing an acute health issue (Ambrose 2019). Across all species, mortality was 39 percent of gross growth, i.e., net growth is 61 percent of gross growth statewide. However, several prominent species across Pennsylvania are over the threshold of risk. Chestnut oak, white ash, American beech, and bigtooth aspen all have mortality to gross growth ratios over 0.6 (Fig. 14). While the situation for white ash, and to a lesser degree American beech, is well known and quite dire, the decline of chestnut oak in the Commonwealth is a more recent phenomenon.

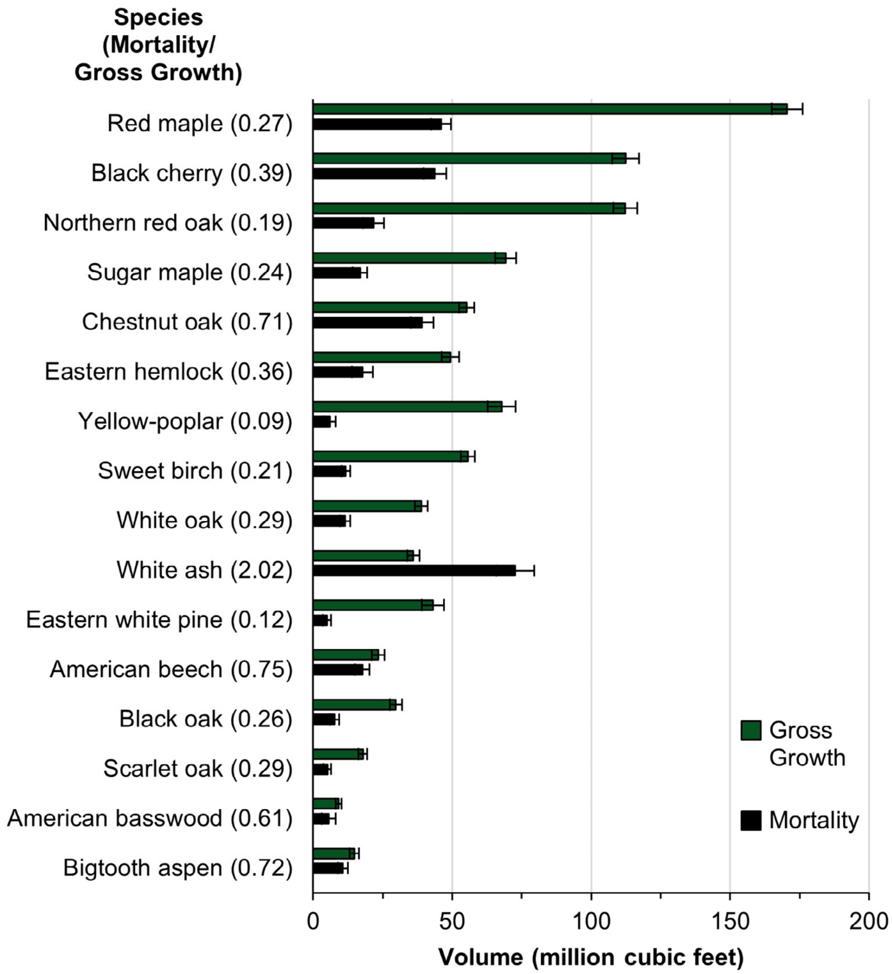

Figure 14.—Average annual gross growth and mortality volume for species having at least 1 percent of overall net volume with mortality to gross growth ratio in parentheses, by species, Pennsylvania 2019. Error bars represent a 68 percent confidence interval.

Comparisons of net growth and harvest removals (NG:HR) give some understanding of the sustainability of management practices. Ratios above 1.0 indicate net growth volume exceeds harvest removal volume. Conversely, ratios below 1.0 mean that volume is removed at a rate exceeding growth, a practice that is unsustainable in the long term. Statewide, net growth has hovered around two times harvested volume since 2009 with NG:HR being 2.1 in 2019 (Fig. 15). The lowest ratio remained in the South Central unit with net growth only 5 percent higher than harvest removals. The Southwestern unit had the highest ratio at 4.2, more than double the 2009 estimate. The largest unit by timberland area, North Central/Allegheny, had the second lowest ratio at 1.7. Statewide, public and private land have similar ratios at 2.1 and 2.2, respectively. High sampling errors associated with low levels of public land in many units make it impossible to compare NG:HR ratios for the major ownerships at the inventory unit level.

