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Abstract

This report summarizes the 2013 results of the annualized inventory of Delaware's forests conducted by the U.S. Forest Service, Forest Inventory and Analysis program. Results are based on data collected from 389 plots located across the State. There are an estimated 362,000 acres of forest land in Delaware with a total live-tree volume of 936 million cubic feet. There has been no change in the area of forest land since 2008, however, live-tree volume in Delaware has been increasing. Forest land is dominated by the oak/hickory forest-type group, which occupies 53 percent of total forest land area. Seventy-four percent of the forest land area is in large diameter stands, 12 percent in medium diameter stands, and 13 percent in small diameter stands. The volume of growing stock on timberland has been rising since the 1950s and currently totals 811 million cubic feet. Between 2008 and 2013, the average annual net growth of growing-stock trees on timberland was approximately 16 million cubic feet per year. Additional information is presented on forest attributes, ownership, carbon, timber products, species composition, regeneration, and forest health. Detailed information on forest inventory methods, data quality estimates, and summary tables of population estimates are available online at https://doi.org/10.2737/NRS-RB-115.

Acknowledgments

The authors would like to thank the many individuals who contributed to the collection, processing, and analysis of Delaware's forest inventory data. Primary field crew staff throughout the 2009-2013 field inventory cycle included Thomas Albright, Joseph Kernan, William Moir, Stephen Potter, Michael Whitehill, and Thomas Willard. Data management personnel included Charles Barnett, Mark Hatfield, Barbara O'Connell, Paul Sowers, and Jay Solomakos. Report reviewers and contributors included William Seybold, Michael Valenti, and Thomas Weber.

Cover: Forest buffer in a patchwork of agricultural land along the Murderkill River, Kent County, Delaware. (NAIP imagery 2011).

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Foreword

Of all the natural resources in Delaware, forests play a key role in improving the quality of life of all Delawareans. Healthy, vigorous trees absorb large quantities of carbon dioxide and release oxygen into the atmosphere and in the process filter out pollutants, thus greatly improving our air quality. Forests protect watersheds, thereby improving the quality of the water that we drink and the water that is so important to the health and functionality of natural ecosystems. Forests produce wood and other products that we use every day in our places of work and in our homes. Many species of wildlife depend on forested habitats for their very survival. And forests provide every citizen with unique recreational opportunities along with aesthetic enjoyment and a general sense of well-being.

With all these wonderful, natural benefits, it should be no surprise that the mission statement of the Delaware Forest Service is "to conserve, protect, and enhance Delaware's forests through education, management, and professional assistance." Protecting and conserving Delaware's remaining forest lands is of utmost importance. The "Delaware Statewide Forest Strategy" (Delaware Forest Service 2010) outlines a number of steps that our foresters, support staff, and cooperating partners have been taking over the last 7 years to: (1) improve forest health and functionality, (2) help develop new forest markets, (3) encourage all forest landowners to practice sustainable forest management, and (4) expand public awareness and appreciation of the forests in Delaware. Our goals are measurable and attainable as we seek to conserve this renewable resource for generations to come.

To this end, the Delaware Forest Service is partnering with numerous agencies, both public and private, in an effort to improve efficiency in reaching the desired results: healthy, sustainable forests. Our most significant partner is the U.S. Forest Service, as this federal agency supports many of our primary landowner assistance programs including urban and community forestry, forest health management, forest stewardship, and wildland fire protection. A key component in planning future management activities for our precious forests is an overall assessment and measurement of the forest resources in Delaware. This is where the U.S. Forest Service, Forest Inventory and Analysis (FIA) program plays a critical role. FIA specialists completed inventories of Delaware forests in 1957, 1972, 1986, 1999, 2008, and most recently in 2013. These data enable us to detect trends in the forest resource, for better or for worse, and to apply such knowledge to sound forest management recommendations. It is in the interest of all Delawareans to safeguard the vitality of our forests. The data contained in this most recent FIA report offers detailed and valuable information that will help all of us with the future challenges we face in conserving, protecting, and enhancing Delaware's forests.

Michael A. Valenti, Ph.D.
State Forester
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Contents

Highlights

On the Plus Side

- Delaware is home to an estimated 362,000 acres of forest land. There has been no net loss in forest land area since the 2008 inventory, indicating that forest land area remains stable following a period of net forest loss between 1986 and 2008.
- Seventy-seven percent of Delaware's forest land is privately owned, and the vast majority of these owners are individuals, families, or other unincorporated groups, collectively called family forest owners.
- Total forest ecosystem carbon stocks in Delaware are estimated to be 31million tons of carbon, an increase of approximately 6 percent relative to 5 years ago. This sequestered carbon helps offset U.S. greenhouse gas emissions.
- Continuous volume increases have brought Delaware's wood resource to record levels. Volume increases are greatest for sawtimber-size trees, which showed a 12.6 percent increase in board-foot volume.
- Since 2008, net growth has been nearly two and a half times that of removals, with the net change amounting to an annual increase of 1.3 percent in inventory volume. This implies that the current level of removals is sustainable and that increases in volume will continue in the State.
- Wildlife habitat provided by standing dead trees (snags) is relatively high, with an average of 12.7 standing dead trees present for every acre of Delaware forest land. Snags can provide critical habitat for many forest-associated wildlife species, including the red-headed woodpecker.

Areas of Concern

- Although there was no significant loss of forest land in Delaware from 2008 to 2013, urban and residential development continue to put pressure on forest land, especially in the most heavily forested county of Sussex.
- Approximately 80 percent of family forest owners do not have a management plan for their forest holdings, and most have not participated in any other traditional forest management planning or assistance programs.
- White oak is intolerant of shade and is among the preferred species for deer browse. Currently, there are fewer white oak species in the smaller diameter size classes than in the sawtimber size class. With limited regeneration potential, white oak may be replaced by other species in the future, and its current presence in the overstory may not be sustainable.

- Invasive plant species, including Japanese honeysuckle and multiflora rose, are widely distributed across Delaware.

Issues to Watch

- Fifty-three percent of the family forest land is owned by people who are 65 years of age and older. As land transfers hands, it will be important to monitor how the next generation of owners manage and care for their forests.
- Delaware is continuing to become more urbanized as measured by increases in housing and population density data and the proportion of forest classified as wildland-urban interface (WUI) forest. This can lead to forest loss and fragmentation, which affects the benefits and services forests provide and makes forest management more difficult.
- Comparing the net growth-to-removals (G/R) ratios of individual species to the average ratio for all species (2.4:1) reveals which species are increasing in importance and which are decreasing. The high G/R ratios for yellow-poplar and sweetgum indicate these species will increase in importance in Delaware forests.
- The condition of ash, eastern hemlock, and maple trees should be monitored closely due to the recent invasion of emerald ash borer and hemlock woolly adelgid, and the likely future invasions by Asian longhorned beetle and Sirex woodwasp.
- While ash is a relatively small component of overall forest land, it's predominance in riparian and urban forests makes the proliferation of emerald ash borer a significant threat to the health and composition of these areas.
- Delaware sawmills only process about 7 percent of the industrial roundwood that is harvested from the State. The rest of the industrial roundwood is processed by mills in other states, and as a result, most of the timber processing jobs and economic values are realized outside the State.
- The trend of increasing forest land area in large diameter stands and the increasing number of larger size trees indicates that Delaware forests are continuing to mature. At the same time, both small and medium diameter stand-size classes have seen gradual declines during recent decades. This, coupled with an increase in stand age, may suggest loss of early successional habitat that is important for some wildlife species in decline.
- The Northern Forest Futures study projects decreases in the area of forest land and tree volume in Delaware over the next 50 years for various future scenarios.

Background

Canada geese take refuge in a Delaware pond. Photo by Andrew Lister, U.S. Forest Service.

Report Overview

The forests of Delaware are valuable due to their importance to the economy and the quality of life of its residents. These forests offer habitat for the State's diverse wildlife populations and help protect Delaware's soil and water resources. Accurate and statistically defensible information is critical for understanding the current conditions, interpreting trends over time, and projecting future scenarios.

The Forest Inventory and Analysis (FIA) program is the nation's forest census. It 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 requirement of the forest and range lands of the United States" (Forest and Rangeland Renewable Resources Planning Act of 1974; 16 USC 1601 [note]). FIA has been collecting, analyzing, and reporting on the nation's forest resources for over 80 years. Data collected on the status and trends of the extent, composition, structure, health, and ownership of the forests are used by policy makers, resource managers, researchers, and the general public to better understand the nation's forest resources and to make more informed decisions about their fate.

This report is the culmination of the first complete remeasurement of the inventory of Delaware's forests using FIA's annualized forest inventory system. Results are based on data collected from 2009 through 2013 on 389 plots (136 of which were at least partially forested) located across Delaware, hereafter referred to as the 2013 inventory. Previous inventories of Delaware's forest resources were completed in 1957 (Ferguson 1959), 1972 (Ferguson and Mayer 1974), 1986 (Frieswyk and DiGiovanni 1989), 1999 (Griffith and Widmann 2001), and 2008 (Lister et al. 2012). Up through the 1999 inventory, data were collected under a different inventory system where states were inventoried periodically with no measurements made between inventories. The annualized system was implemented in Delaware in 2004 to provide updated forest inventory information every year based on a 5-year cycle. The FIA program is the only source of data collected from a permanent network of ground plots from across the Nation that allows for comparisons to be made among states and regions.

This report is divided into chapters that focus on forest features, forest health, and forest economics. Details about the data collection, estimation procedures, and statistical reliability are included in the section "Statistics, Methods, and Quality Assurance," available at https://doi.org/10.2737/NRS-RB-115. The section also includes a glossary (e.g., growing-stock trees, ingrowth, etc.) and numerous tables summarizing the results reported here.

A Guide to the FIA Forest Inventory

What is a tree?

The FIA program of the U.S. Forest Service defines a tree as a perennial woody plant species that can attain a height of at least 15 feet at maturity. Growing-stock trees include live trees of commercial species that have a diameter at breast height (d.b.h.) of 5.0 inches and larger and that meet specified standards of quality or vigor. A complete list of the tree species measured in this inventory can be found in the appendix.

What is a forest?

A forest can come in many forms depending on climate, quality of soils, and the available gene pool for the dispersion of plant species. Forest stands can range from very tall, dense, and multi-structured, to short, sparsely populated, and single layered. FIA defines forest land as land that has at least 10 percent crown cover by live trees or formerly had such tree cover and is not currently developed for a nonforest use. The area with trees must be at least 1 acre in size and 120 feet wide.

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

From an FIA perspective, there are three types of forest land:

- Timberland is unreserved forest land that meets the minimum wood volume productivity requirement of 20 cubic feet per acre per year.
- Reserved forest land is public land withdrawn from timber utilization through legislative regulation.
- Other forest land is commonly found on low-lying sites or high craggy areas with poor soils where the forest is incapable of producing 20 cubic feet per acre per year. In earlier inventories, FIA only measured trees on timberland plots and did not report volumes on all forest land. Since the last periodic inventory in Delaware in 1999, FIA has been reporting volume on all forest land.

With remeasurement completed, comparing two sets of growth, mortality, and removals data as well as studying trends on forest land is now possible. However, since some of the older periodic inventories only reported on timberland, much of the trend reporting in this publication is still focused on timberland. Currently in Delaware, approximately 96 percent of all forest land is classified as unreserved and productive timberland, 3 percent is reserved and productive forest land, and 1 percent is other forest land.

How do we estimate a tree's volume?

Tree volume is generally determined by a set of volume equations developed specifically for a given species from sample trees that are felled and measured for length, diameter, and taper. Several volume equations have been developed at the Northern Research Station using regression analysis for tree species found within the region. Individual tree volumes are based on species, diameter, and merchantable height and are reported in cubic feet or board feet based on the International ¼-inch log rule.

How is forest biomass estimated?

Specific gravity values for each tree species or group of species were developed at the U.S. Forest Service's Forest Products Laboratory and applied to FIA tree volume estimates for developing merchantable tree biomass (weight of tree bole). To calculate total live-tree biomass, the biomass for stumps (Raile 1982), limbs and tops, and belowground stump and coarse roots (Jenkins et al. 2004) needs to be added. Live biomass for foliage is currently not reported. FIA inventories report biomass weights as oven-dry short tons. Oven-dry weight of a tree is the green weight minus the moisture content. Generally, 1 ton of oven-dry biomass is equal to 1.9 tons of green biomass.

Forest Inventory Sample Design

FIA has established a set of permanent inventory plots across the United States that are periodically revisited. Each plot consists of four 24-foot subplots for a total area of approximately one-sixth of an acre. In Delaware, each plot represents about 3,000 acres of land and can be used to generate unbiased estimates and associated sampling errors for attributes such as total forest land area. Full details of sample design and estimation procedures are available in Bechtold and Patterson (2005), and a summary explanation is included in the Statistics, Methods, and Quality Assurance section of this report available at https://doi.org/10.2737/NRS-RB-115.

The inventory is conducted in phases. In Phase 1 (P1), the population of interest is stratified and plots are assigned to strata to increase the precision of estimates. In Phase 2 (P2), tree and site attributes are measured on forested plots established in each hexagon. P2 plots consist of four 24-foot fixed-radius subplots on which standing trees are inventoried. The Northern Research Station (NRS) FIA is currently transitioning its forest health indicator monitoring from the Phase 3 (P3) protocols of the past to the Phase 2 plus (P2+) protocols of the future. The general approach is to reduce the amount of data collected on each plot while increasing the number of forest health plots that are monitored. For example, the P3 protocols required five tree crown health variables, whereas the P2+ protocols only include two crown health variables: crown dieback and uncompacted live crown ratio.

How do we compare data from different inventories?

New inventories are commonly compared with older datasets to analyze trends or changes in forest growth, mortality, removals, and ownership acreage over time (Powell 1985). A pitfall occurs when the comparison involves data collected under different schemes or processed using different algorithms. Recently, significant changes were made to the methods for estimating tree-level volume and biomass (dry weight) for northeastern states, and the calculation of change components (net growth, removals, and mortality) was modified for national consistency. These changes have focused on improving the ability to report consistent estimates across time and space—a primary objective for FIA. Regression models were developed for tree height and percent cull to reduce random variability across datasets.

Before the Component Ratio Method (CRM) was implemented, volume and biomass were estimated using separate sets of equations (Heath et al. 2009). With the CRM, determining the biomass of individual trees and forests has become a simple extension of FIA volume estimates. This allows biomass estimates to be obtained for growth, mortality, and removals of trees from forest lands, not only for live trees, but also for their belowground coarse roots, standing deadwood, and down woody debris.

Another new method, termed the "midpoint method," has introduced some differences in methodology for determining growth, mortality, and removals to a specified sample of trees (Westfall et al. 2009). The new approach involves calculating tree size attributes at the midpoint of the inventory cycle (2.5 years for a 5-year cycle) to obtain a better estimate for ingrowth, mortality, and removals. Although the overall net change component is equivalent under the previous and new evaluations, estimates for individual components will be different. For ingrowth, the midpoint method can produce a smaller estimate because the volumes are calculated at the 5.0-inch threshold instead of using the actual diameter at time of measurement. The actual diameter could be larger than the 5.0-inch threshold. The estimate for accretion is higher because growth on ingrowth, mortality, and removal trees is included. As such, the removals and mortality estimates will also be higher than before (Bechtold and Patterson 2005).

A word of caution on suitability and availability

FIA does not attempt to identify which lands are suitable or available for timber harvesting because suitability and availability are subject to changing laws and ownership objectives. Simply because land is classified as timberland does not mean it is suitable or available for timber production. Forest inventory data alone are inadequate for determining the area of forest land available for timber harvesting because laws and regulations, voluntary guidelines, physical constraints, economics, proximity to people, and ownership objectives may prevent timberland from being available for production.

Forest Features

Early signs of fall in the forest canopy. Photo by Tonya Lister, U.S. Forest Service.

Dynamics of the Forest Land Base

Background

Despite Delaware's small size it hosts a diverse variety of flora and fauna, including northern and southern species at the lower and upper limits, respectively, of their distributions. The majority of Delaware is located in the Coastal Plain ecoregion characterized by fertile lowland areas, so it is not surprising that agricultural is the dominant land use in the State. However, forests cover nearly a third of Delaware's land area and offer a wide range of benefits, including providing wood products, protecting drinking water quality and quantity, improving air quality, controlling erosion and flooding, and providing habitat for forest dwelling and migratory wildlife species.

New Castle County, Delaware's northernmost county, is the most urbanized county in the State. The U.S. Interstate 95 corridor runs through the northern tip of the county, and the landscape in this portion of the State is characterized by a mixture of urban and suburban land uses interspersed with agricultural and other human-impacted ecosystems. Central Kent and southern Sussex Counties are comparatively less developed, have a greater concentration of forest land, and also host the majority of the State's forested wetlands.

Delaware forests play a critical role in the protection of water quality, maintenance of biodiversity, generation of wood products, and provision of other ecosystem services that contribute to the State's unique role in the mid-Atlantic region. Estimates of forest land and timberland area and changes in these estimates through time are important measures for assessing the forest resource and its sustainability. Gains and losses in forest area directly affect the amount of benefits the forests can provide.

What we found

Delaware's forest land is distributed in fragmented patches across the State (Fig. 1). Many of the smaller, linear patches are riparian forests bordering streams and wetlands. Some of the largest forest patches are contained within the State's Forest Legacy areas, including the Redden/Ellendale Forest Legacy Area in central Sussex County and the Cypress Swamp Forest Legacy Area in southern Delaware. Much of the land within these Forest Legacy areas is protected from development due to a land purchase or conservation easement.

Delaware contains an estimated 362,000 acres of forest land that cover 29 percent of the State's land area. Successive inventories in Delaware since the mid-1980s have shown that forest land area is decreasing. However, since 2008, forest land estimates have been relatively stable. The forest land estimate for 2013 is 2.8 percent greater than the 2008 estimate, which may be an indication of a stabilizing forest land base (Fig. 2).

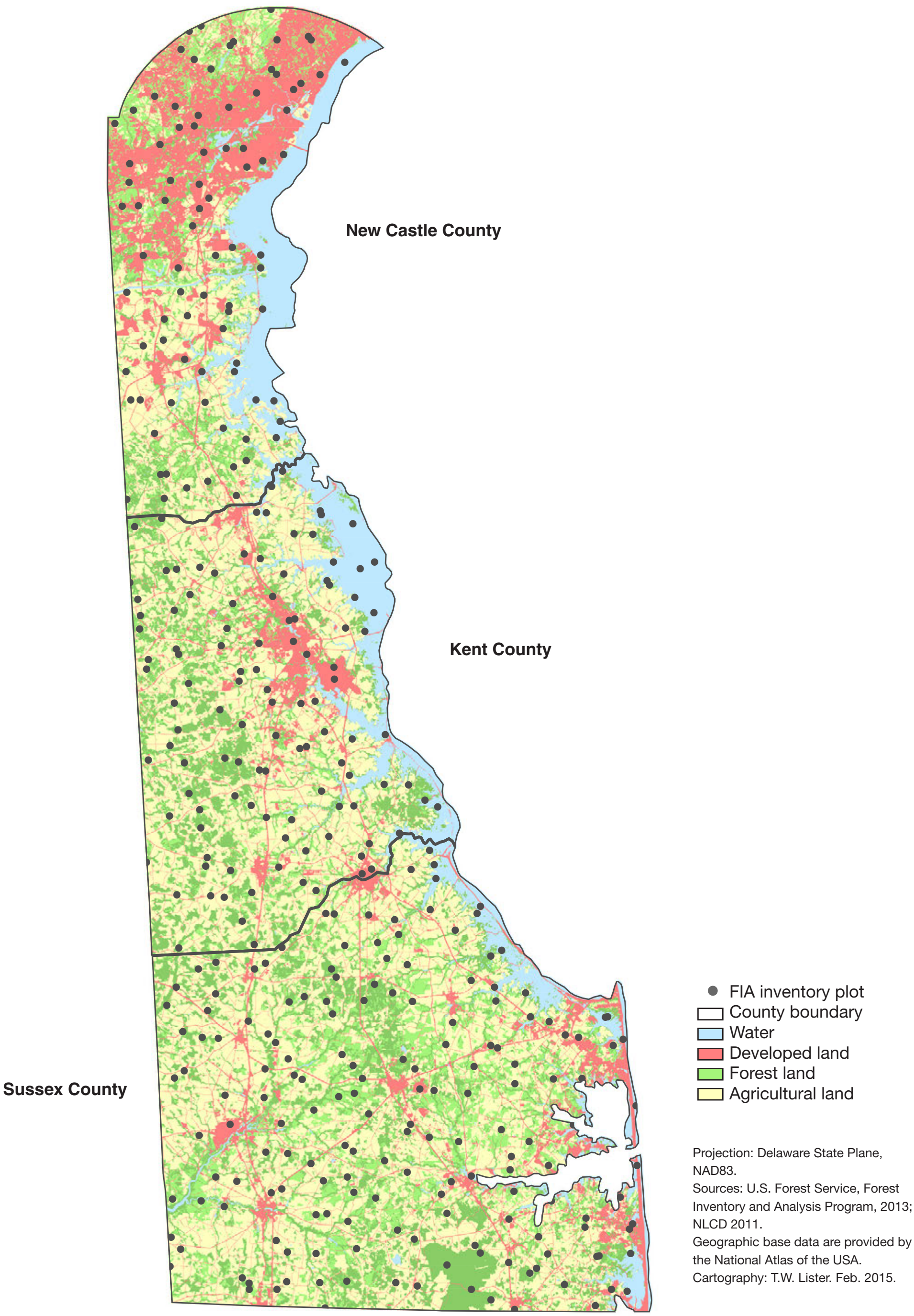


Figure 1.—Land cover and FIA plot distribution, Delaware, 2013. Plot locations are approximate.