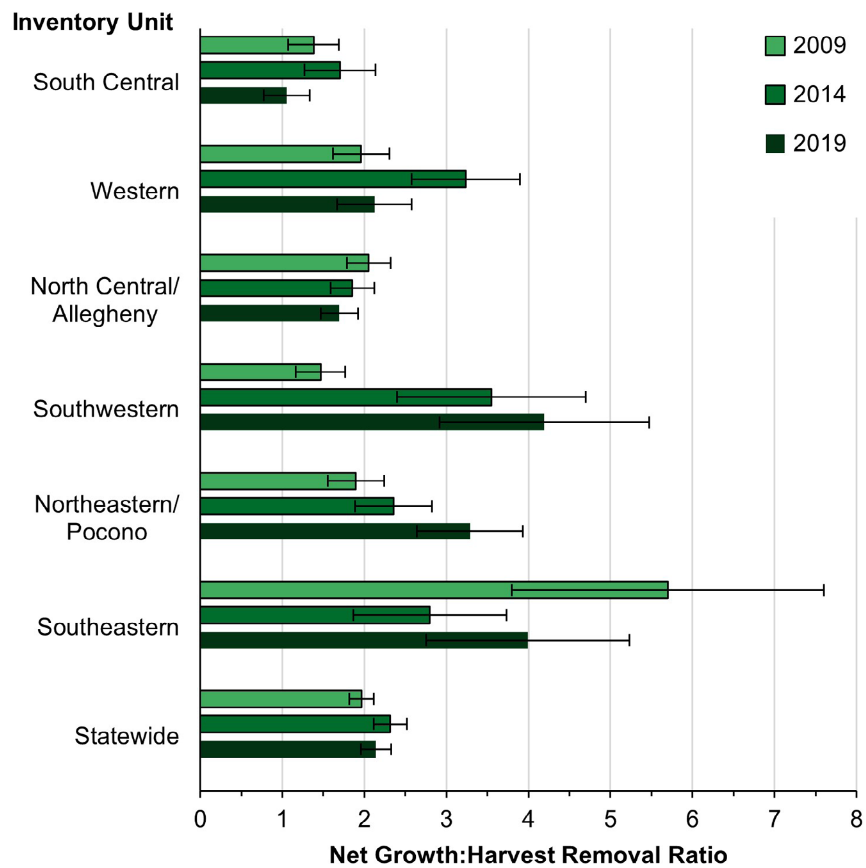

Figure 15.—Net growth of sound volume to harvest removal of sound volume ratio, by inventory unit and year, Pennsylvania. Error bars represent a 68 percent confidence interval.

The forest resources of the Commonwealth continue to exhibit steady rates of gross growth relative to timberland area, though a decrease in the extent of timberland brought about a decrease in total gross growth. However, net growth decreased in both per acre and total estimates. Much of the driving force behind these decreases is the substantial increase in mortality volume, largely due to the devastating effects of emerald ash borer on white ash over the past decade and a half. Several other species exhibited mortality increases, though most continue to have fairly low rates of mortality relative to gross growth and net volume. The exceptions tend to be species with known ongoing health challenges, such as American beech. However, the recent jump in the mortality of chestnut oak, particularly in the South Central unit of the State where it is the most voluminous species, is certainly cause for concern.

Net growth continues to outpace removals by a rate of 2.1 to 1, indicating sustainability of harvest rates statewide. Regions affected by substantial decreases in net growth, however, came closer to harvesting volumes nearly equal to net growth. Again, the South Central unit had a net growth to harvest removal ratio of 1.05, primarily due to the issues noted above. While this can be an indication of unsustainable harvesting practices, it is important to note that FIA cannot determine the status of trees when they were cut.

Salvage harvest operations to utilize timber in high mortality areas are unidentified in the data, therefore harvested volume data must be viewed with some context of local conditions.

Net growth to harvest removal ratios for individual species highlight some issues of concern as well as species that are underutilized. The 1.0 ratio for chestnut oak is a concern; however, the cause is mortality based, not the result of overharvesting. White oak, while under 2.0, is higher now than 5 years ago primarily because of increased net growth, an encouraging result.

Forest Sustainability

Regeneration Status

The regeneration of healthy forests has been a primary concern in the Commonwealth for decades, leading to a study that has been ongoing in some form for over 30 years. Today's forests face an ever-expanding list of old and new stressors. Forests must stand up to native and nonnative pests, poor soils, invasive plant species, deer herbivory, extreme weather events, climate change, legacies of poor management, and increasing fragmentation. All these factors influence forest health and species composition and can eventually lead to interruptions in timber availability. Understanding all stages of stand development is imperative to ensuring the future health of our forest resources.

In 2012, FIA began an intensified regeneration protocol as part of the phase 2 plus (P2+) suite of variables. The measurements in this protocol are made during the summer leaf-on window on 12.5 percent of all plots across the 24 states inventoried by the Station. Additional support for the program from the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry allowed for a measurement intensity of 25 percent of samples in Pennsylvania, or roughly one plot per 24,000 acres. The current protocols build on the prior success of the Pennsylvania Regeneration Study (PRS) begun with the 1989 periodic inventory and adapted for continuous application to the annual inventory in 2001 (McWilliams et al. 2017).

The regeneration indicator (RI) consists of intensified tree seedling measurements and a browse impact code classifying the impact of ungulate herbivory on regeneration. Counts of established tree seedlings are categorized by length into six classes (2.0 to 5.9 inches, 6.0 to 11.9 inches, 1.0 to 2.9 feet, 3.0 to 4.9 feet, 5.0 to 9.9 feet, and 10.0 feet and over). Large-seeded species i.e., oaks, hickories, and walnuts, must be at least 6.0 inches or have a root collar diameter of at least 0.25 inches to be considered established. Additionally, seedlings of these species groups are classified as competitive when they reach a length of 3.0 feet or have a root collar diameter of at least 0.75 inch. Browse impact assessments classify herbivory impacts using evidence including light availability, food availability and preference, competition from understory vegetation, disturbance, and other factors. Five levels of impact (very low, low, moderate, high, very high) describe forest conditions ranging from protection by a well maintained exclosure fence (very low) to all vegetation showing signs of heavy browsing and presence of an obvious browse line (very high) (USDA Forest Service 2018).

For the inventory cycle ending in 2019, a total of 1,034 plots were selected for regeneration indicator measurement from 2013 through 2019. Of these, 687 were forested locations and form the basis for the results presented here.

Statewide, 16 percent of forest land was found to have very low or low browse impact resulting from deer herbivory. High and very high classes accounted for 26 percent of forested area (Fig. 16). Previous inventories saw substantially more area falling into these two higher classes at 43 percent in 2004 and 34 percent in 2009. The moderate class of browse impact represented 59 percent of forest land in 2019, the first time it exceeded 50 percent.