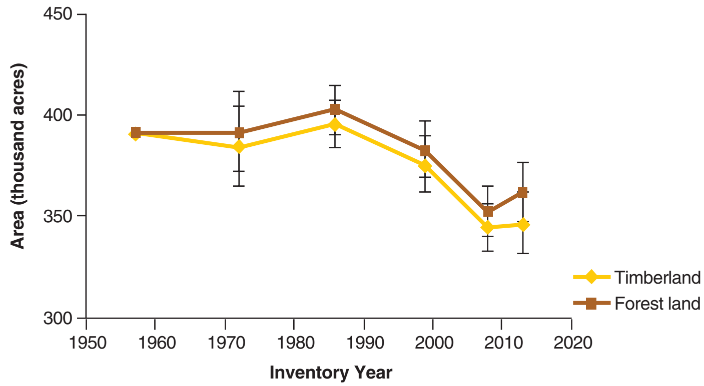


Figure 2.—Area of forest land and timberland by inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

Sussex County is the most forested county in the State with over 194,000 acres of forest land. A gradient of decreasing forest land area runs north to New Castle County, which has nearly 60,000 acres of forest land (Fig. 3). This pattern has persisted since the first FIA inventory in 1956. Over the last two decades, forest land area in Kent and New Castle Counties has remained relatively stable. A loss of forest land occurred in Sussex County between 1986 and 2008, most likely due to land development to accommodate the county's growing population. The 2013 inventory, however, shows a stabilization in the amount of forest land in this county and in the State as a whole.

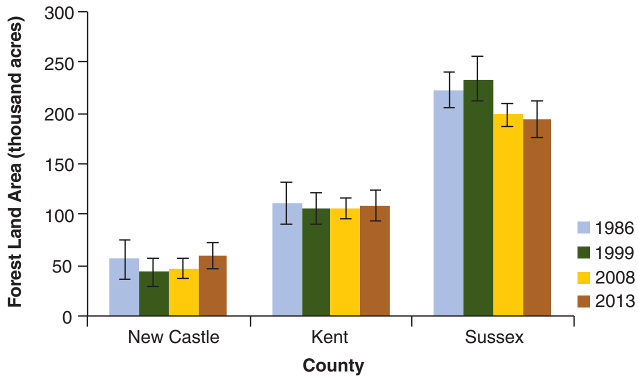


Figure 3.—Area of forest land by county (from north to south) and inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

What this means

Forest change dynamics in Delaware are due to a complex interaction of population growth, land development, reversion of agricultural land to forest, conservation policies, and the availability of land for development. Prior to European settlement, the area that is now Delaware was likely dominated by forests. These forests were almost entirely cleared as the demand for wood products rose and the need for arable land increased during the period of European settlement. As a result, the land area of Delaware became dominated by agriculture. Over time, forest area increased, but never again overtook agricultural land as the dominant land use.

There has been little change in forest land area since 2008; however long-term data show decreases in the amount of forest land between 1986 and 2008. According to the U.S. Census Bureau, the population of Sussex County grew by more than 9 percent between 2006 and 2010 (U.S. Census Bureau 2010), due in part to a large influx of retirees and second home buyers. Since 2010, the population growth rate has decreased in Sussex County, which corresponds to the observed stabilization of the forest land area in the county. This slowdown in population growth may be a temporary result of the poor housing market. As the housing economy improves, there may be a resurgence of residential development pressure in Sussex County and in the State as a whole, making it vulnerable to forest loss.

Availability and Productivity of Forest Land

Background

FIA divides forest land into three categories—timberland, reserved forest land, and other forest land—to characterize the availability of forest resources and facilitate forest management planning. Two criteria are used to make this determination: reserved status (unreserved or reserved) and site productivity (productive or unproductive). Forest land that is capable of growing trees at a rate of at least 20 cubic feet per acre per year and that is not legally restricted from being harvested is classified as timberland. If harvesting is restricted on forest land by statute, then it is designated as reserved regardless of its productivity class. The harvesting intentions of private forest landowners are not used to determine the reserved status. The other forest land category is made up of forest land that is unreserved and low in productivity.

What we found

Forests cover an estimated 29 percent of Delaware's land area, and the vast majority (96 percent) of that forest land meets the definition of timberland. Eighty percent of timberland is in private ownership. All the land in the reserved class is in federal or state ownership. Land classified as other forest land (i.e., unreserved and unproductive) is rare and accounts for less than one percent of total land area (Fig. 4). Current estimates of timberland have remained stable since 2008 (Fig. 2).

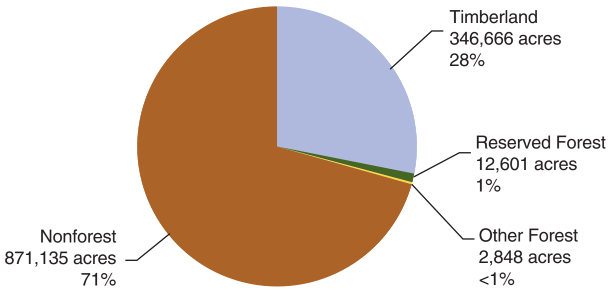


Figure 4.—Land area by major use, Delaware, 2013.

What this means

Because the vast majority of Delaware's forest land is classified as timberland, trends observed on this land are likely to apply to all forest land as well. Timberland is potentially available for harvesting timber or other forest products, and trees growing on timberland represent the resource base that the forest products industry relies upon. In this report, sections on urbanization and the woodland owner study provide more details on how much timberland is actually available and is being actively managed for timber products. Much of the focus of this report is on trees growing on the 347,000 acres of timberland found in the State.

Ownership of Forest Land

Background

How private land is managed is primarily the owner's decision. Therefore, to a large extent, the availability and quality of forest resources, including recreational opportunities, timber, and wildlife habitat, are determined by landowners. By understanding the priorities of forest landowners, the forest conservation community can better help meet the owner's needs, and in so doing, help conserve Delaware forests for future generations. The National Woodland Owner Survey (NWOS; www.fia.fs.fed.us/nwos) is conducted by the U.S. Forest Service, Forest Inventory and Analysis program to study the attitudes, management objectives, and concerns of private forest landowners. It focuses on the diverse and dynamic group of owners that is the least understood—families, individuals, and other unincorporated groups, collectively referred to as "family forest owners." The NWOS data reported here are based on the responses from 190 family forest owners from Delaware that participated between 2011 and 2013 (Butler et al. 2015).

What we found

An estimated 77 percent of the forest land of Delaware is privately owned. The vast majority of these private acres, approximately 204,000 acres, belong to family forest owners. Corporations own an estimated 65,000 acres, and other private owners, including conservation organizations and unincorporated clubs and partnerships, own an estimated 10,000 acres (Fig. 5). Public owners control 83,000 acres of Delaware forest land. State forest, park, and wildlife agencies are stewards of 81 percent of these public forest lands. The remaining public land is fairly evenly divided between federal government agencies, such as the U.S. Fish and Wildlife Service, and local governments.

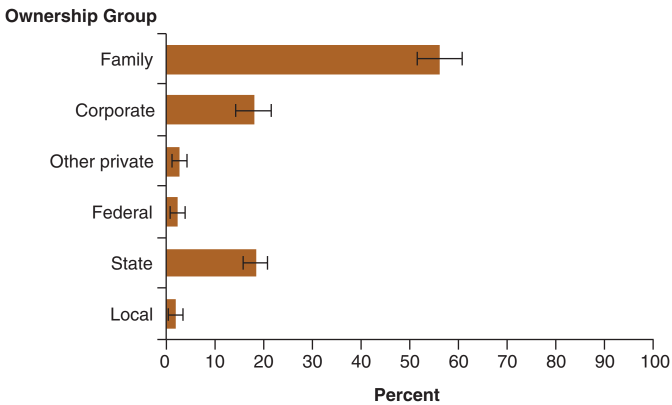


Figure 5.—Distribution of forest land by ownership group, Delaware, 2013. Error bars represent 68 percent confidence intervals around the estimated means.

According to the NWOS, an estimated 4,000 family forest ownerships across Delaware each own at least 10 acres of forest land, for a total of 164,000 acres. The average forest holding size of this group is 44.9 acres. Of these family forest owners, 72 percent own less than 50 acres of forest land, but 65 percent of the family forest land is in holdings of at least 50 acres (Fig. 6). The primary reasons for owning forest land are related to wildlife, family legacy, nature protection, and aesthetics (Fig. 7). The most common activity on private land is personal recreation, such as hunting and hiking (Fig. 8). Most family forest ownerships have not participated in traditional forestry management and assistance programs in the past 5 years, but for those owners that have (20 percent of the ownerships), the most common type is having a written forest management plan (Fig. 9). The average age of family forest owners in Delaware is 64.7 years, with 53 percent of the family forest land owned by people who are at least 65 years of age (Fig. 10).

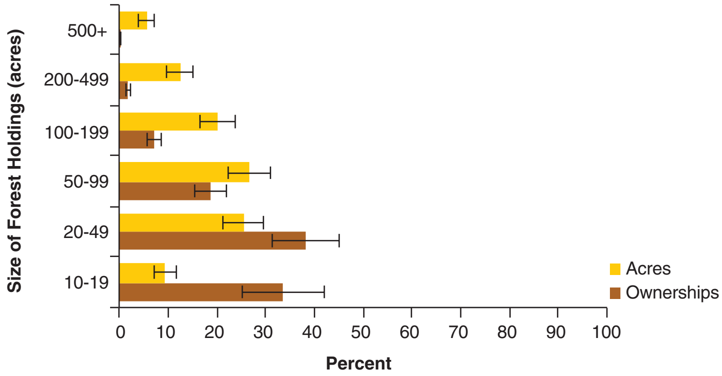


Figure 6.—Percentage of family forest ownerships and acres of forest land by size of forest land holdings, Delaware, 2013. Error bars represent 68 percent confidence intervals around the estimated means.

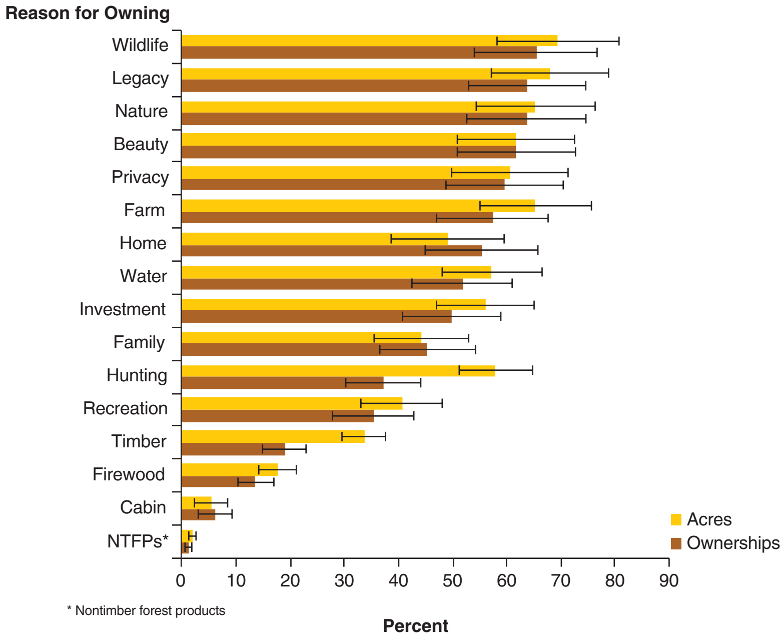
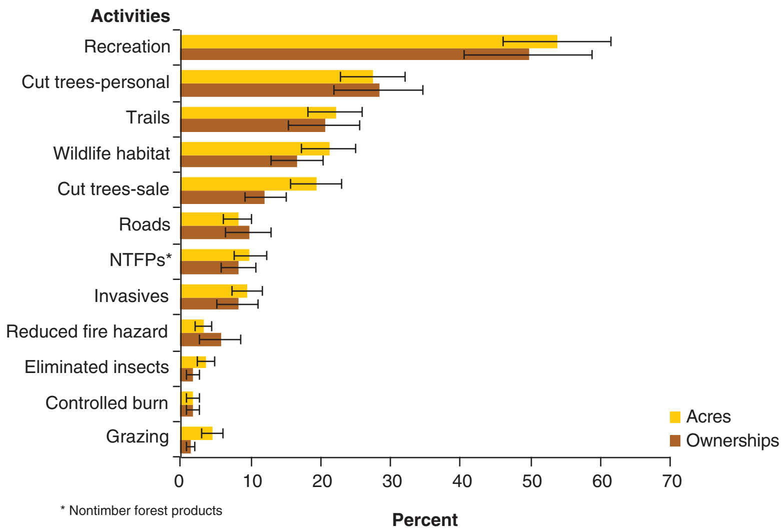


Figure 7.—Percentage of family forest ownerships and acres of forest land by reasons given for owning forest land ranked as very important or important, Delaware, 2013. Categories are not exclusive. Error bars represent 68 percent confidence intervals around the estimated means.



* Nontimber forest products

Figure 8.—Percentage of family forest ownerships and acres of forest land by most common activities in the past 5 years, Delaware, 2013. Categories are not exclusive. Error bars represent 68 percent confidence intervals around the estimated means.

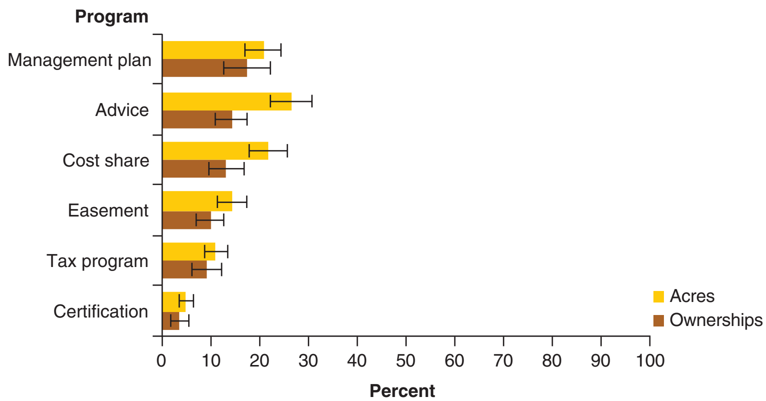


Figure 9.—Percentage of family forest ownerships and acres of forest land by participation in forest management programs, Delaware, 2013. Categories are not exclusive. Error bars represent 68 percent confidence intervals around the estimated means.

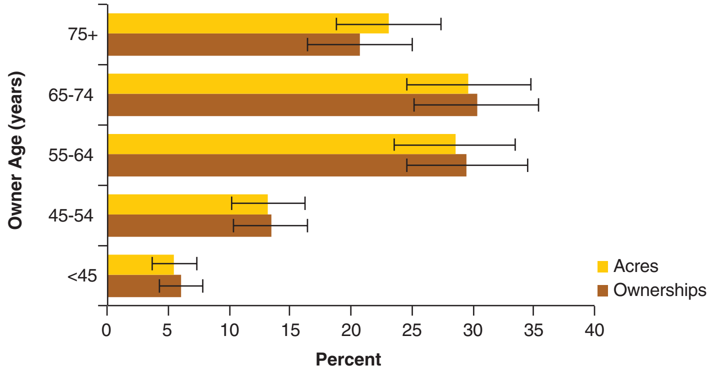


Figure 10.—Percentage of family forest ownerships and acres of forest land by age of primary owner, Delaware, 2013. Error bars represent 68 percent confidence intervals around the estimated means.

What this means

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. Although family forest owners use their land primarily for amenity reasons, many are engaged in land management activities. That being said, more than 80 percent of them do not have a management plan, and most have not participated in any other traditional forest management planning or assistance programs. Many resources and opportunities are available to help owners increase their engagement and stewardship of their lands. Programs such as Tools for Engaging Landowners Effectively (http://www.engaginglandowners.org) can help the conservation community develop and implement programs more effectively and efficiently.

Another important trend to watch is the aging of the family forest owners. With many of them being relatively advanced in age, this portends many acres of land passing on to the next generation in the not too distant future. Programs such as Your Land Your Legacy (http://masswoods.net/monthly-update/your-land-your-legacy-deciding-future-your-land) and Ties to the Land (http://tiestotheland.org) can help owners meet their bequest goals, but it is uncertain who the future forest owners will be and what they will do with their land.

Urbanization and Fragmentation of Forest Land

Background

The expansion of urban lands that accompanies human population growth often results in the fragmentation and urbanization of the surrounding forest land (Wilcox and Murphy 1985). Continuing fragmentation, parcelization, and urbanization can be barriers to stewardship if they result in forest tracts that are too small or too isolated for effective management (Shifley and Moser 2016). Forest fragmentation and habitat loss diminish biodiversity and are recognized as a major threat to animal populations worldwide (Honnay et al. 2005, Rosenberg et al. 1999), particularly for species that require interior forest conditions for all or part of their life cycle (Donovan and Lamberson 2001). Changes in the size of remaining forest patches, in their level of connectivity to other large patches, in the amount of general forest cover surrounding each patch, and in the amount of forest-nonforest edge all directly affect the amount and quality of interior forest and consequently the species and ecosystem functions that depend on these interior conditions.

Urbanization increases the proximity of people, development, and other anthropogenic pressures to natural habitats. Both urbanization and forest fragmentation change the way in which humans use forest land, frequently decreasing the likelihood that it will be managed for forest products and potentially increasing its use for outdoor recreation, although urbanization has also been observed to increase the incidence of posting no trespassing signs on forested land, which decreases outdoor recreation opportunities and alters local cultural use of forest land (Butler 2008, Kline et al. 2004, Wear et al. 1999).

Spatial landscape pattern metrics help quantify these different characteristics of fragmentation. The 2011 National Land Cover Dataset (NLCD) (Jin et al. 2013) shows land cover composition varying from the more urbanized New Castle County (40 percent developed land cover) to the more agricultural Kent and Sussex Counties (48 percent and 46 percent agricultural land cover, respectively). In the last 5-year forest assessment of Delaware (Lister et al. 2012), patch sizes and the amount of forest in edge versus core situations were examined with respect to the most widely used thresholds for interpreting likely impact. The results highlighted the large proportion (68 percent) of Delaware's forest in edge conditions.

Metric values are sensitive to the resolution of the land cover data source used (Moody and Woodcock 1995), similar to the way that animal species see the landscape very differently depending on the scale at which they operate—e.g., the same patch that supplies interior forest conditions for one species is viewed as an unsuitable fragment by another species with higher quality or larger area size requirements. Because important forest ecosystem processes operate at different scales, current levels of fragmentation were examined at two scales by adapting a spatial integrity index (SII) developed by Kapos et al. (2002) for the 2000 Global Forest Resources Assessment (FAO 2002). The SII integrates three important facets of fragmentation that affect some aspect of forest ecosystem function—patch size, local forest density, and patch connectivity to core forest areas—to create a single composite metric for comparison. Since even acceptably low misclassification rates in the source land cover data can be magnified into substantial errors in metric values (Langford et al. 2006, Shao and Wu 2008), spatial integrity is calculated at the two scales corresponding to two reliable and widely available source data sets, the 30 m scale of the 2011 National Land Cover Dataset (Jin et al. 2013) and the 250 m scale of the 2009 FIA forest cover dataset (Wilson et al. 2012).

In the SII calculation, core forest is defined by patch size and the percent forest cover within a certain area, or the local forest density within a defined local neighborhood area. An unconnected forest fragment is defined by its patch size, local forest density, and distance to a core forest area. The spatial integrity of all forest land is scaled between these two ends. Table 1 identifies the thresholds used to define both core forest and unconnected fragments at the 250 m and 30 m scales, respectively. These two scales capture a relatively broad range of definitions for core forest and spatial integrity that should encompass the scales appropriate for understanding impacts on a wide range of wildlife species and ecosystem processes affected by forest fragmentation.