Analysis of PRS and RI datasets in previous reports focused on regeneration adequacy by quantifying the proportion of samples sufficiently stocked with advanced regeneration available to replace a forested stand (Albright et al. 2017). Adequate stocking of regeneration was assessed based on abundance of seedlings in various species groups (desirable, all commercial, high canopy dominants, and all species) at locations with sufficient light available to the forest floor (40 to 75 percent stocked). Statewide, two out of three such sample locations have sufficient advanced regeneration in all species to allow for successful regeneration of a forested stand (Fig. 17). Lesser proportions of samples have adequate stocking of regeneration of more restrictive species groups. Commercial species were adequately stocked on 58 percent of samples. High canopy dominants were adequately stocked on 54 percent of samples. Little more than one-third (38 percent) of plots were sufficiently stocked with the most desirable species of seedlings (e.g., oaks, hickories, maples, ashes, black cherry, yellow-poplar, pines, eastern hemlock) to regenerate the stand.

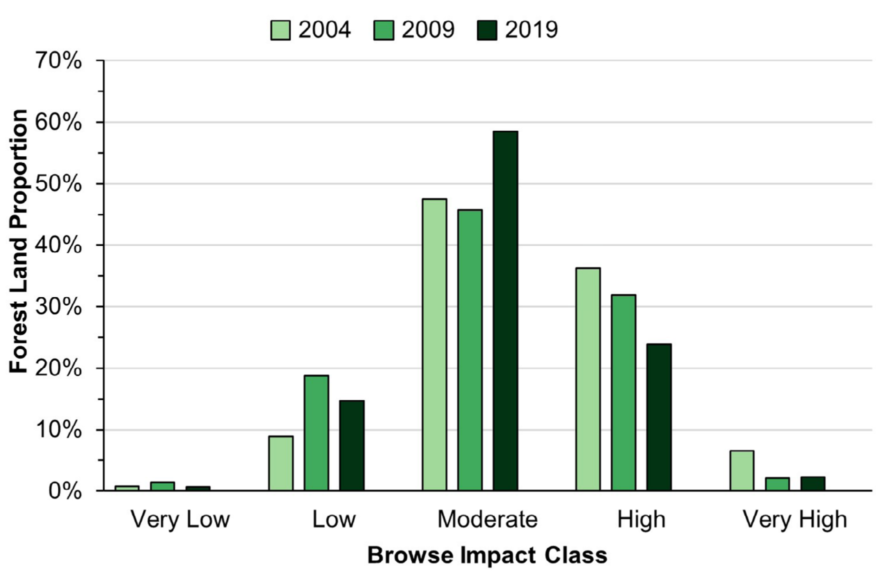

Figure 16.—Forest land proportion by browse impact class and inventory year, Pennsylvania.

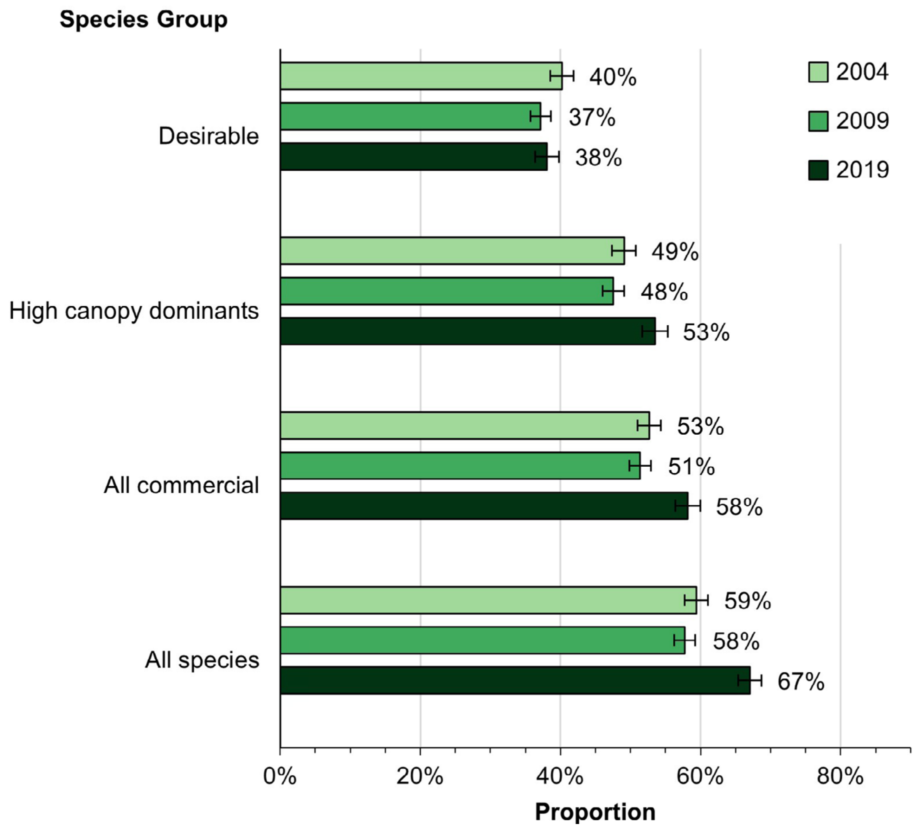

Figure 17.—Proportion of regeneration samples adequately stocked with advanced regeneration for stands from 40 to 75 percent stocked with live trees by species class and inventory year, Pennsylvania. Error bars represent a 68 percent confidence interval.

Herbivory by white-tailed deer continues to have significant effects on understory components with over 25 percent of forested area still showing high or very high browse impacts. However, recent results showing the lowest level of high deer impact in two decades may be the result of changes in management approaches at the Pennsylvania Game Commission (Rosenberry et al. 2009). The overwhelming majority of forest land now shows moderate impacts from deer browse. Though moderate deer browse still has significant impacts on seedlings and understory vegetation, the severity of herbivory effects appears to have decreased in the past 15 years.

Though trends point to increasing proportions of seedlings in the largest size classes, the increased numbers of seedlings 5.0 feet or greater per acre do not carry over into increased sapling numbers. These regeneration challenges span the ecological spectrum with decreased sapling estimates for northern red oak and chestnut oak but also black cherry and sugar maple. Furthermore, despite the major oak species combined having maintained stable estimates of seedlings per acre, lower proportions of oaks meet the definition of a competitive stem that is most likely to produce a dominant stem post-disturbance (Dey 2014).

While regeneration adequacy analysis has shown improvement in most species groups, opportunities to address challenges still exist. Adequate stocking of desirable regeneration has not kept pace with the improvements seen in the other species classes but can be described as stable, at best, with under 40 percent of forest land likely to regenerate with desirable trees. Most inventory units of the State face similar issues, though of varying magnitude. In the Northeastern unit, the discrepancy is particularly stark with less than half the amount of forest land adequately stocked with desirable species when compared with all species. High proportions of high browse impact in the unit likely have a substantial negative effect on adequacy estimates. In the North Central/Allegheny unit, despite signs of improvement over 15 years and faring slightly better in both measures of regeneration adequacy, desirable species still lag behind all species.

Invasive Plants

Invasive plant species (IPS) are native or nonnative species that can negatively affect ecosystems. Several factors contribute to the success of invasive plants such as rapid growth, prolific seed production, survival in harsh environments, and vegetative propagation. Humans, ungulates, fragmentation, and disturbance promote the spread of IPS. Once established, they can quickly take over an area, displacing other species and affecting habitat suitability.

FIA assesses the presence and cover of 40 IPS (39 species and 1 undifferentiated genus) on P2+ plots. To maintain regional consistency, this species list is not customized for Pennsylvania, but represents native and nonnative species of concern in the 24 states of the Northern Research Station. In 2019 there were 688 plots monitored for IPS in Pennsylvania.

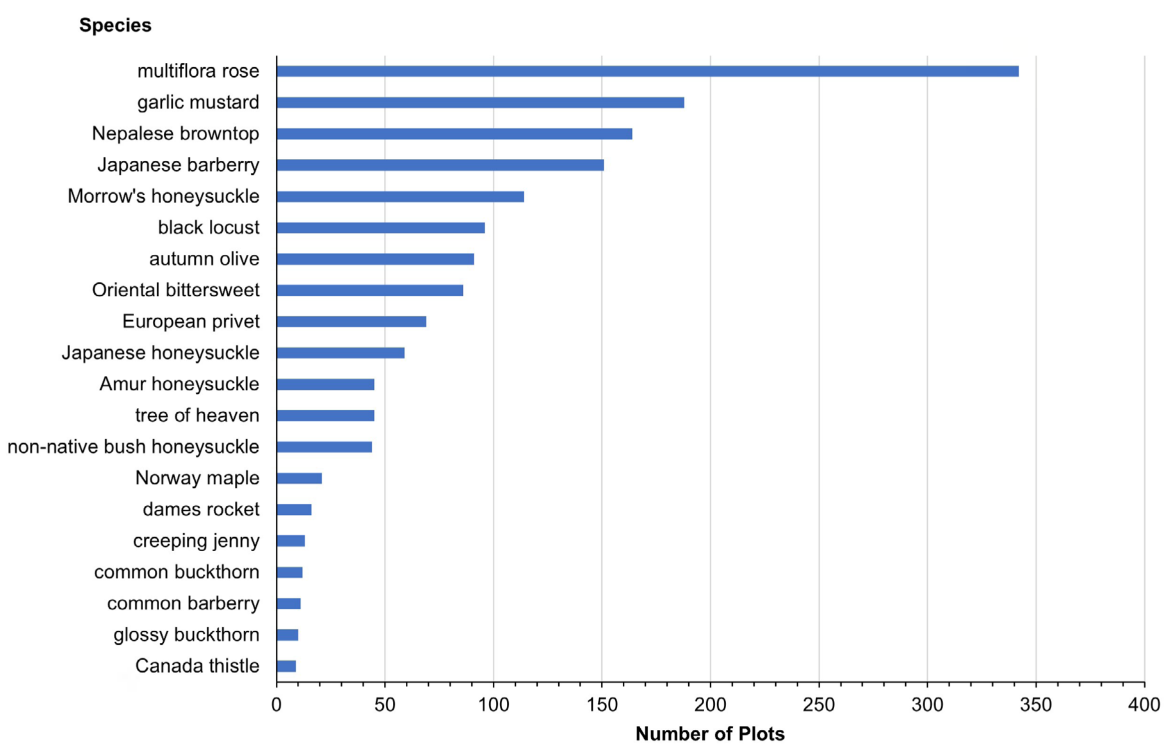

Figure 18.—Number of observations for 20 most abundant invasive plant species, Pennsylvania, 2019.

In general, IPS were found throughout the State with the southern part having the highest number of IPS per plot. Between 2014 and 2019 the number of plots with invasive plants increased slightly. In 2014, 61.0 percent of plots had one or more IPS versus 64.2 percent in 2019.

Of the 27 IPS recorded in Pennsylvania, multiflora rose was the most commonly observed. This shrub was recorded on 342 plots (49.7 percent) and was found throughout the State (Fig. 18). While it was the most observed invasive species, multiflora rose coverage averaged under 7 percent where present. Honeysuckle and garlic mustard were also numerous, each found on roughly 27 percent of plots. The number of IPS per plot varied from 0 to 12.

Health Indicators

Forest Insect and Disease Activity

Emerald Ash Borer

First detected in western Pennsylvania in 2007, emerald ash borer (EAB) spread to every county by 2017. All North American ash species are hosts of EAB; however, host preference appears to vary by species, with consistent observations of high mortality among green ash and black ash and variable mortality of white ash (Herms and McCullough 2014, McCullough 2020). Although EAB shows some preference for stressed trees, all trees 1.0 inch d.b.h. or greater are susceptible regardless of vigor.