Table 1.—Spatial integrity index (SII) parameters used in calcuations at each scale

	Scale	
Definition of Core	**250 m**	**30 m**
Patch size	>1,544 acres	>22 acres
Local forest density	90%	90%
Neighborhood radius	0.78 mile	0.09 mile
Definition of Unconnected Fragment	**250 m**	**30 m**
Patch size	<30 acres	<2.5 acres
Local forest density	10% or less	10% or less
Neighborhood radius	0.78 mile	0.09 mile
Distance to core	>4.2 miles	>0.5 miles

The population of Delaware increased by 14.6 percent between 2000 and 2010, to 0.9 million people. During that same time period, the number of housing units increased by 18.3 percent (U.S. Census Bureau 2010). Stated another way, between 2000 and 2010 housing units increased at a pace 1.3 times the rate of increase in population, a trend not unique to Delaware. In recent decades this housing growth has occurred not only in increasing suburban rings around urban areas but also in more rural areas. Lepczyk et al. (2007), Theobald (2005), and Hammer et al. (2004) observed that areas currently facing rapid increases in housing density and areas predicted to increase in the future are amenity-rich rural areas around lakes and other forest recreation areas. The 38 percent increase in the number of reported second homes in Delaware from 2000 to 2010 could be a partial reflection of this trend (U.S. Census Bureau 2010), which can put additional pressure on forested areas even above the general increases in population density and housing density.

Because SII is calculated from a land cover data source that does not incorporate underlying house density or proximity to roads, it does not represent completely intact forest conditions. The wildland-urban interface (WUI) is the zone where human development meets or intermingles with undeveloped wildland vegetation (Radeloff et al. 2005). It is associated with a variety of human-environment conflicts. Radeloff et al. (2005) have defined this area by housing density ("intermix" areas that require a minimum of 16 houses per square mile), proximity to developed areas ("interface" areas), and percentage of vegetation coverage (minimum 50 percent). WUI intermix areas (U.S. Census Bureau 2010) were intersected with forest land in the 2011 NLCD (Jin et al. 2013) to examine changes in the amount of forest land co-occurring with WUI house densities. In addition, the coincidence of SII core or intact forest (based on forest canopy) and WUI intermix was identified.

Neither of the two previous indices captures the full impact of roads on forest land. Roads have a variety of effects: direct hydrological, chemical, and sediment effects; serving as vectors for invasive species; facilitating human access and use; increasing habitat fragmentation; and wildlife mortality. Actual impacts will vary depending on road width, use, construction, level of maintenance, and hydrologic and wildlife accommodations (e.g., Charry and McCollough 2007, Forman et al. 2003). Based on the 2001 NLCD (Homer et al. 2007), the amount of forest land within 650 and 1310 feet from a road (U.S. Census Bureau 2000) was identified. In general, when greater than 60 percent of the total land area in a region is within 1310 feet of a road, which has likely been true in Delaware for some time, cumulative ecological impacts from roads should be an important consideration.

What we found

Considering SII at the 250 m scale, 4 percent of the forest land in Delaware is core forest, 11 percent has high integrity, 10 percent has medium integrity, 2 percent has low spatial integrity, and 72 percent of the forest is in unconnected fragments. At the 30 m scale, with a patch size of 22 acres or greater considered core forest, 37 percent of the forest land in Delaware is core forest, 28 percent has high spatial integrity, 13 percent has medium or low integrity, and 23 percent of the forest is in unconnected fragments (Table 2). Forest integrity (patch size, local forest density, connectivity) is highest in Sussex County and lowest in New Castle County. It is important to note that the SII is depicting tree cover only and may not incorporate the presence of local development associated with or underlying this tree cover. Addressing this requires the use of census housing density information.

Table 2.—Forest land spatial integrity index (SII) by county, scale, and with and without incorporating WUI areas into the SII calculation, Delaware

Unit	30 m Scale						250 m Scale					
	Forest fragment	Low SII	Medium SII	High SII	Core forest	Core forest if WUI removed	Forest fragment	Low SII	Medium SII	High SII	Core forest	Core forest if WUI removed
	percent						*percent*					
Kent	21	2	12	30	36	23	75	5	10	7	2	2
New Castle	41	2	11	22	23	14	84	1	8	6	0	0
Sussex	19	1	10	29	41	27	68	1	11	14	6	6
State	23	2	11	28	37	24	72	2	10	11	4	4
State after removing WUI areas	23	3	11	39	24		72	5	10	9	4	

The proportion of forest land with sufficient underlying housing density to qualify as WUI areas has been slowly but steadily increasing. In 1990, approximately 20 percent of Delaware forest land was in low and medium density WUI. This increased to 23 percent of the forest land in 2000 and 35 percent in 2010. When SII results at the 30 m scale were integrated with WUI, core forest drops from 37 to 24 percent statewide (Table 2). At the 250 m scale, core forest remains constant at 4 percent, although there is a decrease in high integrity forest land from 11 to 9 percent (Table 2). This represents a substantial impact on core forest land from underlying or nearby house densities. Figure 11 shows the spatial distribution of WUI-adjusted forest land by SII classes. At the 250 m scale, remaining large areas of relatively continuous forest clearly stand out. At the 30 m scale, the lower threshold of 22 acres for defining core forest means that more forest patches are considered core and high integrity.

Roads are pervasive in the landscape, sometimes hidden from aerial view under areas of continuous canopy. In 2000, close to half of the forest area statewide was within 650 feet of a road, ranging from 38 percent of the forest land in Kent County to 57 percent in New Castle County (Table 3), and 75 percent of Delaware's forest land was within 1310 feet of a road.

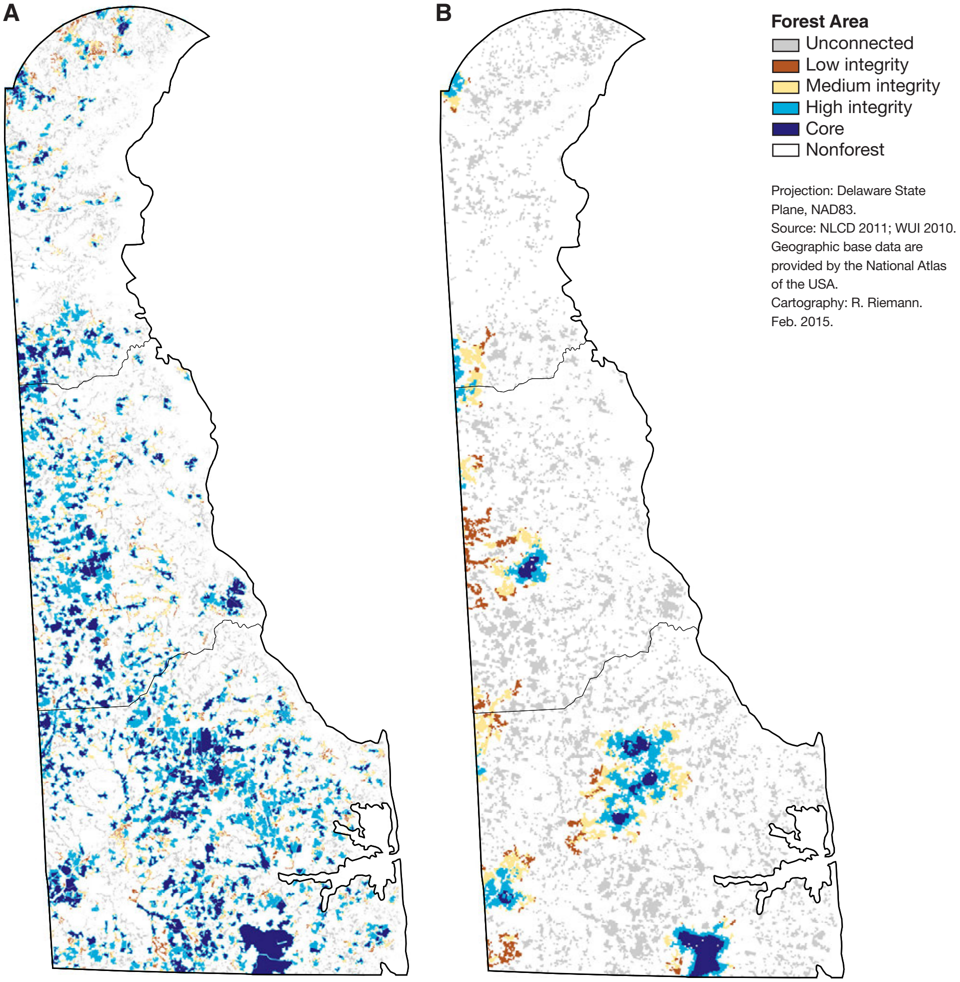


Figure 11.—Spatial Integrity Index (SII) for wildland-urban interface-adjusted forest land at the 30 m scale (A) and 250 m scale (B), Delaware, 2010.

Table 3.—The distribution of forest land with respect to several urbanization and fragmentation factors, expressed as a percentage of the forest land in each county, Delaware

County	Percentage of area in forest[a]	Percentage of forest land in WUI[b]	Percentage of forest land <650 feet from a road[c]
Kent	27	26	38
New Castle	24	28	57
Sussex	33	35	46
State total	29	31	46

[a] Percent forest estimate based on NLCD 2011 (Jin et al. 2013). Values are generally higher than estimates from FIA plot data.

[b] Approximating the forest land potentially affected by underlying or nearby development (U.S. Census bureau 2010).

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

What it means

When considering SII at both the 250 m and 30 m scales, 4 to 37 percent of Delaware's forest land meets the definition of core forest, and between 23 and 72 percent of the forest land is in unconnected fragments. If WUI areas are removed, core forest drops by over a third at the 30 m scale (from 37 to 24 percent) statewide but remains at 4 percent at the 250 m scale. This effect is the same within individual counties.

Fragmentation and urbanization continue to change how Delaware forests function. Forest health and sustainability are affected, and fragmentation diminishes the benefits and services forests can provide, making forest management more difficult. If housing development continues to extend into forested areas, the remaining forest land will be further fragmented, and forest integrity will be further reduced. Factors that increase fragmentation, such as development incursions into core and high integrity forest areas, should be the focus of conservation and planning activities, and factors that decrease forest fragmentation, including maintaining or even creating connectivity between forest patches, should be considered. In addition, the characteristics and maintenance of roads and development play a role in their actual impact on the resilience of forest land and its ability to continue to supply the social and ecosystem services many rely on, such as protecting water quality, reducing fluctuations in water quantity, supporting air quality, and providing wildlife habitat and recreation opportunities.

Forest Structure

Background

Tree diameter measurements are used by FIA to assign one of three stand-size classes to sampled stands as a general indication of stand development. The categories are determined by the size class that accounts for the most stocking of live trees per acre. Small diameter stands are dominated by trees with a d.b.h. of less than 5 inches. Medium diameter stands have a plurality of trees at least 5 inches d.b.h. but less than the d.b.h. of large diameter stands. Large diameter stands consist of a preponderance of trees at least 9 inches in d.b.h. for softwoods and 11 inches d.b.h. for hardwoods.

Generally, as stands mature and trees become larger, the number of trees per acre decreases and stand volume increases. The number of trees per acre and their diameters are used to determine stocking levels. Stocking is a measure of the relationship between the growth potential of a site and how much of the land is occupied by trees.

Stocking levels for Delaware forests are based on all live trees or on growing-stock trees only. Growing-stock trees are the economically important trees and do not include noncommercial species or trees with large amounts of cull (rough and rotten trees).

Five classes of stocking are reported by FIA: nonstocked (0-9 percent), poorly (10-34 percent), moderately (35-59 percent), fully (60-100 percent), and overstocked (>100 percent). The growth potential of a stand is considered to be reached when it is fully stocked. As stands become overstocked, trees become crowded, growth rates decline, and mortality rates increase. Poorly stocked stands can result from harvesting practices or poor site quality. In contrast to moderately stocked stands, poorly stocked stands are not expected to grow into a fully stocked condition for timber production within a practical amount of time.

What we found

In Delaware, the distribution of forest land by size class continues to trend toward larger diameter stands. Sampling errors are high for estimates, but the data suggest a trend of decreasing area of medium diameter stands and an increase in area of large diameter stands since 1986 (Fig. 12). The increasing trend toward large diameter trees is even more pronounced when current timberland estimates are compared with those from the 1957 inventory (Ferguson 1959). Area in large diameter stands now makes up 75 percent of timberland area compared to 55 percent in 1957 (Fig. 13).

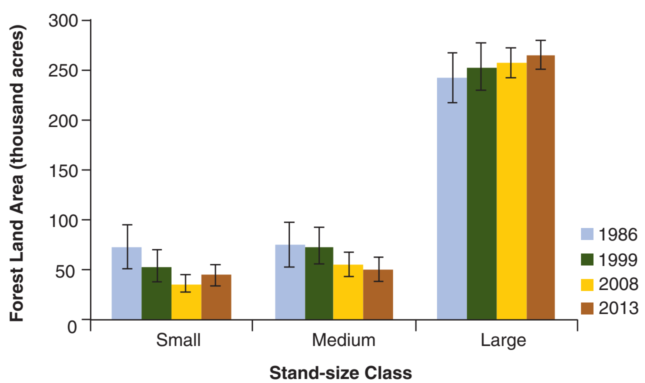


Figure 12.—Area of forest land by stand-size class and inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

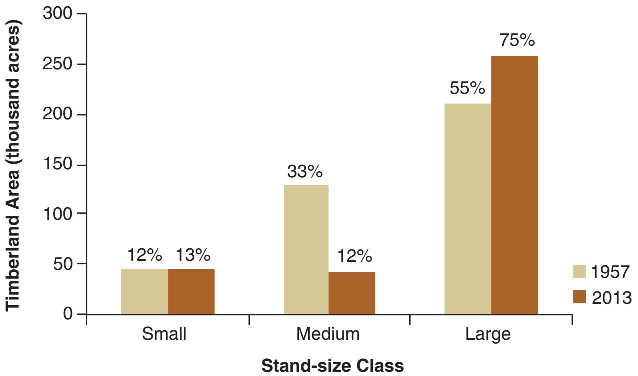


Figure 13.—Area of timberland by stand-size class, Delaware, 1957 and 2013. Percentage of area in each stand-size class and inventory is shown above the bars.

Delaware forest land is composed of approximately 240 million trees, with an estimated 233 million growing on timberland. The number of trees has not changed significantly since the last inventory; however from 1986 to 2008, with each successive inventory the number of trees shifts toward larger diameter classes (Fig. 14). Between 1986 and 1999, there was a 22 percent increase in the number of large trees with a d.b.h. of 13 inches and larger. From 1999 to 2008, the number of saplings (1 to 4.9 inches d.b.h.) and small trees (5 to 8.9 inches d.b.h.) decreased by 15 percent and 9 percent, respectively. Since 2008, there has been little change in the number of smaller diameter trees (less than 12.9 inches d.b.h.); however there was a 12 percent increase in larger trees (13 inches d.b.h. and greater) (Fig. 15).

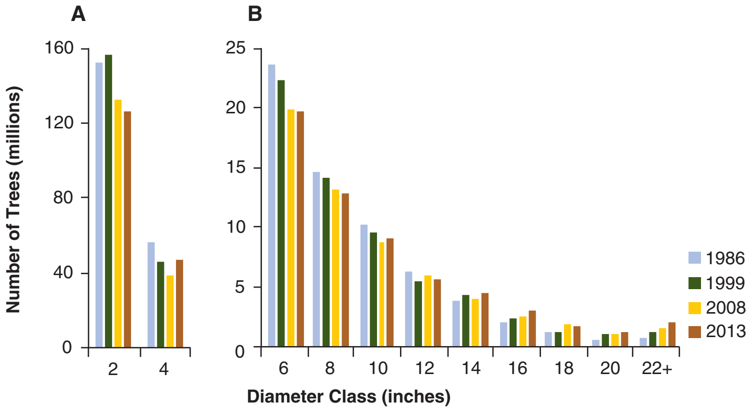


Figure 14.—Number of live trees on timberland by diameter class and inventory year for saplings (A) and trees (B), Delaware.

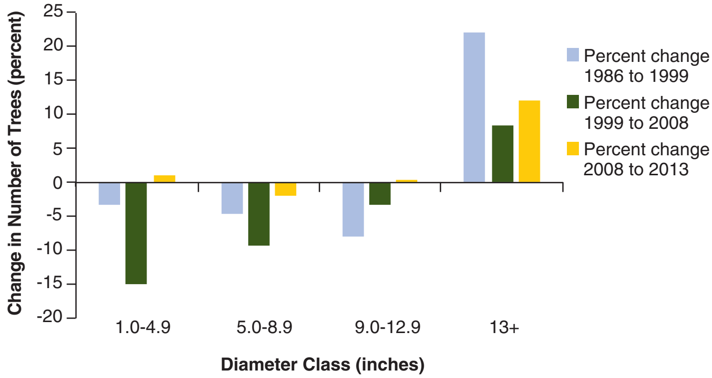


Figure 15.—Percentage change in the number of live trees by diameter class and inventory year, Delaware. Note different number of years in each period.

In Delaware there are 193,000 acres of timberland that are fully stocked with live trees, 113,000 acres with medium stocking, and 21,000 acres that are either poorly stocked or nonstocked (Fig. 16). Since 2008, there has been very little change in forest area by stocking level. From 1999 to 2013, however, moderately stocked stands increased by 43 percent while fully stocked stands decreased by 16 percent. When considering only the commercially-important growing-stock trees, 50,000 acres are poorly stocked; this is 29,000 acres more than when considering all live trees (Fig. 17).

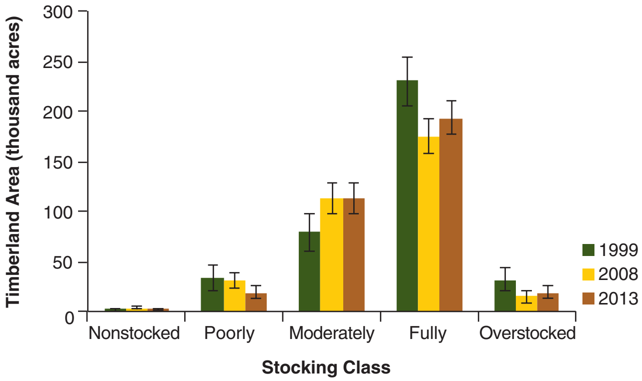


Figure 16.—Area of timberland by stocking class and inventory year, for all live trees, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

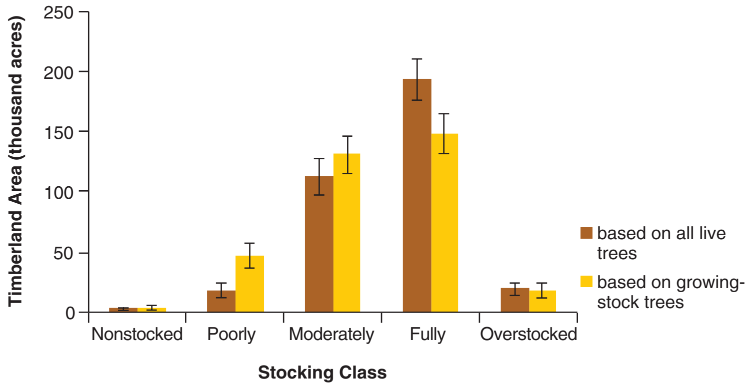


Figure 17.—Area of timberland by stocking class for all live and growing-stock trees, Delaware, 2013. Error bars represent 68 percent confidence intervals around the estimated means.

Stocking levels vary by forest-type group in Delaware. A wide range of stocking classes is represented in oak/hickory stands, which is the most prevalent forest-type group in Delaware. Nearly all the poorly or nonstocked stands fall within this forest-type group. Only 50 percent of oak/hickory stands are fully or overstocked with trees, compared to loblolly/shortleaf pine and oak/pine forest-type groups which are 85 percent and 92 percent fully or overstocked, respectively (Fig. 18). Forty-two percent of poorly or nonstocked timberland acres are less than 20 years old and 83 percent are less than 80 years old (Fig. 19). The distribution of age classes is explored further in a subsequent section on forest habitats.

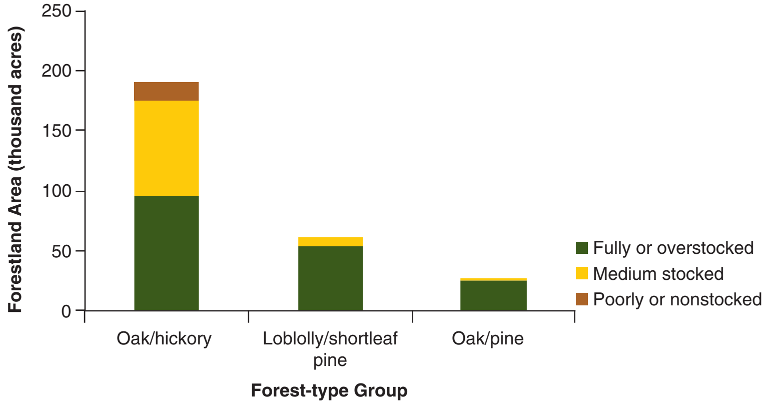


Figure 18.—Area of forest land by forest-type group and stocking class for all live trees, Delaware, 2013.