Ash trees represent 2.7 percent of total species abundance on forest land in Pennsylvania. There are an estimated 211.1 million ash trees (greater than or equal to 1.0 inch d.b.h.), a 31.3 percent decrease since 2004. White ash is most abundant (92.7 percent), followed by green ash (5.7 percent) and black ash (1.7 percent).

Combined, ash species have a high mortality-to-gross growth ratio, which increased from 0.4 to 2.1 between 2014 and 2019. While this increase is due to increasing ash mortality and decreasing ash growth across all inventory units, it is largely influenced by changes within the South Central unit, where the mortality-to-gross growth ratio increased from 1.0 to 9.0 between 2014 and 2019. Black ash has the highest mortality-to-gross growth ratio at 3.8, followed by white ash at 2.0 and green ash at 0.9. Average annual mortality as a percentage of total volume is highest for black ash (70.5 percent), followed by white ash (6.1 percent) and green ash (2.7 percent).

Pennsylvania's ash trees are an important component of the statewide forest resource. Since its initial detection, EAB has had a large impact on ash resources throughout Pennsylvania. The high mortality-to-gross growth ratio indicates that current statewide mortality of ash exceeds growth. Ash mortality is expected to increase as EAB persists and populations spread. Continued monitoring will help to identify the long-term impacts of EAB.

Oak Wilt

Caused by the fungus *Bretziella fagacearum*, oak wilt is an important source of oak mortality in Pennsylvania. All species of oak are susceptible to oak wilt; however, the disease occurs more frequently and progresses more rapidly in species of the red oak group (Haugen et al. 2022). Previously, oak wilt was only known to exist in areas of the State west of the Susquehanna River, with the majority of counties in the region having some incidence of the disease (Fig. 19); however, oak wilt has recently been detected in southeast Pennsylvania.

Pennsylvania has an estimated 770.7 million oaks on forest land, which represents 9.7 percent of total species abundance. Five oak species account for 95 percent of total oak abundance. Of the red oaks, northern red oak is the most abundant at 228.3 million trees, followed by black oak (73.3 million trees) and scarlet oak (55.6 million trees). Chestnut oak is the most abundant species in the white oak group (222.2 million trees) followed by white oak (154.2 million trees).

While the mortality-to-gross growth ratio for chestnut oak increased from 0.3 to 0.7 since 2009, the ratios for northern red oak, black oak, scarlet oak, and white oak have remained relatively low. The mortality rate as a function of total volume is highest for chestnut oak; however, the mortality rates for all oak species is less than 1.6 percent.

Oaks provide several ecological benefits, including mast production for wildlife, and are valued timber species. While the current statewide impacts from oak wilt are generally low, continued spread of this disease could increase oak mortality and have long-term effects on forest composition.

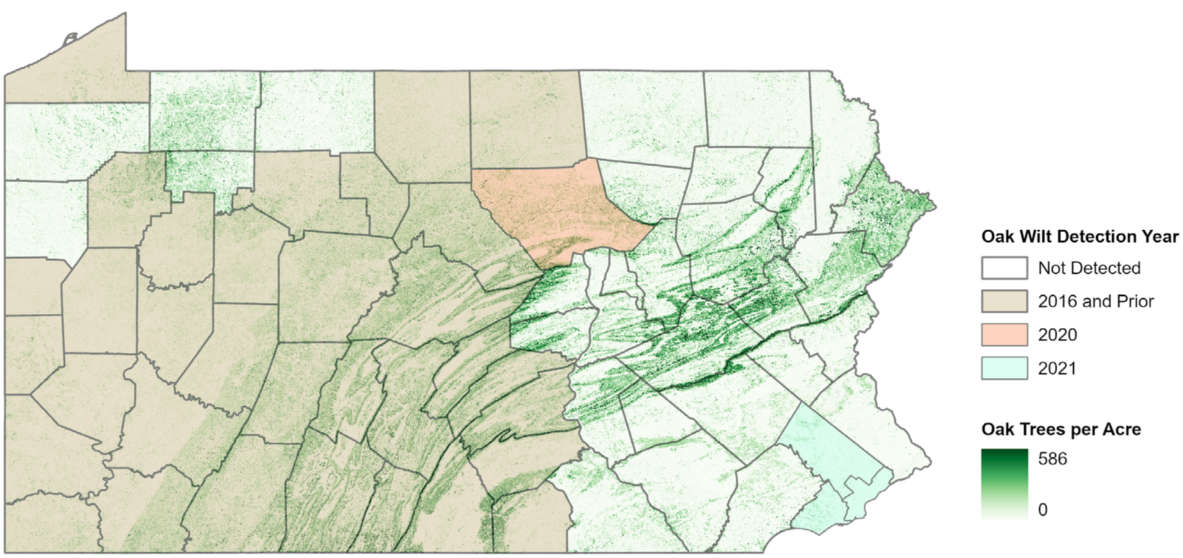

Figure 19.—Distribution of top five oak species in trees per acre with year of oak wilt detection by county, Pennsylvania.

Projection: Web Mercator WGS 1984. Source USDA Forest Service, Forest Inventory and Analysis program, 2019; USDA Forest Service 2021. Geographic base data are provided by the National Atlas of the USA. FIA data and tools are available online at https://www.fs.usda.gov/research/products/dataandtools/forestinventorydata*. Cartography: T.A. Albright, USDA Forest Service, December 2021.*

Tree Crown Health and Damage

The overall health and crown condition of trees can be impacted by various types of stressors. Biotic stressors can include native or introduced insects, diseases, invasive plants, and animals. Abiotic stressors include storm damage, drought, flooding, cold temperatures, nutrient deficiencies, the physical properties of soils that affect moisture and aeration, and toxic pollutants. Invasions by exotic diseases and insects are one of the most important threats to the productivity and stability of forest ecosystems around the world (Liebhold et al. 1995, Pimentel et al. 2000, Vitousek et al. 1996).

All trees at least 5.0 inches in d.b.h. are assessed for damages from biotic and abiotic agents on the full set of FIA plots. Up to three damages are recorded on each tree with a focus on the most severe impacts affecting survivability, growth, and merchantability.

Tree damage was recorded on approximately 32 percent of all trees in Pennsylvania. There is a general pattern of higher damage in the Pocono Mountain area, the northern tier, and the southwest portion of the State. Decay/disease was the most frequent type of damage overall, ranging from nearly 0 percent on many species to above 20 percent on red maple, black cherry, American beech, and sugar maple. Notably, insect damage was present on nearly 13 percent of eastern hemlock, 16 percent of white ash, and 21 percent of American beech trees. The occurrence of all other damage types was very low (Fig. 20).

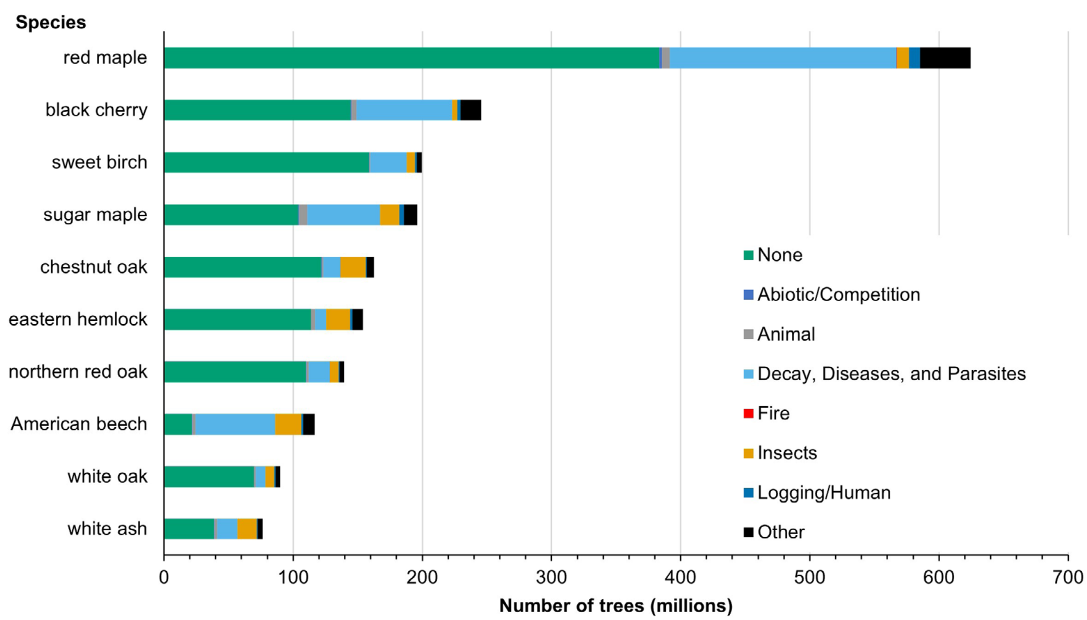

Figure 20.—Number of trees by damage type and species for 10 most abundant species, Pennsylvania, 2019.

Though the occurrence of damage is similar in New York (35 percent) and Ohio (36 percent), it is lower in Maryland (19 percent), New Jersey (19 percent), and West Virginia (28 percent). In sugar maple, the high occurrence of insect damage is likely due to the sugar maple borer, which can cause lumber defects but rarely causes mortality (Hoffard and Marshall 1978). In eastern hemlock, the high occurrence of insect damage is likely due to hemlock woolly adelgid.

Forest Ecosystem Services

Forest Carbon

Among terrestrial ecosystems, forests contain the largest reserves of sequestered carbon. The accumulation of carbon in forests helps to mitigate emissions of carbon dioxide to the atmosphere from sources such as wildfires or the burning of fossil fuels. Carbon accumulates in growing trees via the photosynthetically driven production of structural and energy-containing organic (carbon) compounds that primarily accumulate in trees as wood. Approximately 50 percent of tree biomass is carbon (based on dry weight). Over time, this stored carbon also accumulates in standing dead trees, down woody materials, litter, and forest soils. The FIA program uses a combination of field measurements and models to estimate forest carbon stocks. Procedures for the estimation of carbon are detailed in the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018 (U.S. Environmental Protection Agency 2020). Forest carbon is often broken down into storage pools. The carbon pools and their components discussed here are defined as: live biomass (live trees at least 1.0 inch d.b.h. and live understory vegetation); dead wood (standing dead trees at least 1.0 inch d.b.h. and down dead wood); forest floor litter; and soil organic matter estimated to a depth of 1 meter (39 inches).

Total forest ecosystem carbon stocks in Pennsylvania are an estimated 1.74 billion tons, which has remained relatively unchanged since 2014 despite a small decrease in the area of forest land. Carbon density is an estimated 104 tons per acre of forest land. Soil organic carbon and live trees are the largest components; combined, these account for 90 percent of forest carbon stocks (Fig. 21).