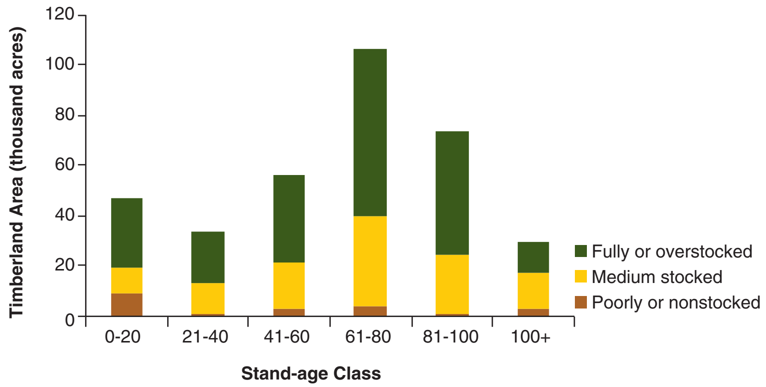


Figure 19.—Area of timberland by stand-age class and stocking class for growing-stock trees, Delaware, 2013.

What this means

The trend of increasing forest land area in large diameter stands and the increasing number of larger size trees indicates that Delaware forests are continuing to mature. An important component of forest biodiversity is complex structural features. Although the area of forest in smaller diameter stands has decreased, Delaware's mature stands do provide diverse structures due to gap dynamics and the presence of shade-tolerant species in the understory. The diversity of tree ages and sizes provides a broad range of habitats for wildlife and other organisms and makes forests more dynamic and better able to recover from disturbance.

Between 1999 and 2008, there was a slight loss of timberland area in overstocked and fully stocked stands and gains in area in moderately stocked stands (Lister et al. 2012). The current inventory results, however, show stocking levels have stabilized, as there has been little change since 2008. The majority of timberland in Delaware is in fully or overstocked stands, and this presents opportunities for forest management. Managing these stands can keep them growing optimally. Thinning overstocked stands leads to growth on residual trees, which improves the overall health of the stand in addition to providing wood for utilization and income to landowners.

Thirty-nine percent of timberland is less than fully stocked with live trees. When considering only growing-stock trees, the percentage increases to 52 percent. The 50,000 acres of timberland that are nonstocked or poorly stocked with growing-stock trees represents a loss of potential growth. These stands either have trees that are widely spaced or contain a high proportion of trees with low commercial value. Sixty four percent of these poorly or nonstocked stands occur in the oak/hickory forest-type group, and 42 percent of the stands are less than 20 years old. Poorly stocked stands may have originated from farmland that reverted to forest or be the result of poor harvesting practices.

Carbon Stocks

Background

Carbon has become a part of forest resource reporting in recent years primarily because forests sequester carbon from the atmosphere, helping to mitigate the effects of global climate change. Among terrestrial ecosystems, forests contain the largest reserves of sequestered carbon. Regional and national greenhouse gas reporting forums include forest carbon stocks because increases in forest carbon stock represent quantifiable partial offsets to other greenhouse gas emissions. For example, carbon sequestration by U.S. forests represented an offset of more than 11 percent of total U.S. greenhouse gas emissions in 2013 (US EPA 2015), and the continuing increase in Delaware forest carbon stocks contributes to this effect.

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. Over time, this stored carbon also accumulates as dead trees, woody debris, litter, and forest soils. For most forests, the understory grasses, forbs, and nonvascular plants as well as animals represent minor pools of carbon stocks. Within soils, the larger woody roots are readily distinguished from the bulk of soil organic carbon, so the roots are generally reported as the belowground portion of trees and not included in the soils estimates. Carbon loss from a forest stand can result from mechanisms such as respiration (including live trees and decomposers), combustion, runoff or leaching of dissolved or particulate organic particles, or by direct removal such as through the harvest and utilization of wood. From the greenhouse gas reporting perspective, it is important to note that not all losses result in the release of carbon dioxide to the atmosphere; some wood products represent continued long-term carbon sequestration.

The carbon pools discussed here include living plant biomass (live trees 1 inch d.b.h. and larger and understory vegetation), dead wood and litter (nonliving plant material including standing dead trees, down dead wood, and forest floor litter), and soil organic matter exclusive of coarse roots and estimated to a depth of 34 inches. Carbon estimates by ecosystem pool are based on sampling and modeling; for additional information on current approaches to determining forest carbon stocks see US EPA (2015), U.S. Forest Service (2014), and O'Connell et al. (2014). The level of information available for calculating the carbon estimates varies among pools. For example, the greatest confidence is in the estimate of live-tree carbon due to the level of sampling and availability of allometric relationships applied to the tree data. Limited data and high variability are associated with lower confidence in the soil organic carbon estimates, and for this reason interpretation of these estimates is limited. Ongoing research is aimed at improving the estimates (US EPA 2015). The carbon estimates provided here are consistent with the methods used to develop the forest carbon reported in the U.S. Environmental Protection Agency's "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013" (US EPA 2015), but the 2013 inventory summarized here includes some newer data relative to the Delaware forests.

What we found

Live trees and soil organic carbon account for 87 percent of forest carbon stocks within Delaware forest ecosystems, with 30 percent of that carbon being in the wood and bark of the bole of trees with a d.b.h. of 5 inches or larger (Fig. 20). Average aboveground carbon per acre increases with stand age, with the greatest net accumulation occurring within the aboveground biomass (live tree and understory) rather than the aboveground nonliving (standing dead, down dead, and litter) pools (Fig. 21). Total carbon stocks are the product of carbon per acre and total acres of forest within each age class. Sixty percent of total aboveground carbon stocks are represented by the two age classes spanning stand ages of 61 to 100 years; in contrast, the two youngest age classes together account for only 12 percent of forest carbon stocks.

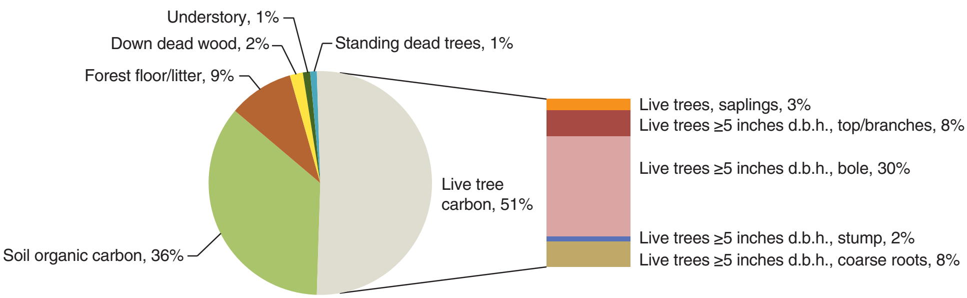


Figure 20.—Estimated carbon stocks on forest land by forest ecosystem component, Delaware, 2013.

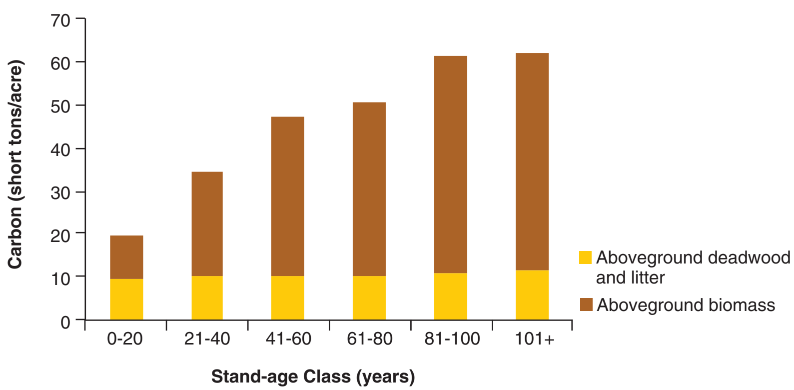


Figure 21.—Aboveground live and nonliving carbon stocks per acre by stand-age class, Delaware, 2013.

Species composition can affect carbon stocks as illustrated by the variability in average carbon tons per acre for the more common forest-type groups identified within Delaware forests (Fig. 22). In Delaware, 51 percent of total carbon stocks are in the oak/hickory forest-type group. The largest single pool is biomass within the oak/hickory forest-type group, with 9 million tons of carbon, or about 29 percent of all Delaware forest carbon stocks. Total forest ecosystem carbon stocks are estimated by FIA to be 31 million tons of carbon.

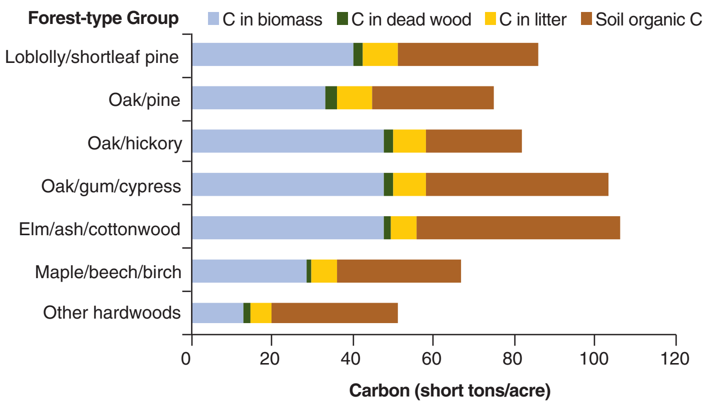


Figure 22.—Average carbon stock per acre by forest-type group and component, Delaware, 2013.

The current carbon estimation methods and data were also applied to the 2008 Delaware forest inventory (data not shown) to produce summaries consistent with those provided here for the 2013 inventory. Overall, forest carbon per acre increased by 2.8 percent relative to 5 years ago, and live-tree carbon values increased by 5.9 percent. Total forest area increased by 2.8 percent over the same period, so total carbon stocks in 2013 are 5.6 percent greater than the equivalent values calculated for 2008.

What this means

Although estimates of the status and dynamics of forest carbon stocks are correlated with other measures of forest resources such as stand age, volume, or stocking, these summaries are useful because they provide the context for comparing Delaware's carbon data with those from published regional or national forest carbon reports. The carbon summaries show that most of the carbon is in live trees (closely followed by soils), the majority of carbon is in stands of 61 to 100 years, and total forest carbon in Delaware has increased over the past 5 years.

Biomass

Background

The primary renewable energy resources in Delaware are biomass and solar energy. Although these sources make up only about 2 percent of the net energy generated by the State, there is interest in increasing this proportion. Delaware forests serve as a potential source of renewable biofuel that will help meet this goal. In order to effectively manage this resource, decisionmakers need to understand both the economic potential and ecological value of forest resources. The increasing interest in production of biofuels, as well as increased risk of forest fire due to fuel loading, makes estimates of biomass a critical component of the FIA program. Tree biomass is a measure of the mass or weight of trees and is often broken out by individual component parts of the tree. Aboveground biomass is defined by FIA as the weight of live trees composed of the boles, aboveground portion of stumps, tops, and limbs (excluding foliage). In general, the carbon content of tree biomass is equal to half the biomass weight measured in dry tons. Estimates of tree biomass are important for knowing not only the amount of carbon storage, but also the potential amount of carbon that can be captured or sequestered as the trees grow. Tree biomass estimates can also give an indication of the amount of biomass available for use as a biofuel.

What we found

The forest land of Delaware has an estimated 26 million dry tons of aboveground tree biomass or an average of 71 tons per acre. This aboveground biomass is distributed in fragmented patches across Delaware, with the greatest biomass concentrated in the southern part of the State (Fig. 23).

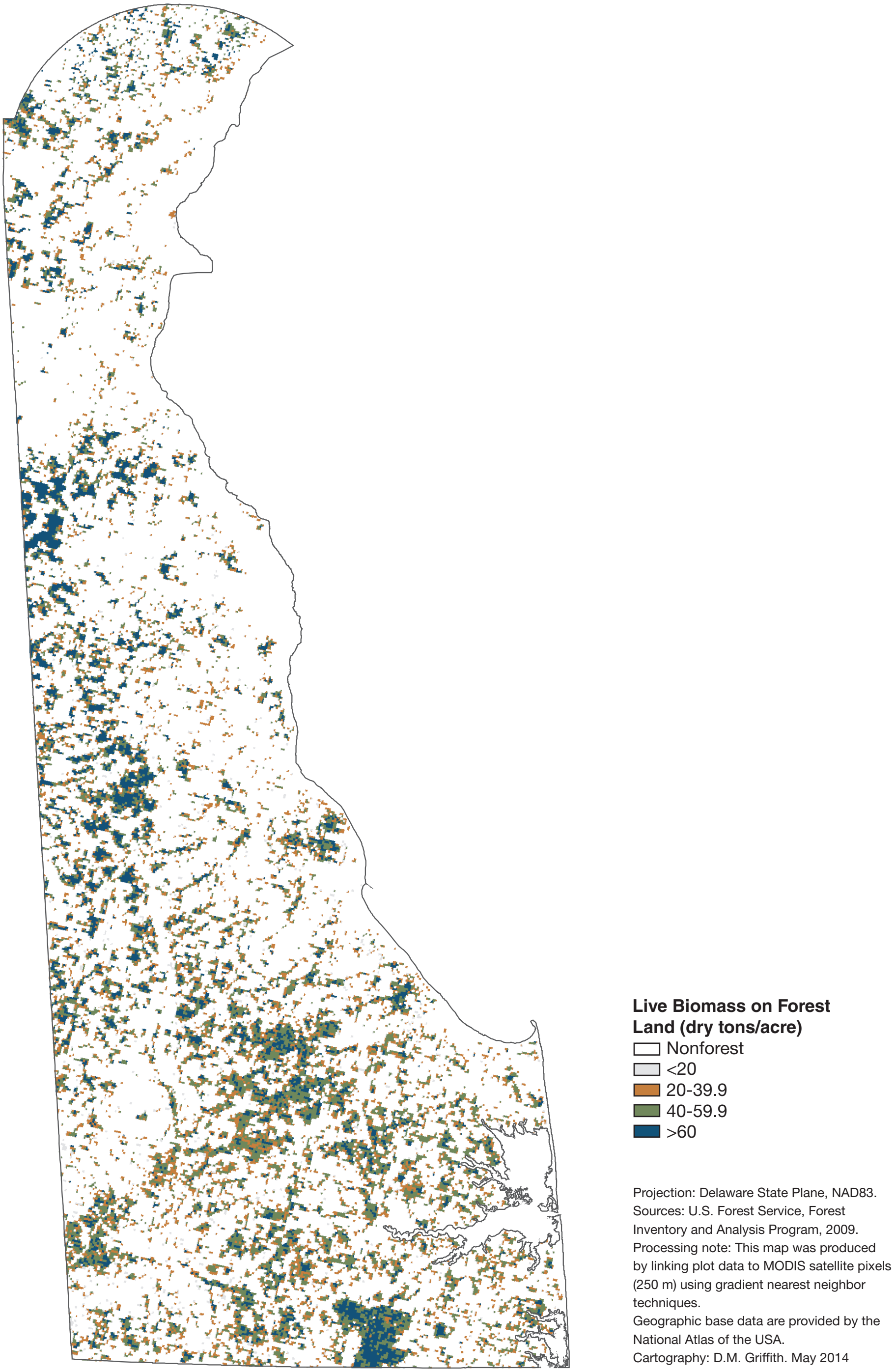


Figure 23.—Distribution of live-tree biomass on forest land, Delaware, 2009.

Total dry live biomass on forest land in the State has increased by 9 percent since 2008 (23.6 to 25.7 million dry tons). This increase is primarily due to the increasing size of sawtimber trees in Delaware. By contrast, biomass in sapling- and poletimber-size trees remained relatively constant over the time period (Fig. 24).

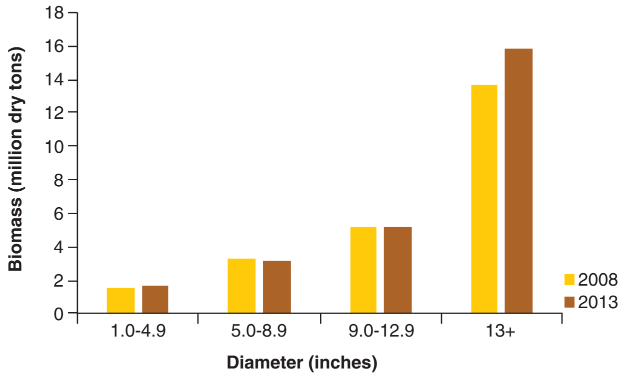


Figure 24.—Distribution of live-tree biomass (trees at least 1 inch d.b.h.) on forest land by diameter class and inventory year, Delaware.

The largest portion (67 percent) of the aboveground biomass is in the boles of growing-stock trees, which are also the part of the tree resource that can be converted into valuable wood products. The other 33 percent of the biomass is in tops, limbs, stumps, cull trees, or trees of noncommercial species (Fig. 25).

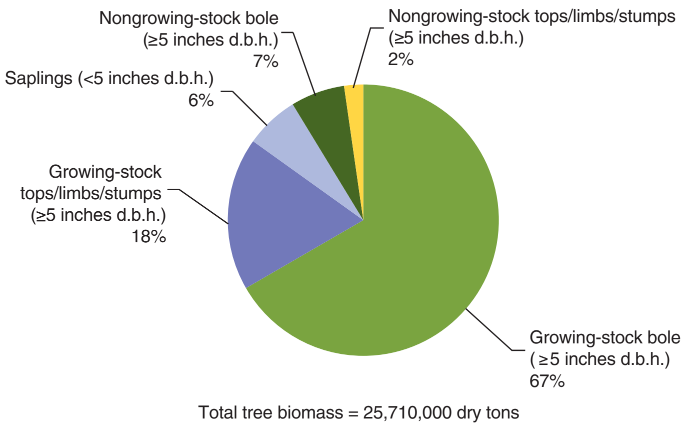


Figure 25.—Live-tree biomass for saplings and trees on forest land by aboveground component, Delaware, 2013.

What this means

Delaware forests are continuing to accumulate biomass as the forests mature. Because most of the biomass is contained in the boles of growing-stock trees, and most of the gains in biomass stocks are found in these higher value sawtimber-size trees, only a fraction of the accumulated material is available for use as whole tree chips for large wood fuel users. If the demand for biomass increases with increases in heating, power production, and potentially the production of liquid fuels, the wood-using market would become more competitive. Because biomass is a renewable source of energy, it can help reduce the Nation's dependence on fossil fuels. Using biomass for fuel provides markets for low grade and underutilized wood.

Private forest landowners are the holders of the majority (77 percent) of Delaware's biomass, so they play an important role in developing and sustaining this resource. There may be opportunities for enhancing forest management practices to increase the supply of traditional forest products and bioenergy.

Volume on Timberland

Background

Assessing estimates of tree volume provide the opportunity to evaluate trends in the wood resource, potential uses of that wood, and its economic value. FIA reports live-tree volume as total sound wood volume, net volume, and growing-stock volume in cubic feet; sawtimber volume in board feet (International ¼-inch rule); and biomass in dry tons. Each of these measures characterizes the wood resource in a different way and provides insights into its use and management. Although FIA does not provide direct estimates of the economic value of the wood resource, inventory and wood volume data can be combined with auxiliary data for economic analyses. Because of changes in procedures, comparisons to past inventories are more consistent for some measures than others.

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

What we found

There are 1.1 billion cubic feet of sound wood volume in live trees on Delaware forest land (Fig. 26), a 9.6 percent increase since 2008. Ninety-four percent (1.0 billion ft^3) of this volume is contained in trees on timberland. Of the volume on timberland, 81 percent is categorized as growing-stock volume, 10 percent as cull in growing-stock trees, and 9 percent as cull trees. Trees classified as rough or rotten cull do not meet growing-stock standards because they either have large amounts of defect or are noncommercial species. Besides the volume of trees growing on timberland, there is an additional 61 million cubic feet of sound volume growing on reserved and other forest land. Although the volume on reserved land is not available for harvesting, it provides habitat for wildlife and many ecosystem services, including carbon storage.

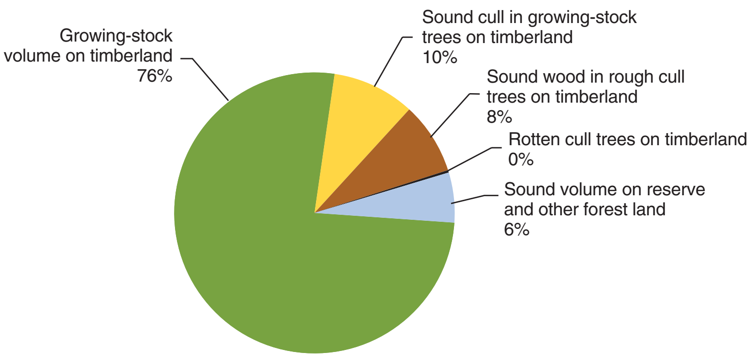


Figure 26.—Components of live sound wood volume on forest land, Delaware, 2013.

Since 2008, net volume has increased by 8.3 percent on timberland; softwood species volume increased by 11.5 percent and hardwood species volume increased by 7.7 percent. Growing-stock volume on timberland increased by 3.2 percent to 811 million cubic feet, and the portion of this volume qualifying as sawtimber increased by 12.6 percent to 3.1 billion board feet. Volume increases since 2008 are a continuation of a 56-year trend (Fig. 27). On a per-acre basis, the average net volume has steadily increased, from 1,419 cubic feet per acre in 1956 to 2,545 cubic feet per acre in 2013.