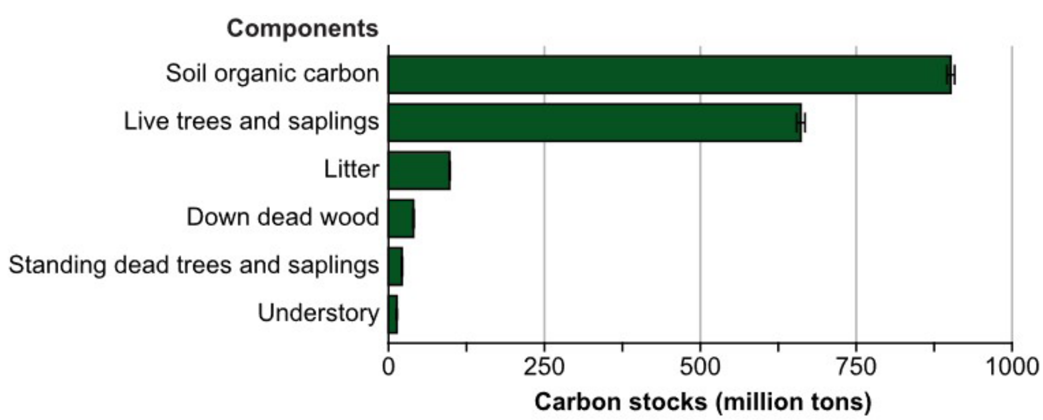

Figure 21.—Carbon stocks on forest land by component, Pennsylvania, 2019. Error bars represent a 68 percent confidence interval.

Most of Pennsylvania forest carbon stocks are in stands between 61 and 100 years old (59 percent of total forest carbon). Twenty-three percent of total forest carbon is found in stands 60 years old and younger, and 18 percent is in stands older than 100 years. As stands age, total carbon density generally increases, driven in large part by net carbon accumulation in live biomass (Fig. 22). Total carbon density in stands 20 years and younger is 71 tons per acre, with 14 percent of that in the live biomass carbon pool, increasing to 118 tons per acre in stands over 100 years old (43 percent in the live biomass pool).

While forest ecosystem carbon stocks have remained relatively stable in Pennsylvania, density has risen slightly as a result of maturing stands accumulating carbon in the live biomass pool, coinciding with a small loss of forest land area. Soil organic carbon stocks represent the largest pool in Pennsylvania and are important to long-term carbon storage. The amount of carbon stored in the soil is similar across forest types and age classes, making loss or gain in the pool a slow process as long as the land remains forested. The carbon stocks in live biomass also represent a substantial amount of the total carbon as well as opportunities to increase carbon stocks in the near term, as this pool is most affected by forest management. The greatest threat to the carbon stocks of Pennsylvania forests is loss of forest land. As mitigating U.S. greenhouse gas emissions becomes increasingly important, an understanding of trends in carbon sequestration in the face of land use change will be an essential tool for forest managers.

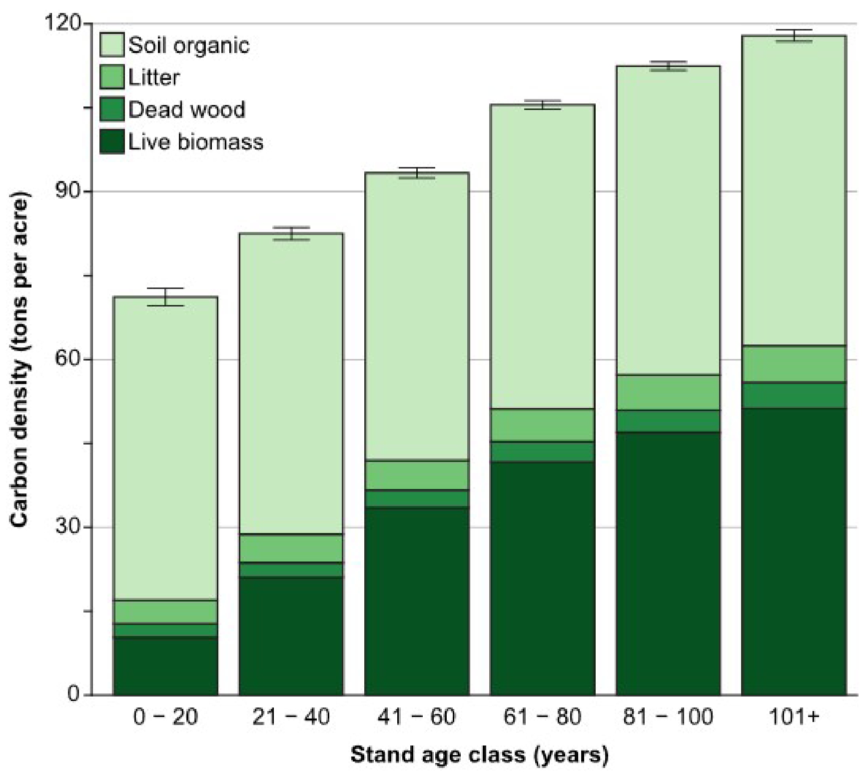

Figure 22.—Carbon density by stand-age class and carbon pool, Pennsylvania, 2019. Error bars represent a 68 percent confidence interval around the total density estimate (all pools).

Forest Economics

While Pennsylvania contains significant volumes of eastern hemlock and eastern white pine, it holds the largest hardwood resource in the Nation, and this resource is renowned for its quality (Pennsylvania HDC 2020). This timber volume and reputation has allowed Pennsylvania to have the highest level of direct employment in forest product industries in the Northeast and Midwest regions (Leefers et al. 2020). In 2018, the wood products industries in Pennsylvania employed 10 percent of the State's manufacturing work force and had a $21.5 billion direct impact and a $36 billion indirect impact on the State's economy.

Sawmills are Pennsylvania's most important user of hardwood sawtimber. The major sawmill products are lumber used in appearance applications, sawn industrial products, and low-grade lumber. However, since the beginning of the 21st century, the domestic market for lumber used in appearance applications has declined by over 50 percent (Fig. 23). This decline was primarily the result of globalization of furniture manufacturing, the decline in home construction, and the substitution of wood composite and non-wood products for hardwood lumber (Luppold and Bumgardner 2016).