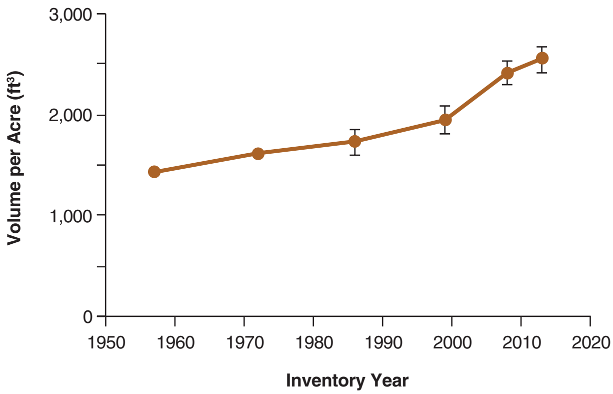


Figure 27.—Average net volume per acre on timberland by inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

Volume continued to shift toward larger diameter trees (Fig. 28). Between 1999 and 2013, net volume decreased by 10 percent in diameter classes less than 11 inches, while volume in trees 11 inches and larger increased. Both softwood and hardwood species show this shift in volume toward larger diameter trees. Nearly all of the gains in volume were in trees large enough to produce saw logs.

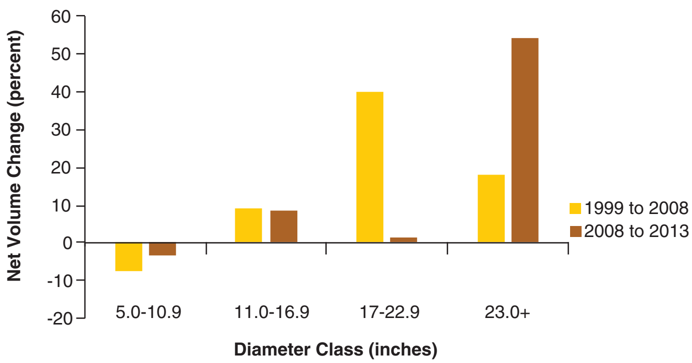


Figure 28.—Percentage change in net volume on timberland by diameter class, Delaware.

Red maple continues to be the species with the highest volume, followed by loblolly pine, and sweetgum (Fig. 29). These three species compose nearly half the total net volume. Since 2008, yellow-poplar and loblolly pine have experienced large increases in volume. Together, oak species make up 25 percent of total volume. The volume of oak species that grow in moist areas, including water and willow oak, increased more than oaks that grow in upland areas, such as white, scarlet, and southern red oak. Red maple, yellow-poplar, blackgum, and water and willow oak combined, experienced the most consistent increases in volume since 1999, while loblolly pine volume has fluctuated. Since 2008, increases in growing-stock volume by species were less than those for net volume, with the most notable differences being those for red maple and blackgum (Fig. 30). Long-term, changes in growing-stock volume by species show that most major species exhibited increases in volume since 1986, although net volume decreases were observed for loblolly pine, southern red oak, and Virginia pine.

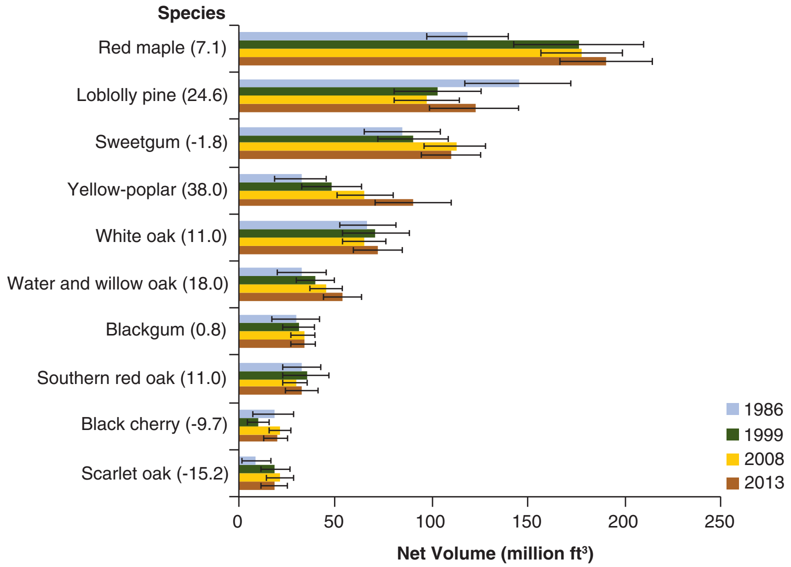


Figure 29.—Net volume on timberland by species and inventory year, Delaware. Percentage change from 2008 to 2013 is shown in parentheses. Error bars represent 68 percent confidence intervals around the estimated means.

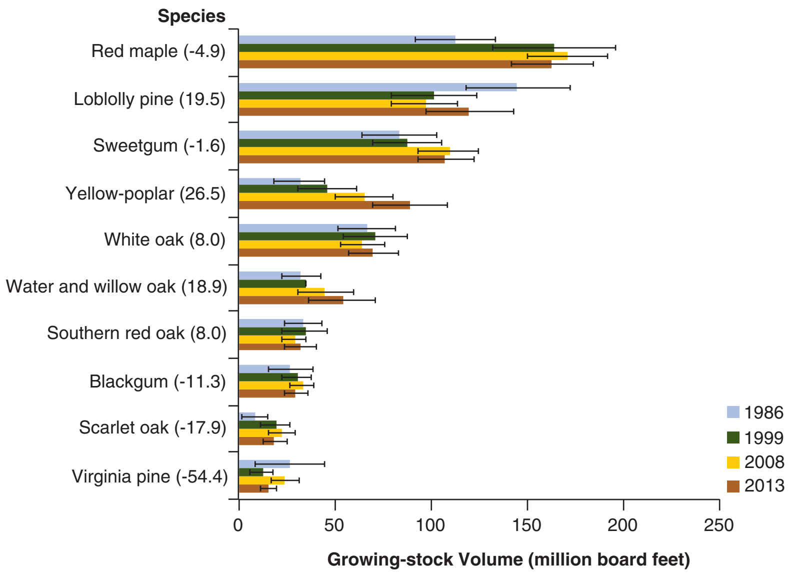


Figure 30.—Growing-stock volume on timberland by species and inventory year, Delaware. Percentage change from 2008 to 2013 is shown in parentheses. Error bars represent 68 percent confidence intervals around the estimated means.

Historical trends in sawtimber volume for major species groups show that hardwood sawtimber volume continues to increase, but softwood volume has remained fairly flat since the 1950s (Fig. 31). Since 2008, softwood volume increased by 20.5 percent and hardwood volume increased by 11.1 percent. Red maple is the leading sawtimber species by volume, followed by loblolly pine and yellow-poplar (Fig. 32). The volume of yellow-poplar sawtimber has more than doubled since 1999. Loblolly pine sawtimber volume returned to a level observed in 1986.

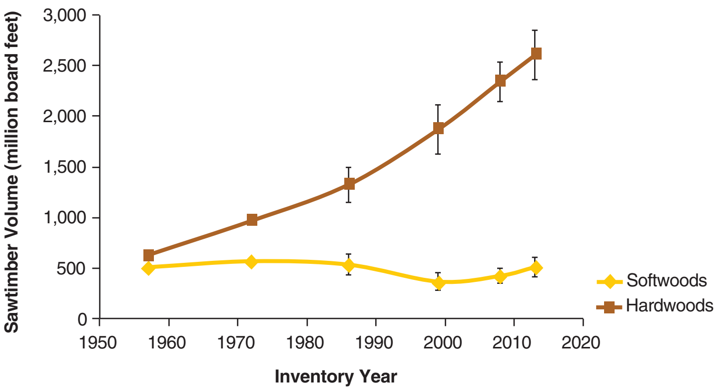


Figure 31.—Softwood and hardwood sawtimber volume by inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

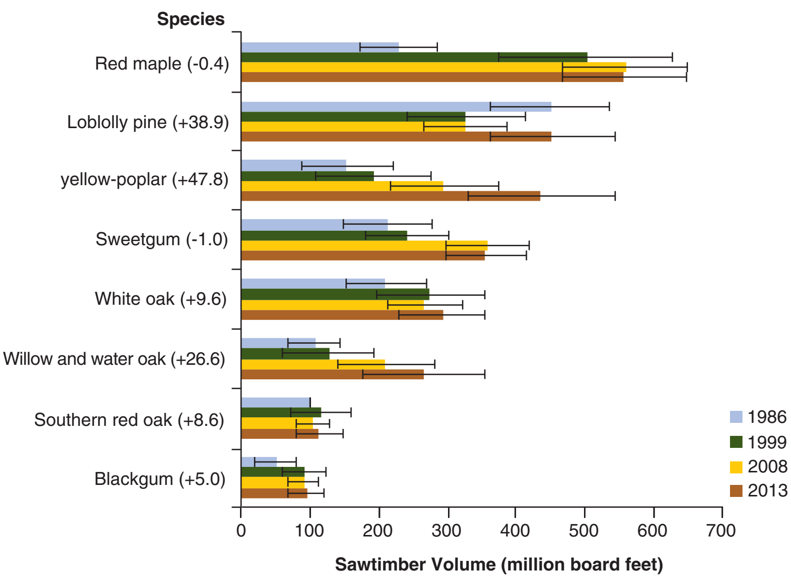


Figure 32.—Sawtimber volume (International ¼-inch rule) on timberland by species and inventory year, Delaware. Percentage change from 2008 to 2013 shown in parentheses. Error bars represent 68 percent confidence intervals around the estimated means.

The distribution of hardwood sawtimber volume by tree grade shifted between the 1999 and 2013 inventories, with the lowest tree grade gaining the most in terms of volume and as a proportion of total volume. Eighteen percent of hardwood sawtimber volume was contained in trees graded 1 in 1999 versus 26 percent in 2013 (Fig. 33). In absolute terms, the volume in grades 1 and 2 increased by 56 percent to 1.2 billion board feet, while volume in the lowest grade (tie/local use) increased by 78 percent to 0.8 billion board feet. Of the major species in the State, white oak, yellow-poplar, and sweetgum have the largest percentages of their volume in grades 1 and 2, with each having more than half their volume in these valuable grades (Fig. 34). Red maple, the leading species in board-foot volume, has the least volume in tree grade 1.

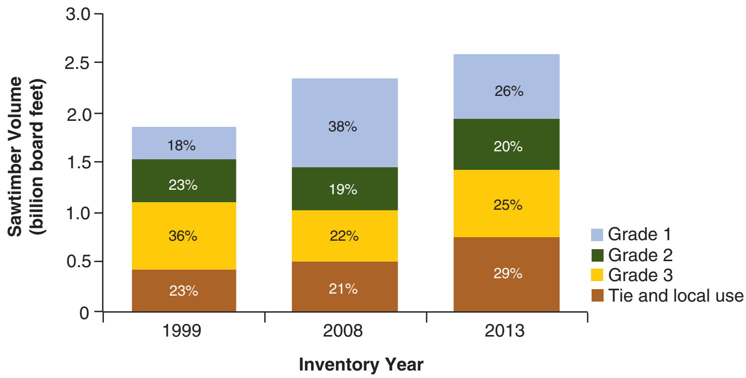


Figure 33.—Hardwood sawtimber volume by tree grade and inventory year, Delaware.

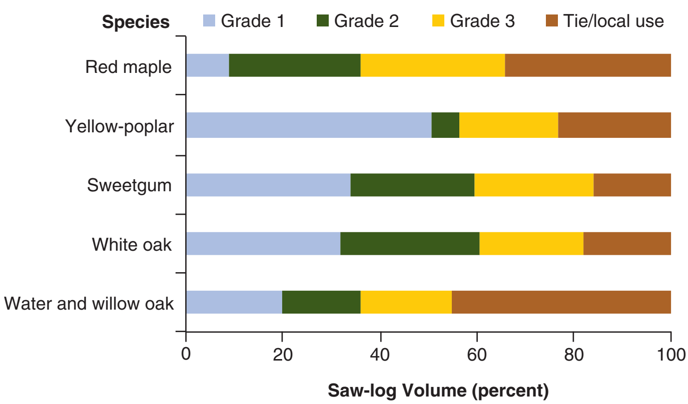


Figure 34.—Proportion of saw-log volume by tree grade for selected species, Delaware, 2013.

What this means

Continuous volume increases have brought Delaware's wood resource to record levels for all measures of volume. Most of the inventory volume is in trees that qualify as growing-stock trees. Volume increases are concentrated in sawtimber-size trees, which explains why increases in board-foot volume (+12.6 percent) were higher than increases in net volume and growing-stock cubic-foot volume (+8.3 percent and +3.2 percent since 2008, respectively). The shift in volume toward larger diameter trees is further evidence that Delaware's forests are maturing. Tree value can increase abruptly as trees grow to sawtimber size because they can be used for higher value timber products. Despite the substantial increase in sawtimber volume, trends in tree quality and species composition raise concern for the sustainability of some high value species.

Since 2008, net volume increased by more than twice that of growing-stock volume, which may indicate that low value wood is increasing faster than the higher quality timber in the State. Additionally, within growing-stock volume, saw-log volume realized a greater percentage increase in the tie/local use class than in grades 1 and 2 combined. The larger percentage increase in lower quality sawtimber can be attributed to a combination of timber harvest methods that remove higher value trees and leave residual trees of lower grades, and ingrowth of trees species that typically make up the poorer grade timber species (i.e., red maple and water and willow oak). Tree grades for sweetgum indicate that a large percentage of sweetgum volume is in high quality trees, but because lumber produced from this species is difficult to dry, it is not typically utilized in the production of high quality lumber. Loblolly pine stands are intensively managed for the production of commercial lumber. The return to higher volumes of this species is the likely result of decreased harvesting after the 2008 economic recession that slowed home building. Because of sharp declines in the number of loblolly pines less than 11-inches in diameter, increases in volume for this species are unlikely to continue.

The increasing amounts of sound volume in the cull sections of growing-stock trees and trees classified as rough and rotten cull present opportunities for increased utilization of low value wood in the State. Much of this wood is now left during harvesting operations either as standing live trees or as logging residue. Having markets for small trees and lower grade wood products, such as pallets, wood pellets, and biomass energy, can promote best management practices and improve overall stand quality. Although cull trees have low value for wood products, they are often of high value for wildlife habitat. Many of the same features that decrease the value for wood products, such as bole cavities, large amounts of rot, and broken tops, increase their value for wildlife. Cull trees and portions of growing-stock trees left in the woods as logging residues provide habitat for wildlife and increase nutrient recycling.

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

Background

Well-tended forests supply a continuous flow of products and services while maintaining long-term productivity and ecological integrity. One way to judge the sustainability of a forest is to examine the components of annual change in inventory volume: growth, removals, and mortality. Net growth includes growth (accretion) on trees measured previously, ingrowth[1] of trees that have reached the 5-inch threshold for volume measurement, deductions for mortality due to natural causes, and volume of trees on lands reverting to forest. Removals include trees that were harvested and trees that are no longer counted as part of the inventory because the forest land was converted to a nonforest use, such as agriculture or residential uses. On timberland, removals also include trees that are on land that has been reclassified as either reserved or other forest land. Analysis of these individual components can help us better understand what is influencing net change in volume.

What we found

The growth of trees has greatly outpaced mortality and removals during the past 50 years. The most recent inventory revealed that since 2008, the gross growth in the net volume of live trees on timberland was 28 million cubic feet annually (Fig. 35). Annual mortality averaged 8 million cubic feet, resulting in a net growth of 20 million cubic feet per year. The annual removals of trees due to harvesting and land use change averaged 8 million cubic feet, leaving an annual surplus or net increase of 12 million cubic feet on Delaware's timberland. As a percentage of the current inventory, gross growth was 3.2 percent; mortality, 1.0 percent; net growth, 2.2 percent; and removals, 0.9 percent. These result in an average annual net increase in total volume of 1.3 percent.

On land classified as timberland in both 2008 and 2013, it was found that 89 percent of net growth was on trees previously in the 5 to 7 inch diameter class and larger (accretion), and the remaining 11 percent was from trees growing into diameter classes 5 inches and larger (ingrowth). Accretion growth was well distributed across diameter classes, although growth on trees in the 18 inch diameter class and larger was mostly in hardwood species (Fig. 36). Nearly half (46 percent) of the growth on softwood species was in planted stands, whereas only 5 percent of hardwood growth occurred in planted stands.

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

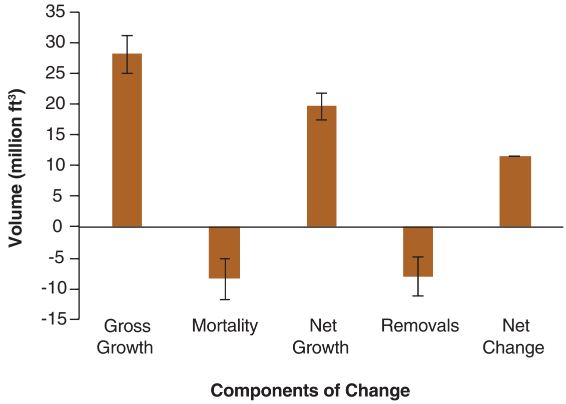


Figure 35.—Components of average annual change in net volume on timberland, Delaware, 2008 to 2013. Error bars represent 68 percent confidence intervals around the estimated means.

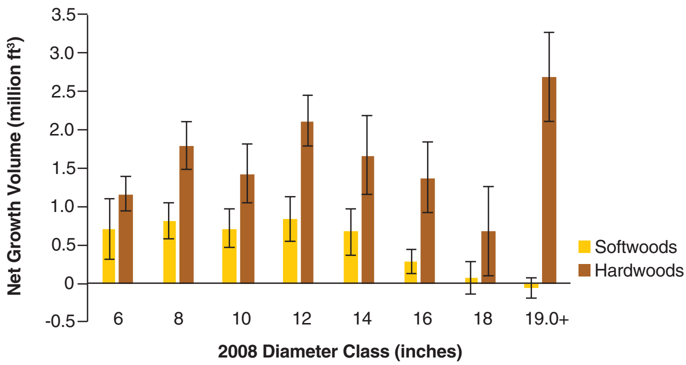


Figure 36.—Average annual net growth (volume) of live trees (i.e., accretion) on timberland by 2008 diameter class and species group, Delaware, 2008 to 2013. Error bars represent 68 percent confidence intervals around the estimated means.

Statewide, 89 percent of the removals were from the harvesting of trees on land that remained in timberland, 2 percent was due to timberland being diverted to a nonforest land use, and 9 percent was from timberland being reclassified as other forest land. On land that was timberland in both 2008 and 2013, softwood species accounted for 27 percent of removals and hardwoods for 73 percent. Softwood removals tended to mostly be trees in the lower diameter classes, while hardwood removals were more evenly distributed across all diameter classes (Fig. 37). Softwood removals were nearly evenly split between stands of natural and planted origin, whereas nearly all of the hardwood removals came from naturally regenerated stands.

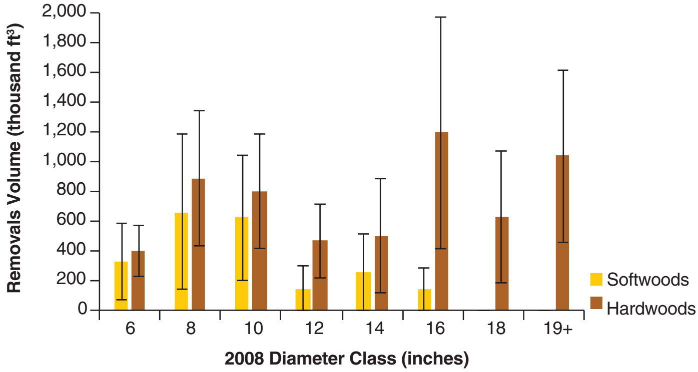


Figure 37.—Average annual removals (volume) of live trees on timberland by 2008 diameter class and species group, Delaware, 2008 to 2013. Data excludes removals due to forest land being diverted to nonforest uses. Error bars represent 68 percent confidence intervals around the estimated means.

Between 2008 and 2013, cutting occurred on an average of 3,600 acres per year, an amount equivalent to 1 percent of the timberland acres being harvested annually. Harvests were primarily from sawtimber-size stands (75 percent) and stands with a live-tree basal area of at least 120 square feet per acre.

In terms of growth and removals by species, loblolly pine experienced the largest increase in net growth volume since 2008, accounting for 27 percent of total growth. All oak species combined accounted for the greatest amount (37 percent) of removals (Fig. 38). On timberland, the ratio of total net growth-to-removals (G/R) averaged 2.4:1 from 2008 to 2013. For the 10 highest volume species, G/R ratios varied considerably, from yellow-poplar with a G/R ratio of 7.1:1, to southern red oak with a G/R ratio of 0.8:1. The G/R ratio for all oaks combined was 1.5:1.

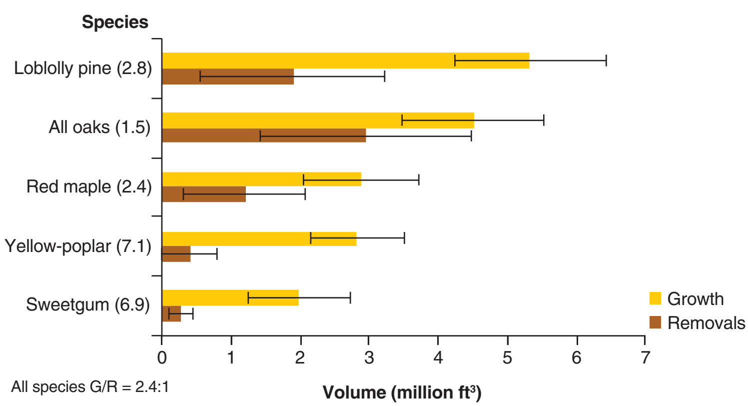


Figure 38.—Average annual growth and removals of net volume on timberland by species, Delaware, 2008 to 2013. Growth-to-removals ratio is shown in parentheses. Error bars represent 68 percent confidence intervals around the estimated means.

What this means

Today's well-stocked forests are a product of growth consistently outpacing removals during the last half century and the surplus timber accumulating in the forest. Since 2008, net growth has been nearly two and a half times that of removals, with the net change amounting to an annual increase of 1.3 percent in inventory volume. This implies that the current level of removals is sustainable and that increases in volume will continue in the State. The G/R ratios indicate that net growth exceeds removals for all the major species. Harvesting pressure is greatest on species of oak and is least on yellow-poplar and sweetgum. The large amount of softwood growth and removals from planted stands, mainly loblolly pine plantations, shows that softwoods are being managed more intensely than hardwood species in the State. Comparing the G/R ratios of individual species to the average ratio for all species (2.4:1) reveals which species are increasing in importance and which are decreasing. The high G/R ratios for yellow-poplar and sweetgum indicate these species will increase in importance in Delaware's forests.

On the forest land that was harvested, very low volumes per acre were retained on approximately three-fifths of the acres, and high volumes were retained on about two-fifths of the acres. This implies that harvests were either very intense or very light. The intense harvest will promote the ingrowth of new trees of early successional species such as pines and create early successional habitats, whereas the light harvest will promote growth on residual trees, and the reproduction that does occur will favor more shade-tolerant species. Having a balance of harvesting intensities helps sustain diversity in both species composition and stand size.

Mortality

Background

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

What we found

In Delaware, the average annual rate of mortality for live trees on timberland was 1.0 percent between 2008 and 2013. If only growing-stock trees are considered, the morality rate for this period was 0.8 percent; this is nearly the same growing-stock mortality rate that occurred during the period from 1999 to 2008. Mortality rates of live trees in Delaware are about the same as those found in the neighboring states of Virginia (0.8 percent), Pennsylvania (0.9 percent), Maryland (1.0 percent), and New Jersey (1.1 percent).

Mortality rates were lower for trees in the 12, 14, and 16-inch diameter classes than for trees in either larger or smaller diameter classes (Fig. 39). The mortality rate in the 6-inch class was 1.9 percent per year, about twice the rate across all diameter classes. Three of the five leading species/species groups by volume have mortality rates higher than the State average: sweetgum (1.3 percent), red maple (1.1 percent), and all oaks combined (1.0 percent) (Fig. 40). These three species/species groups account for 69 percent of total mortality, although they only account for 59 percent of total volume. Within the oak species group, northern red oak and scarlet oak had notably high mortality rates (8.2 and 2.6 percent, respectively). The mortality rate for Virginia pine was 5.9 percent (data not shown).

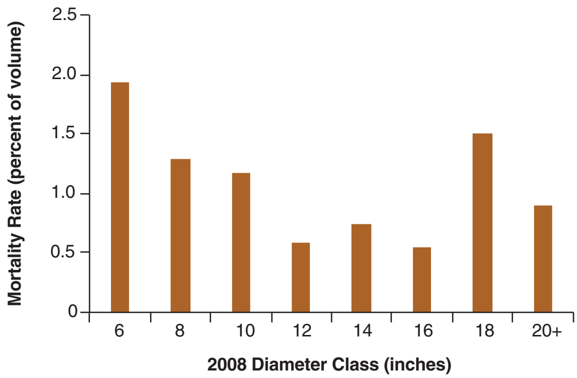


Figure 39.—Average annual mortality as a percentage of current live tree volume on timberland by 2008 diameter class, Delaware, 2013.

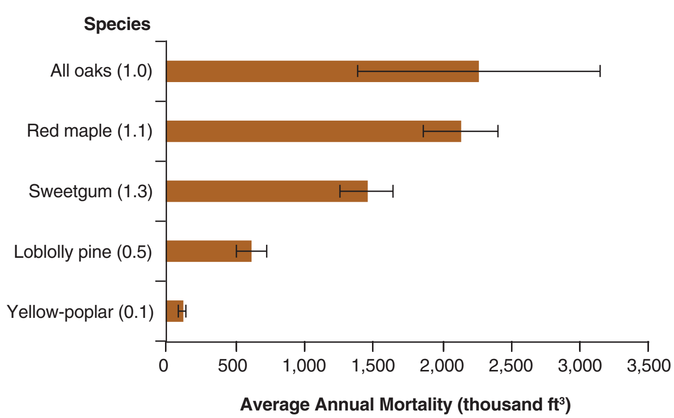


Figure 40.—Average annual mortality (volume) on timberland for major species, Delaware, 2013. Mortality rate (mortality as a percent of current volume) is shown in parentheses. Error bars represent 68 percent confidence intervals around the estimated means.

What this means

Mortality rates in Delaware are similar to those in surrounding states, and much of this mortality can be explained by natural stand dynamics. As a forest matures, growing conditions become more crowded, and as trees compete for light and growing space, some fall behind their neighbors, lose vigor, and eventually succumb to insects and diseases. This is evident in the higher mortality rates in small diameter classes. Species that are classified as early successional, such as Virginia pine, should be expected to decline in importance as stands age, as is the case in Delaware. The low mortality rate for loblolly pine is likely the result of this species being managed more intensely than other species. By thinning stands, crowded conditions are avoided and many small trees that would otherwise die from crowding are removed by harvesting. Mortality rates vary among species, with many species deviating substantially from the State average. Having a large diversity of species contributes to the overall resilience of Delaware forests to the impacts of insects and diseases that attack individual species.

Species Composition

Background

The species composition of a forest is the result of the long-term interaction of climate, soils, disturbance, competition among trees species, and other factors. Causes of forest disturbances in Delaware include timber harvesting, droughts, wildfire, changes in the drainage patterns (water table), land clearing followed by abandonment, and insects and diseases (e.g., gypsy moth *[Lymantria dispar L.]*, southern pine beetle *[Dendroctonus frontalis Zimmerman],* and dogwood anthracnose *[Discula destructive]*). White-tailed deer (*Odocoileus virginianus*) can also impact species composition by heavily browsing some species while avoiding others. As forests recover from disturbances and mature, changes in growing conditions favor the growth of shade-tolerant species over shade-intolerant species in the understory unless forest management practices intervene to work toward the perpetuation of the shade-intolerants species.

FIA records several forest attributes that describe forest composition including forest type and numbers of trees by species and size class. Forest types describe groups of species that frequently grow in association with one another and dominate the stand. Similar forest types are combined into forest-type groups. Changes in area by forest type are driven by changes in the species composition of the large diameter trees, and while these large trees represent today's forest, the composition of the smaller diameter classes represents the future forest. Comparisons of species composition by size can provide insights into future changes in overstory species.

What we found

The 2013 inventory identified 53 tree species (see appendix for list) and 31 forest types that are found in seven forest-type groups in Delaware. The 10 forest types with the most area cover 75 percent (308,000 acres) of Delaware's forest land (Fig. 41). The white oak/red oak/hickory, loblolly pine, and yellow-poplar/white oak/northern red oak forest types are common to the mesic upland forests of the Atlantic coastal plain region that encompasses nearly all of Delaware. The loblolly pine forest type covers the greatest area, and when combined with the loblolly/hardwood forest type, almost all of the 29,000 acres of forest land identified by field crews as having been planted falls within these two groups. Planted stands account for only a small portion of Delaware's forest land, with 92 percent of the forest in Delaware originating from natural regeneration. Other major forest types including the sweetbay/swamp tupelo/red maple and sweetgum/Nuttall oak/willow oak are closely associated with hardwood swamps and floodplains in the region.

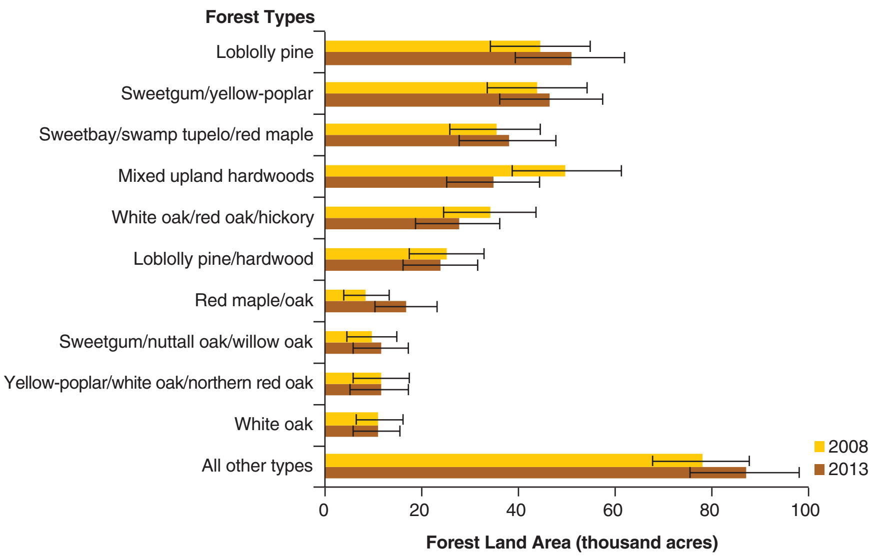


Figure 41.—Forest land area by forest type and inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

American holly is the most numerous seedling-size tree (trees less than 1 inch d.b.h. and greater than 1 foot tall) and represents about 24 percent of all seedlings, followed by sweetgum, red maple, and loblolly pine (Fig. 42). Many of the top-ranked seedling species are associated with moist or poorly drained soils, including American holly, willow oak, water oak, sweetbay magnolia, and blackgum, and to a lesser extent sweetgum and red maple. These species are common to hardwood swamps and floodplains in the Atlantic coastal plain region.

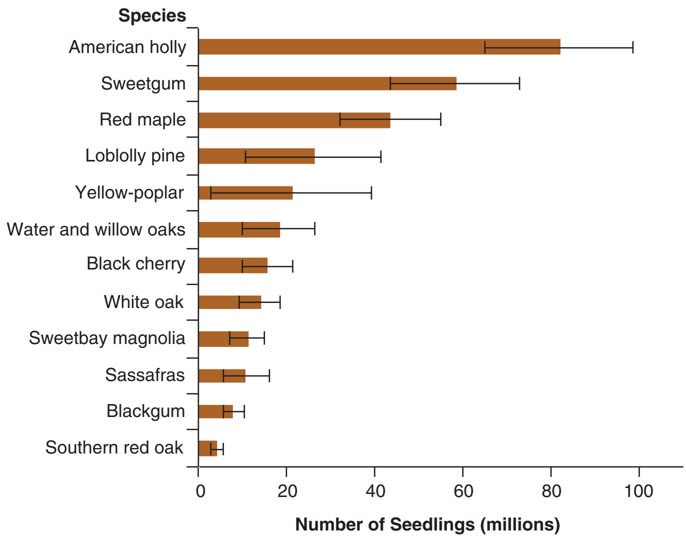


Figure 42.—Number of seedlings (at least 1 foot tall and less than 1 inch d.b.h.) by species, ranked by total number of stems, Delaware, 2013. Error bars represent 68 percent confidence intervals around the estimated means.

The ranking of number of saplings (trees 1 to 4.9 inches d.b.h.) by species is similar to that of seedlings (Fig. 43). Again American holly is the most numerous, followed by red maple, sweetgum, and blackgum. These four species account for 68 percent of all sapling-size trees in the State. The total number of saplings has remained nearly unchanged since 2008. Increases in the numbers of American holly and loblolly pine canceled out losses observed in many other species.

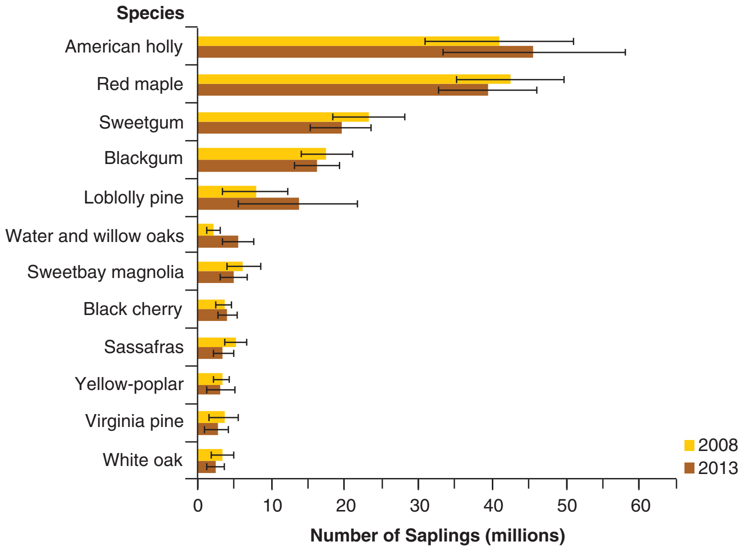


Figure 43.—Numbers of sapling (trees at least 1 inch and less than 5 inches d.b.h.) by species and year, ranked by total number of stems in 2013, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

The total number of trees (5 inches d.b.h, and larger) remained nearly unchanged between 2008 and 2013, and the list of top species and species groups ranked by number also remained unchanged (Fig. 44). Red maple continues to be the most numerous tree species, followed by loblolly pine, sweetgum, and American holly. Most of the top-ranked species increased in number, although numbers of red maple, American holly, black cherry, and white oak have decreased since 2008.

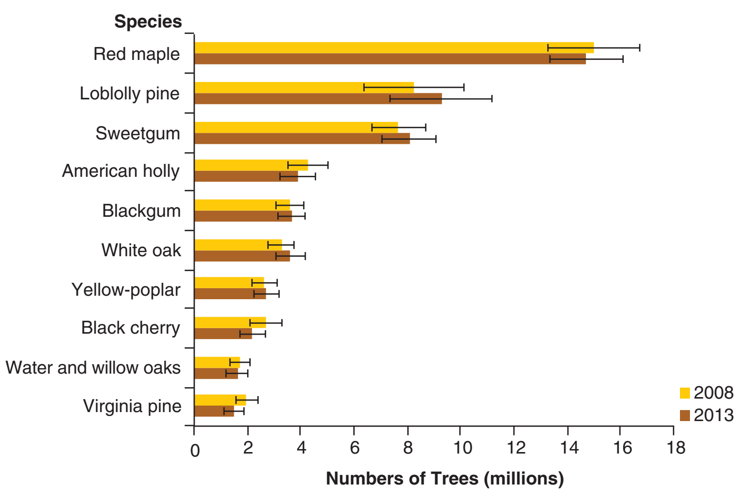


Figure 44.—Numbers of trees (5.0 inches d.b.h and larger) by species and year, ranked by total number of stems in 2013, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

A comparison of species composition by diameter class shows that white oak, yellow-poplar, and the water oak/willow oak species are better represented in larger diameters classes (11 inches and larger) than they are in smaller diameter classes (Fig. 45). White oak accounts for 9 percent of trees (11 inches in diameter and larger) and 1 percent of saplings, and yellow-poplar accounts for 8 percent of trees (11 inches in diameter and larger) and 2 percent of saplings. In contrast, American holly, makes up 26 percent of saplings and only 1 percent of trees 11 inches and larger, and blackgum, accounts for 9 percent of seedlings and 4 percent of trees 11 inches and larger.

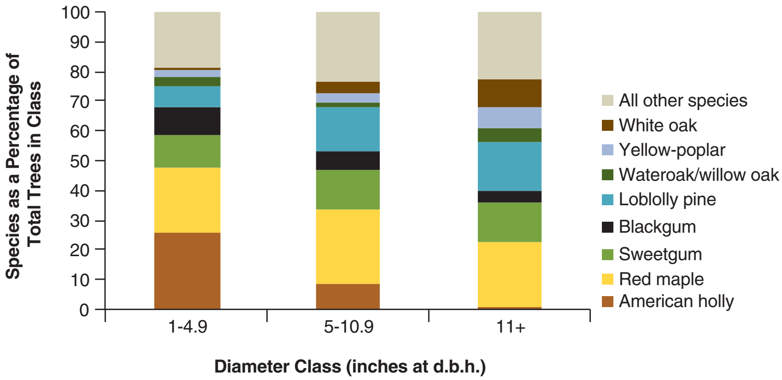


Figure 45.—Species composition as a percentage of all trees on forest land by diameter class, Delaware, 2013.

Delaware forests are overwhelmingly composed of species native to the conterminous United States. In 2013, four nonnative species were found: Norway maple, Siberian elm, white mulberry, and ailanthus. Together these species represent less than one percent of the total number of trees with a d.b.h. of 1 inch and larger.

What this means

Delaware forests are unique in that many species that grow there are near the northern extent of their range. These species include loblolly pine, overcup oak, southern red oak, willow oak, sweetgum, and baldcypress. Additionally, though rare, Atlantic white cedar swamps are found in the State. The average elevation of Delaware is 60 feet above sea level and the topography is mostly level to slightly sloped. Small changes in elevation can have large effects on soil moisture and drainage. The amount of water in the soil appears to be an important factor in determining species composition within Delaware forests. Although the majority of forest types are considered upland types, they contain many species that are tolerant of moist soil conditions. This reflects the close proximity to water of many of Delaware's forests. Much of Delaware's forest land borders the many small streams that dissect the State.

Another factor affecting species composition is the successional stage of the forest. Many of the species that are thriving in the understory are tolerant of shaded conditions. As Delaware forests mature, shade tolerant species will likely replace the more shade-intolerant species now growing in the overstory. Both yellow-poplar and white oak are intolerant of shade. They account for a lower proportion of the trees in the smaller size classes than they do in the sawtimber size class (11 inches minimum diameter for hardwoods), suggesting that they will be replaced by other species and that their current occurrence in the overstory may not be sustainable. This contrasts with American holly and blackgum that are both very tolerant of shade. American holly and blackgum make up a larger proportion of stems in the seedling and sapling size classes when compared to their presence in sawtimber-size trees, indicating that these species may play a larger role in Delaware's future forest. Red maple, sweetgum, and loblolly pine are numerous across all diameter classes, suggesting that they have adequate regeneration and will continue to dominate in the larger size classes.

In addition to shade tolerance, browse by white-tailed deer is a contributing factor in determining which species regenerate successfully in Delaware forests. Blackgum, sweetgum, sweetbay magnolia, American holly, and loblolly pine are not preferred browse for white-tailed deer and are common in the seedling and sapling size classes, whereas species of oaks, which are more favored browse, are poorly represented in seedling and sapling size classes. Currently, successional stage, soil moisture, and browse by white-tailed deer appear to be driving trends in species composition in Delaware.

Ecosystem Indicators and Services

Young hardwood forest. Photo by Tonya Lister, U.S. Forest Service.

Tree Crown Health and Damage

Background

Trees are influenced by various biotic and abiotic stressors, and their condition can be assessed by measuring crown health and observing the presence of damage. Abiotic stressors include drought, flooding, cold temperatures or freeze injury, nutrient deficiencies, soil physical properties affecting soil moisture and aeration, and toxic pollutants. Biotic stressors include native or introduced insects, diseases, invasive plant species, and animals. Invasions by exotic diseases and insects are one of the most important threats to the productivity and stability of forest ecosystems around the world (Liebhold et al. 1995, Pimentel et al. 2000, Vitousek et al. 1996). Over the last century, Delaware forests have suffered the effects of well-known exotic, invasive agents such as European gypsy moth (*Lymantria dispar Linnaeus)*, as well as the native southern pine beetle (*Dendroctonus frontalis Zimmermann*). More recently, invasion by the hemlock woolly adelgid (*Adelges tsugae*) is threatening the health of eastern hemlock, and the detection of Thousand Cankers Disease in Maryland and Pennsylvania has raised concerns about possible future infestations affecting the black walnut resource in Delaware. Additionally, Asian longhorned beetle (*Anoplophora glabripennis*) and emerald ash borer (*Agrilus planipennis*), though not found in Delaware during the 2013 inventory period, are emerging threats that have been confirmed in nearby states.