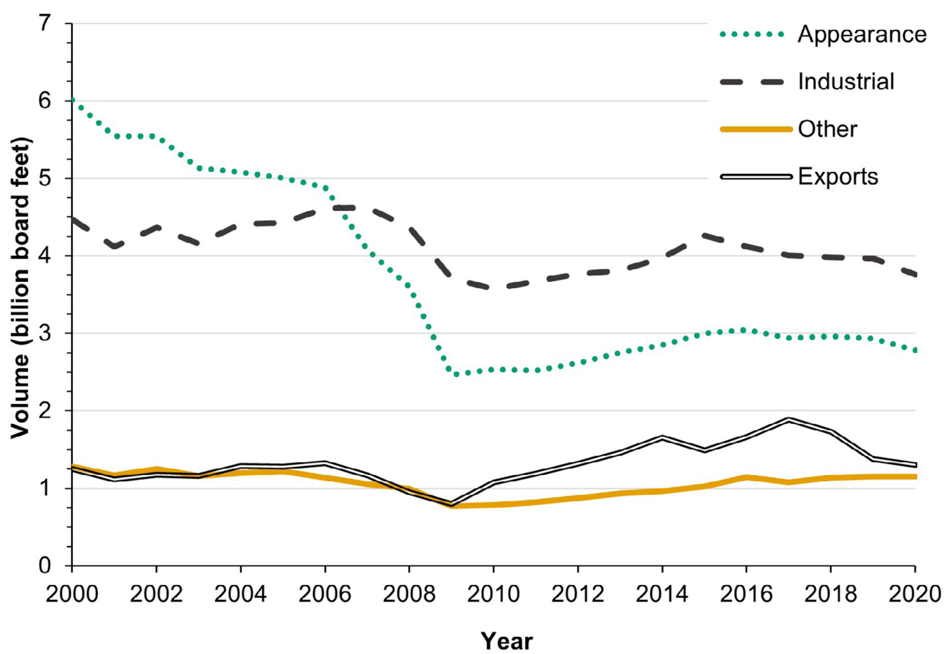

Figure 23.—Volume of U.S. sawn hardwood lumber consumption for appearance applications, industrial applications, other applications, and exports from 2000 to 2020. (Sources: UNECE/FAO 2021, USDA FAS 2021) (assuming 2.36 cubic meters per thousand board feet).

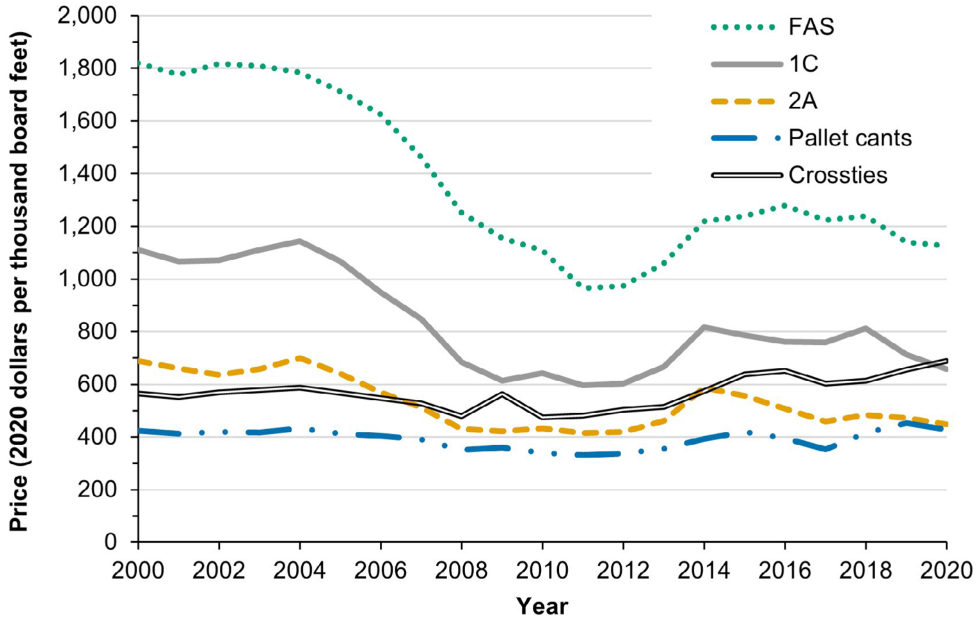

Figure 24.—Resource volume weighted aggregate FAS, 1C, and 2A green lumber prices for Pennsylvania compared to northeastern hardwood pallet prices, from 2000 to 2020 (using procedures in Luppold and Bumgardner 2021b).

One market for appearance hardwood lumber that initially grew after the 2009 recession was exports, and historically Pennsylvania has been the largest exporter of hardwood lumber (USDC ITA 2021). While the growth in exports between 2009 and 2017 did not compensate for the loss of domestic markets for appearance lumber, it was estimated that exports accounted for over 60 percent of the total markets for high and mid-quality lumber in 2017 (Luppold and Bumgardner 2021a).

Perhaps the most significant change within the hardwood industry in the 21st century is the declines in the prices of appearance lumber (Fig. 24). These declines can be depicted for Pennsylvania in aggregate (multiple species) terms using procedures described in Luppold and Bumgardner (2021b).

Pennsylvania retains its status as the leading provider of high-quality hardwood timber, which contributes tens of billions of dollars to the State's economy and employs tens of thousands of people. However, economic crises and decreased demand due to product alternatives have resulted in reduced values for hardwood products. And, like many manufacturing industries, increased production efficiencies have put additional pressure on employment numbers. Housing starts and construction lumber pricing will continue to affect employment and timber values in the hardwood industry. Reversing recent hardwood price trends through market development would be beneficial in allowing for increased returns for forest management activities as well as the maintenance of the long-term quality of the forest resource in perpetuity.

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