Tree-level crown dieback, defined as recent mortality of branches with fine twigs, is collected on P2+ plots and reflects the severity of recent stresses on a tree. A crown is labeled as "poor" if crown dieback is greater than 20 percent. This threshold is based on findings by Steinman (2000) that associate crown ratings with tree mortality. Crown dieback has been shown to be the best crown variable to use for predicting tree survival (Morin et al. 2015).

Tree damage is assessed for all trees with a d.b.h. of 5.0 inches or greater. Up to two of the following types of damage can be recorded: insect damage, cankers, decay, fire, animal damage, weather, and logging damage. If more than two types of damage are observed, decisions about which two are recorded are based on the relative abundance of the damaging agents (U.S. Forest Service 2010).

What we found

The incidence of poor crown condition is low across Delaware. Plots with greater than 5 percent of basal area with poor crown health are concentrated in central Delaware (Fig. 46). Most species have a very low proportion of live basal area with poor crowns. However, black cherry, willow oak, and red maple all have greater than 5 percent of their basal area in trees with unhealthy crowns, and that proportion has increased since 2008 (Table 4). Mean dieback ranged from nearly 0 for blackgum to 6.4 percent for black cherry (Table 5).

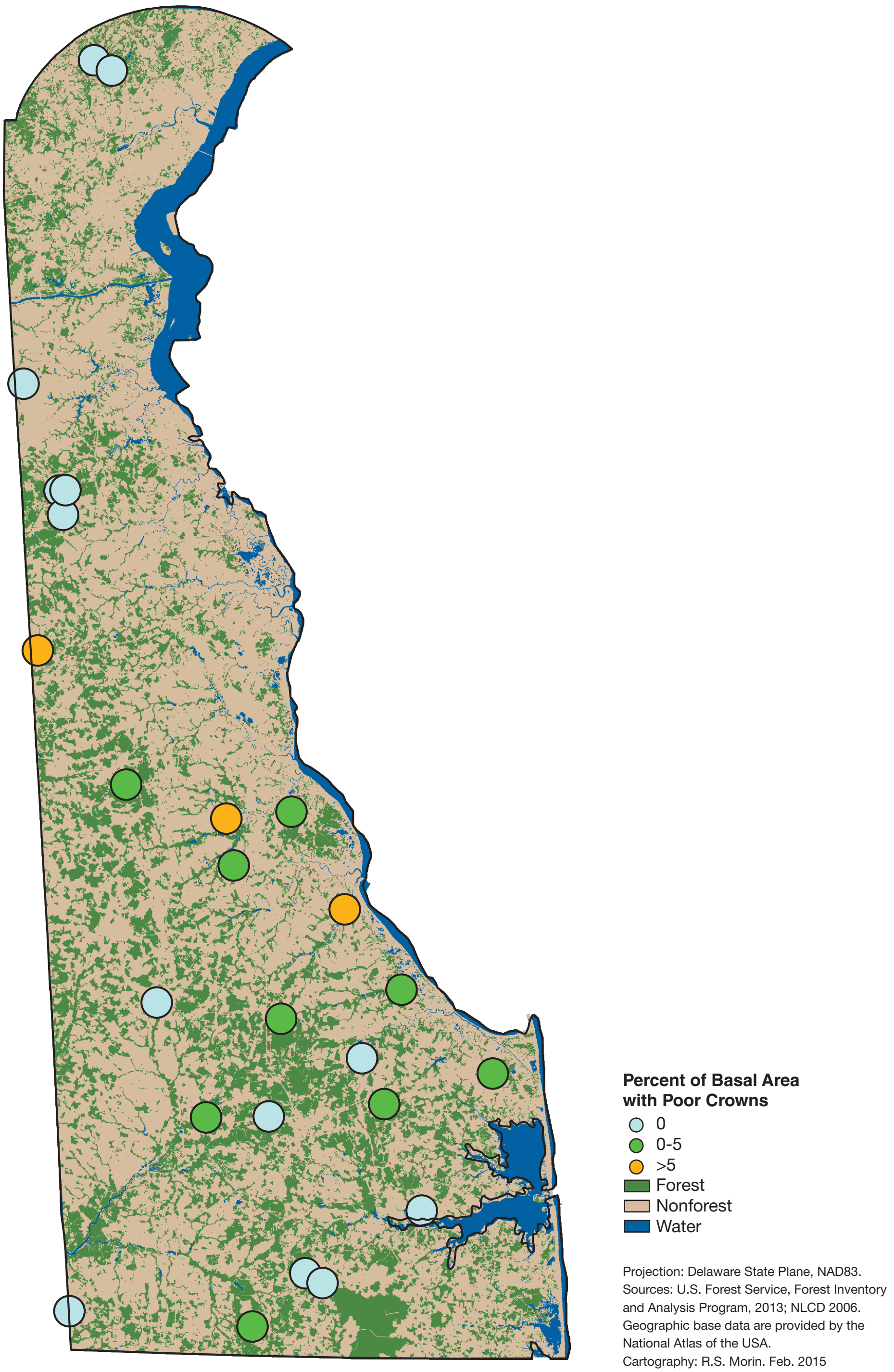


Figure 46.—Percentage of live basal area with poor crowns, Delaware, 2013. Depicted plot locations are approximate.

Table 4.—Percentage of live basal area with poor crowns, Delaware, 2008 and 2013

Species	Basal area with poor crowns	
	2008	2013
	percent	
Black cherry	2.0	10.0
Willow oak	0.0	9.3
Red maple	0.1	5.1
Sweetgum	1.5	1.7
Yellow-poplar	0.5	1.1
Loblolly pine	0.3	0.8
Blackgum	1.7	0.0
White oak	0.7	0.0
Scarlet oak	0.0	0.0
Southern red oak	1.7	0.0

Table 5.—Mean crown dieback and other statistics for live trees (>5 inches d.b.h.) on forest land by species, Delaware, 2013

Species	Trees	Mean	SE	Minimum	Median	Maximum
	number	*percent*				
Black cherry	25	6.4	3.98	0	0	99
Red maple	116	5.2	1.54	0	0	99
Willow oak	19	4.5	2.88	0	0	55
Yellow-poplar	25	4.4	3.95	0	0	99
Scarlet oak	5	2.0	2.00	0	0	10
Sweetgum	61	1.5	0.46	0	0	20
Southern red oak	25	1.2	0.52	0	0	10
White oak	26	1.2	0.42	0	0	5
Loblolly pine	84	1.1	0.76	0	0	50
Blackgum	41	0.1	0.12	0	0	5

An analysis of trees from the 2008 inventory that were remeasured in the 2013 inventory revealed that the proportion of trees that die increases with increasing crown dieback (Fig. 47). Sixty percent of trees with crown dieback above 20 percent during the 2008 inventory were dead when visited again during the 2013 inventory.

Damage was recorded on approximately 16 percent of the trees in Delaware and varied considerably among species. The most frequent damage on all species was decay (12 percent of trees), which ranged from 2 percent on loblolly pine to 22 percent on red maple. Decay was also recorded for 15 percent of black cherry and yellow-poplar trees. The occurrence of all other injury types was very low (Table 6).

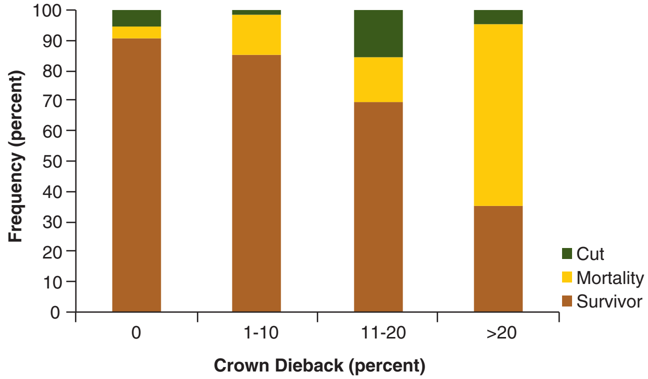


Figure 47.—Crown dieback distribution by tree survivorship for remeasured trees, Delaware, 2008 to 2013.

Table 6.—Percentage of trees with damage by species, Delaware, 2013

Species	Damage type							
	None	Animal	Cankers	Decay	Insect damage	Logging/ human	Other	Weather
All	84	1	1	12	1	1	1	0
Black cherry	76	1	8	15	0	0	2	1
Blackgum	87	1	1	9	1	1	1	0
Loblolly pine	97	0	0	2	1	1	0	0
Red maple	76	1	0	22	1	0	1	0
Scarlet oak	87	6	0	5	0	0	2	0
Southern red oak	93	0	0	4	3	0	0	0
Sweetgum	89	1	1	8	0	1	1	0
White oak	86	1	0	6	2	3	4	0
Willow oak	93	0	0	5	2	0	0	0
Yellow-poplar	82	1	0	15	0	0	1	2

What this means

In Delaware forests, trees of important species are generally in good health, but for several species the proportion of trees that are in poor health has increased. Because red maple, willow oak, and black cherry do not typically have health concerns, the status of these species needs to be observed in future inventories. As in many eastern forests, decay is the most commonly observed damage in Delaware forests. This is not unusual given that the majority of large diameter stands are composed of mature trees. Additionally, red maple is a relatively short-lived species that is likely to develop decay as it ages. The condition of ash trees, maple trees, and eastern hemlock should be monitored closely due to the recent invasion of hemlock woolly adelgid and emerald ash borer, and likely future invasions by Asian longhorned beetle and Sirex woodwasp (*Sirex noctilio*) (see Forest Insect Pests section).

Down Woody Materials

Background

Down woody materials, in the various forms of fallen trees and shed branches, fulfill a critical ecological niche in the forests of Delaware. Down woody materials provide valuable wildlife habitat, stand structural diversity, a store of carbon/biomass, and contribute toward forest fire hazards via surface woody fuels.

What we found

The total carbon stored in down woody materials (fine and coarse woody debris and residue piles) on Delaware forest land exceeded 800,000 tons. Downed woody debris carbon was normally distributed by stand-age class (Fig. 48) with moderately aged stands having the highest total carbon (~300,000 tons). The downed dead wood biomass within Delaware forests was dominated by coarse woody debris (Fig. 49) at approximately 953,000 tons, with fine woody debris representing more than a third of statewide totals. The total volume of coarse woody debris was highest in the private ownership category at approximately 81 million cubic feet (Fig. 50). State and local forests had the second largest, albeit substantially lower, totals of coarse woody debris volume (24 million cubic feet) compared to private ownerships; however, the amount of coarse woody debris per acre of forest land varied little by ownership with 275 and 279 cubic feet per acre on public and private land, respectively. Privately owned forest lands had the highest volume of dead wood in piles at over 11 million cubic feet albeit with a high level of uncertainty (>100 percent sampling error).

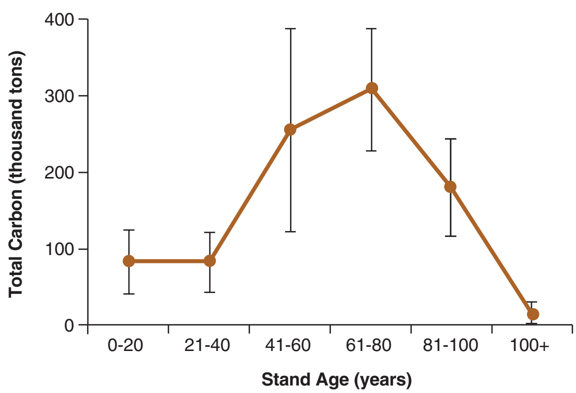


Figure 48.—Total carbon (short tons) in down woody materials (fine and coarse woody debris and piles) on forest land by stand-age class, Delaware, 2006-2010. Error bars represent 68 percent confidence intervals around the estimated means.

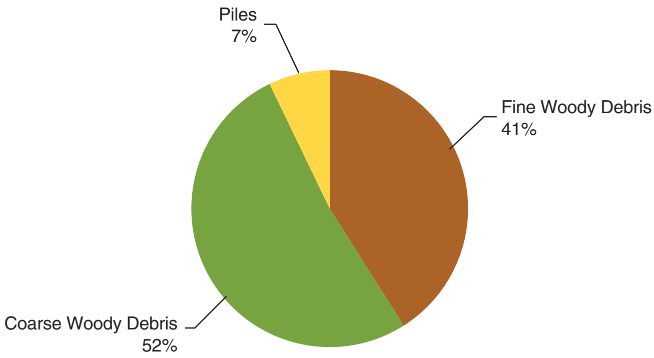


Figure 49.—Proportion of down woody material biomass on forest land by component (fine and coarse woody debris and residue piles), Delaware, 2006-2010.

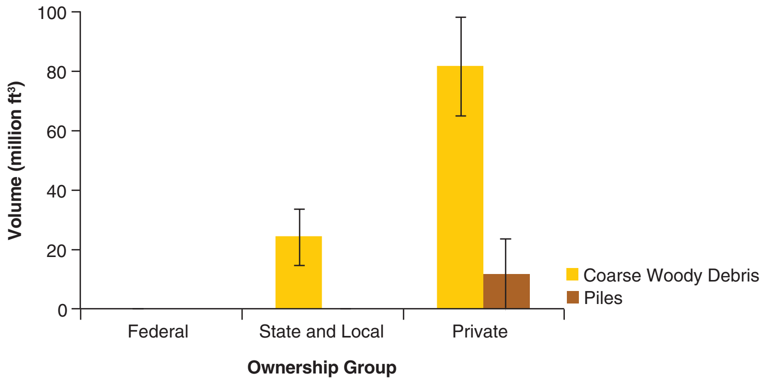


Figure 50.—Total volume of coarse woody debris and deadwood piles on forest land by ownership group, Delaware, 2006-2010. Error bars represent 68 percent confidence intervals around the estimated means.

What this means

Given the relatively moist temperate forests across Delaware, biomass from down woody materials would only be considered a fire hazard during times of drought. Although the carbon stocks of down woody materials are relatively small compared to those of soils and standing live biomass across Delaware, down woody material is still a critical component of the carbon cycle as a transitory stage between live biomass and other detrital pools such as the litter. Beyond the transition of dead wood carbon to other pools, if future temperature and precipitation patterns change, there is a potential for a reduction in these stocks due to increased rates of decay (Russell et al. 2014a, 2014b). The loss of dead wood carbon stocks could indicate the reduction of other pools in the future. Compared to southeastern states where there is more pervasive industrial management of forests (Woodall et al. 2013), there were relatively few residue piles sampled in this first down woody materials inventory of Delaware's forests. Given that the vast majority of coarse woody debris volume was estimated to be in private ownership, it is the management of Delaware's private forests that may affect the future of down woody material contributions to statewide forest carbon stocks and wildlife habitat (i.e., stand structure). Overall, because fuel loadings are estimated to be low across Delaware, possible fire dangers are likely to be outweighed by the numerous ecosystem services provided by down woody materials.

Regeneration Status

Background

The composition and abundance of tree seedlings drive the sustainability of forest ecosystems in the early years of stand development and set the stage for future composition, structure, and associated ecosystem services. Forest systems of Delaware are stressed by invasive plants, insects, diseases, herbivory, climate change, stressor interactions, and other factors. As stands that make up these systems mature and undergo stand replacement disturbances (e.g., final harvest or catastrophic mortality), it is imperative to understand the status of the regeneration component.

Although artificial methods (planting or seeding) are an option in some forest types such as the loblolly pine type, the region is dominated by oak/hickory, oak/gum/cypress, and other systems that typically regenerate naturally. In most situations, establishing desirable advance regeneration is required so high-canopy species are replaced with species that meet the objectives of the managers (Nyland 2002, Smith 1997). Oak in particular is subject to regeneration problems due to lack of wildfire and other disturbance, its preference as deer food, and competition from more shade-tolerant species, such as red maple (Holt and Fischer 1979). Recruitment of seedlings into the sapling size class is a basic tenet of successful regeneration (Dey et al. 2014), and when managing forests, tending young stands to control composition and stocking levels is an important consideration (Jackson and Finley 2011, Johnson et al. 2002).

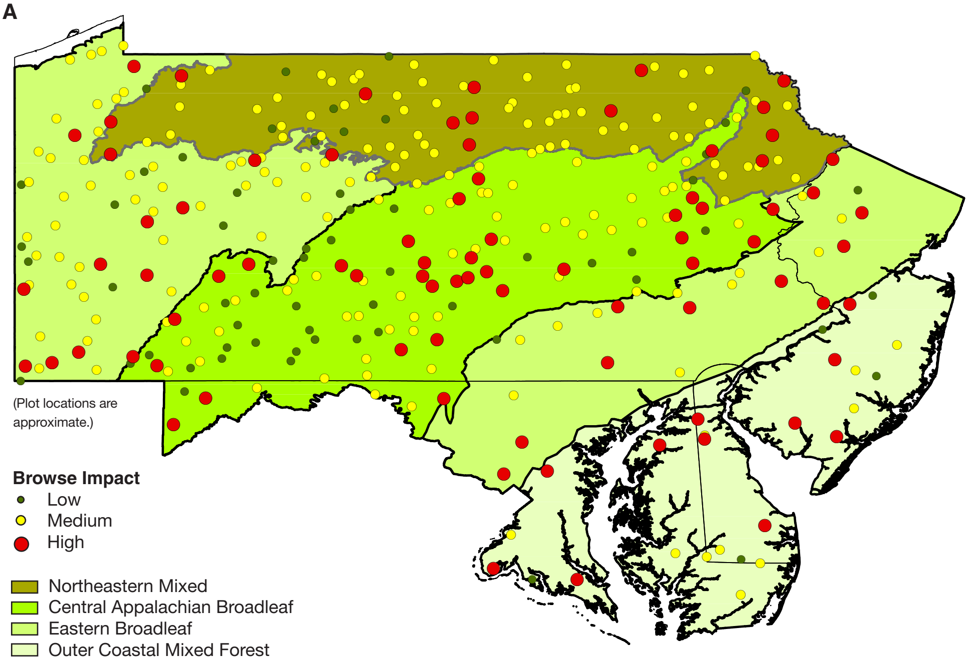
Seedling and sapling stands provide wildlife habitat and support biological diversity (Greenberg et al. 2011). Wildlife that depend on young forest habitat include the golden-winged warbler (*Vermivora chrysoptera*), American woodcock (*Scolopax minor*), and cottontail rabbit (*Sylvilagus floridanus*) (Gilbart 2012). Young forests are also an important food source for white-tailed deer (*Odocoilius virginiana*), a keystone species that impacts the regeneration, composition, and abundance of forest understory vegetation (Waller and Alverson 1997). If the amount of deer pressure is out of balance with available food, deleterious impacts on tree seedling establishment and development can be expected (Augustine and DeCalesta 2003, Russell et al. 2001). If browse pressure is too high, new and novel understory vegetation of undesirable taxa and growth habits (low canopy trees, shrubs, and vines) can result and persist for long periods (Royo et al. 2010). The vitality of Delaware forests over the long term will depend directly on the abundance, composition, and condition of tree regeneration during the stand establishment phase.

To address the need for more detailed information on regeneration, the FIA program added regeneration measurement protocols for collecting data on a subset of NRS-FIA sample plots (McWilliams et al. 2015). The results presented here for Delaware reflect only two of the seven panels of measurements that will eventually make up the first full baseline dataset for the regeneration indicator and include only seven sample plots visited in 2012 and 2013. All established tree seedlings less than 1 inch in diameter at breast height were measured by height class and include a browse assessment for the area around the sample location. Due to the relatively small number of samples for Delaware (7), Maryland (19), and New Jersey (17), some of the regeneration indicator results for these States are depicted together with Pennsylvania (292) to leverage information that can be obtained from having more samples.

What we found

Young forests have become a minor component of Delaware forests. Since 1986, the area of forest land in the small (or sapling-seedling) stand-size class decreased from 19 percent of the total forest to 12 percent. The area of oak/hickory sapling-seedling forest was 19 percent of the total and is now 9 percent. The browse impact assessment showed that 86 percent of the forest land had either medium or high levels of browse of understory plants (Fig. 51). Examination of browse impact results by ecological province and state shows the context of surrounding Coastal Plain Mixed Forest. While no distinct pattern other than localized impacts are apparent, it is clear that the province has substantial browse impact occurring.

A



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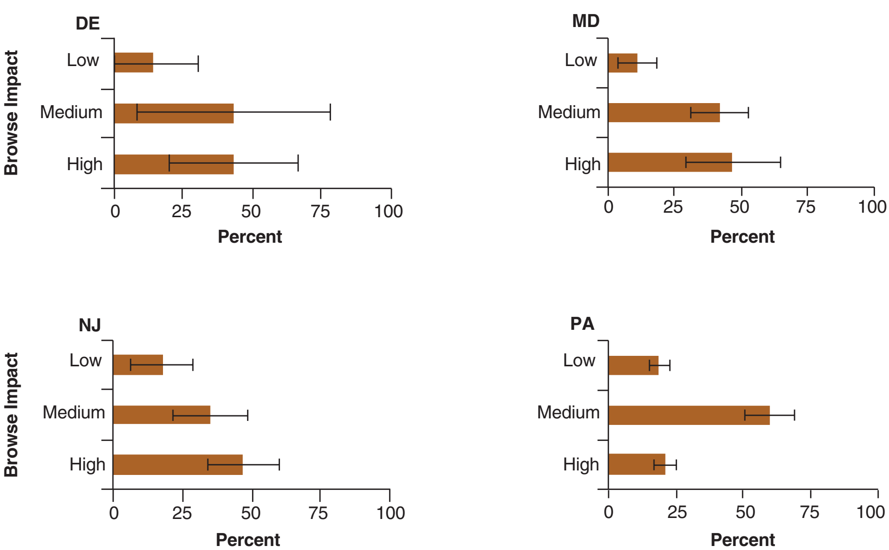


Figure 51.—Distribution (A) of forested P2+ samples by browse impact class and ecological province (Cleland et. al. 2007), and percentage (B) of forest land by browse impact class and state, 2012-2013. Error bars represent 68 percent confidence intervals around the estimated means.

The total number of seedlings in Delaware forests is estimated at 1.7 billion, or an average of over 4,000 seedlings per acre. Fifty-two percent of the seedlings are less than 1 foot tall, 36 percent are from 1.0 to 4.9 feet, and 12 percent are 5.0 feet and taller (Fig. 52). Red maple, American holly, sweetgum, sweetbay, black cherry, blackgum, and white oak were the most common species and made up about three quarters of the total number of seedlings, but high sampling errors make distinguishing importance within this group difficult (Fig. 53). Overall, seedling abundance is somewhat uniform across Delaware with no particular pattern evident from the data (Fig. 54).

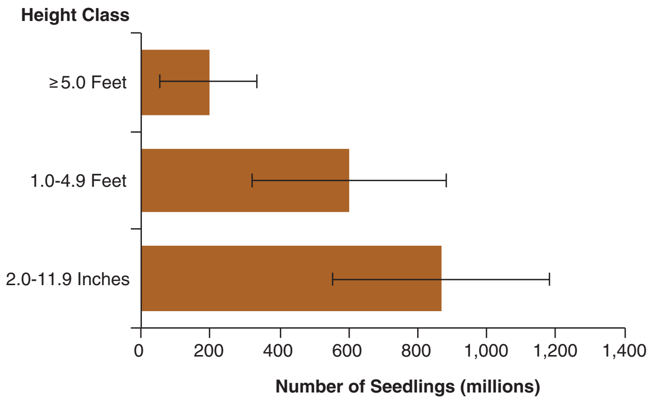


Figure 52.—Number of seedlings on forest land by height class, Delaware, 2012-2013. Error bars represent 68 percent confidence intervals around the estimated means.

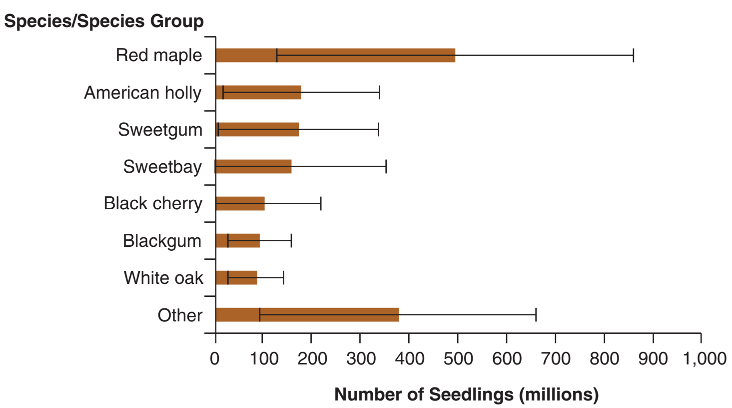


Figure 53.—Number of seedlings on forest land by species/species group, Delaware, 2012-2013. Error bars represent 68 percent confidence intervals around the estimated means.

A

(Plot locations are approximate.)

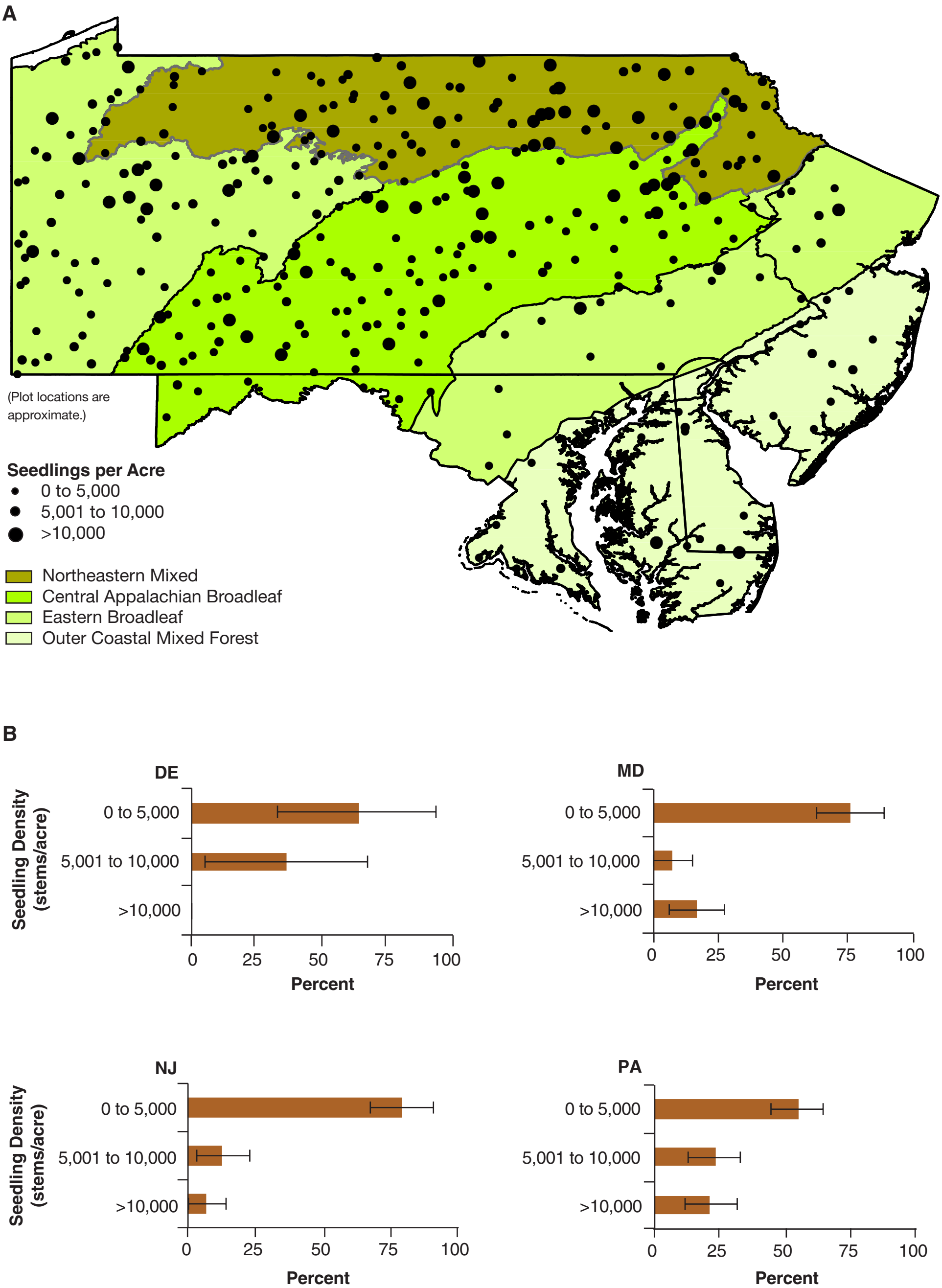


Figure 54.—Distribution (A) of forested P2+ samples by seedlings per acre class and ecological province (Cleland et. al. 2007), and percentage (B) of forest land by seedlings per acre class and state, 2012-2013. Error bars represent 68 percent confidence intervals around the estimated means.

What this means

The distribution of Delaware's forest land by age class indicates an imbalance between young and older forests. The area of young sapling-seedling forest has been decreasing concurrent with increases in the area of large (or sawtimber) stands. At some point, regeneration will be necessary to replace older forests following stand-replacement disturbances. This means that management and policy decisions will be needed regarding regeneration and ways to retain the desirable saplings that are the platform for sustainable benefits of clean air and water, aesthetics, timber, and other services. Because the Outer Coastal Plain Mixed Forest is characterized by relatively high deer impact, it will be necessary to consider both deer browse and the forest fragmentation that can intensify deer browse impacts. The oak/hickory forest-type group accounts for 53 percent of the State's forest land, but the presence of oak seedlings in the sample has been rare so far. Management prescriptions can help to ameliorate the impacts of deer browse, which will help to maintain the composition and value of future forests.

The next five-year inventory report for Delaware will provide a more complete baseline dataset. This will allow more detailed analyses, including comparisons of all taxa and height classes, and will improve the level of statistical confidence in the estimates. These more detailed findings will reveal species that are under- or over-represented in the regeneration pool compared to the composition of the canopy dominants. The dataset will also facilitate research to evaluate plot-level regeneration adequacy for the major forest-type groups and will provide a more complete understanding of future trends in composition, structure, and health of the State's forests.

Forest Habitats

Forests and woodlands provide habitats for many species of Delaware birds (99), mammals (33), and amphibians and reptiles (34) (NatureServe 2009). Like all states, Delaware has developed a comprehensive wildlife conservation strategy, also known as a state wildlife action plan (Delaware Division of Fish and Wildlife 2016). Species (and habitats) of greatest conservation need (SGCN) are listed in the plan, including species of mammals, birds, reptiles, amphibians, and invertebrates, categorized by status. Tier 1 SGCN are defined as being most in need of conservation action in order to sustain or restore their populations, while Tier 2 SGCN are defined as being in need of conservation action but without the urgency of Tier 1 species.

Delaware SGCN early successional upland habitats include 12 Tier 1 and 29 Tier 2 species. Upland forests include 26 Tier 1 and 66 Tier 2 SGCN. The condition and trends in forest age and size are reported in order to characterize the status of habitat for a variety of wildlife species. For example, late successional forest habitat is important for cerulean warbler (*Setophaga cerulea*), while the golden-winged warbler requires early successional forest habitat. One of the intermediate scale conservation issues associated with forest habitats is the presence and abundance of snags and nest cavities. In this report, data are also presented on the quantity and distribution of standing dead trees.

Forest Age and Stand Size

Background

Some wildlife species depend upon various combinations of early successional forests, including stands of smaller, younger trees; interior forests containing large trees with complex canopy structures; or edge conditions that contain elements of both. Other species may require multiple structural stages of forests at different points in their development or along their migratory paths. In Delaware, early successional forest habitat SGCN include American woodcock, American burying beetle (*Nicrophorus americanus*), milk snake (Lampropeltis triangulum), and least shrew (*Cryptotis parva*). Upland forest SGCN include species such as Delmarva fox squirrel (*Sciurus niger cinereus*), Cooper's hawk (*Accipiter cooperii*), eastern box turtle (*Terrapene carolina carolina*), and barking treefrog (*Hyla gratiosa*).

Forest abundance and trends in structural and successional stages serve as indicators of population carrying capacity for wildlife species (Hunter et al. 2001). Historical trends in Delaware forest habitats are reported for timberland, which accounts for 96 percent of all forest land in the State. For current habitat conditions, estimates are reported for all forest land.

What we found

Thirteen percent of Delaware's timberland area is in the small diameter stand-size class, a decrease from the 1986 estimate of 18 percent, but an increase from the 2008 estimate of 10 percent (Fig. 55). The large diameter class accounts for nearly three-fourths of the area of Delaware timberland, an increase over 1986 (62 percent). The medium diameter size class decreased from 20 percent of timberland area in 1986 to 12 percent of timberland area in 2013, similar to the decreasing trend in the small diameter class (Fig. 55). Abundance of timberland in young (0-20 years) and old (100+ years) age classes has changed very little since 2008 (Fig. 56). It is difficult to interpret the amount of change in age class since the 1986 and 1999 inventories because a large area of timberland was classified as the "mixed" age class in these older inventories (Fig. 56). Forest classified in the large diameter stand-size class contain all age classes and is predominated by 61-100 year-old forests (Fig. 57). Medium stand-size class forests are predominated by forests of 21-80 years of age. Almost all small diameter class forest is composed of stands in the 0-20 year age class.

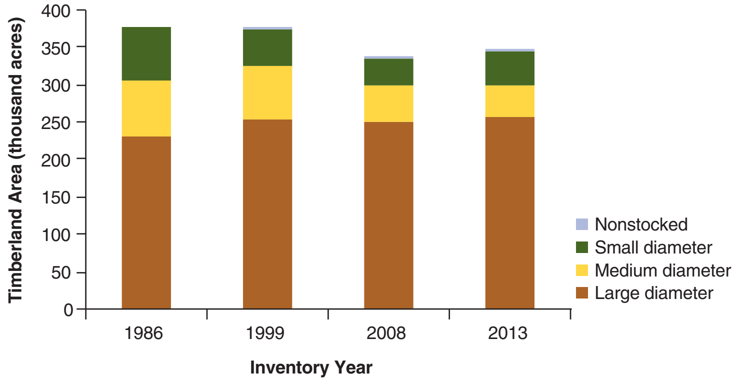


Figure 55.—Area of timberland by stand-size class and inventory year, Delaware.

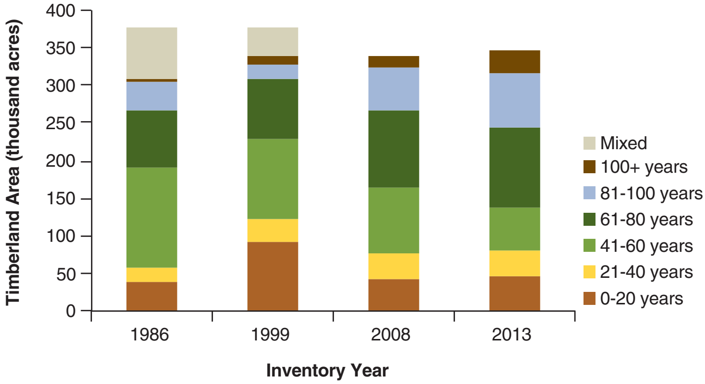


Figure 56.—Area of timberland by stand-age class and inventory year, Delaware.

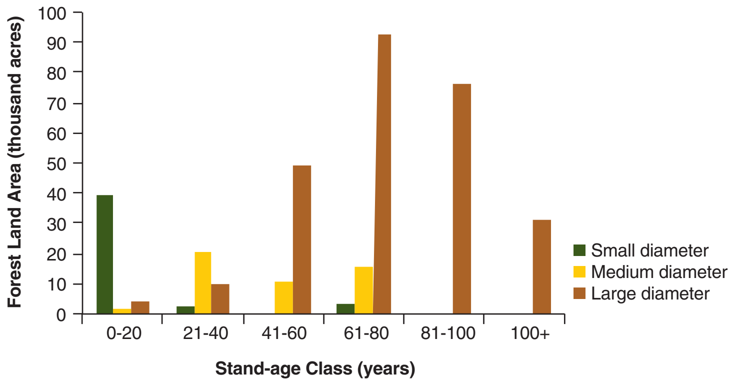


Figure 57.—Area of forest land by stand-age class and stand-size class, Delaware, 2013.

What this means

The area of small and medium diameter stand-size classes have both seen gradual declines during recent decades. In contrast, the area of large diameter timberland increased during this period. Similarly, the area of forests aged 81-100 and 100+ years has increased since the previous inventory, while young and intermediate ages have declined in area. Historical comparisons are more problematic due to a change in age class definitions.

Both stand-size class and stand-age class are indicators of forest structural/successional stage. The smallest stand-size class and youngest age class (0-20 years) are consistent with one another, but stands become progressively more heterogeneous as they grow larger and older. Such mixtures of different aged or sized trees provide a vertical diversity of vegetation structure that can enhance habitat conditions for some species. Managing forest conditions in both younger and older age classes (and smaller and larger structural stages) to maintain both early and late successional habitats may conserve habitat and viable populations of many forest-associated wildlife species.

Standing Dead Trees

Background

Specific habitat features like nesting cavities and standing dead trees provide critical habitat components for many forest-associated wildlife species. Standing dead trees that are large enough to meet habitat requirements for wildlife are referred to as "snags." There are ongoing research efforts to determine the characteristics of dead trees that provide habitat for a given species. The Society of American Foresters define the size threshold for a snag as being at least 10 inches (25.4 cm) in diameter at breast height and at least 6 feet (1.8 m) tall (Society of American Foresters 1998); however standing dead trees of smaller size and diameter are also considered beneficial for some wildlife species. Standing dead trees serve as important indicators not only of wildlife habitat, but also of past mortality events and carbon storage. They serve as sources of down woody material (discussed elsewhere in this report), which also provides habitat features for wildlife. The number and density of standing dead trees, together with decay classes, species, and sizes, define an important wildlife habitat feature across Delaware's forests.

What we found

According to the 2013 inventory data, 4.6 million standing dead trees (5 inches d.b.h. and larger) are present on Delaware forest land. This equates to an overall density of 12.7 standing dead trees per acre of forest land, with similar densities on public (12.5 trees per acre) and private (12.8 trees per acre) ownership classes. Four species groups each contributed more than half a million standing dead trees, with the top three groups each contributing more than 600,000 standing dead trees (Fig. 58). Loblolly pine (611,000) and red maple (607,000) are the two individual tree species with the most standing dead trees. Eight species groups exceeded 10 standing dead trees per 100 live trees (5 inches d.b.h. and larger) of the same species group (Fig. 59). Over 83 percent of standing dead trees are smaller than 11 inches d.b.h., and only 6 percent of standing dead trees are over 17 inches (Fig. 60). Half of all standing dead trees fall within the two intermediate classes of decay; the class of most decay (no evidence of branches remain) comprises only 4 percent of standing dead trees (Fig. 60). Distribution of decay classes follow this same general pattern for smaller diameter classes.

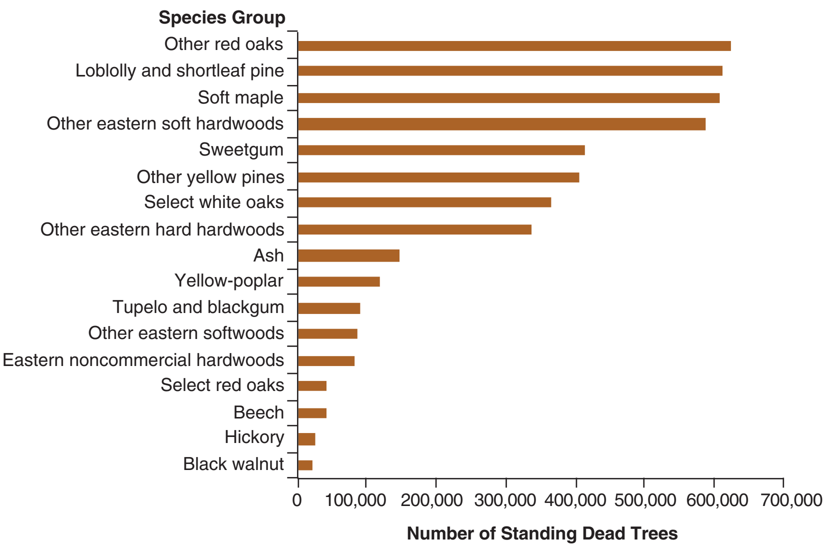


Figure 58.—Number of standing dead trees (5 inches d.b.h. and larger) by species group, Delaware, 2013.

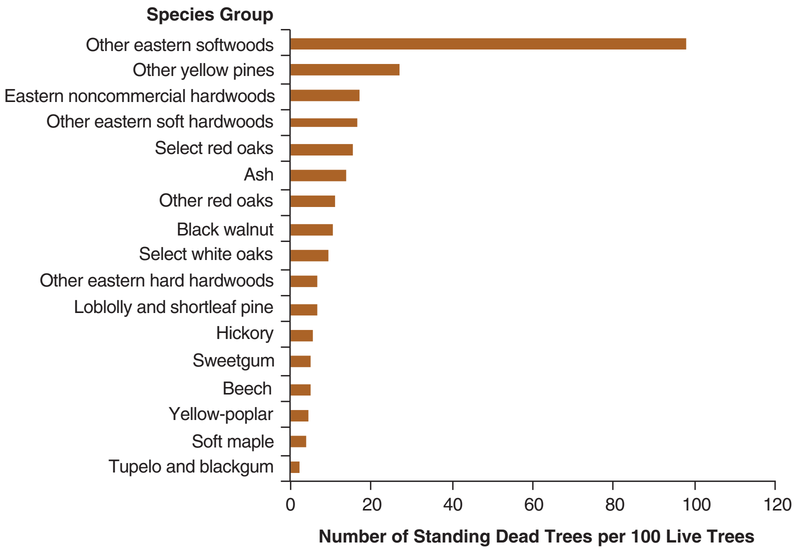


Figure 59.—Number of standing dead trees per 100 live trees (5 inches d.b.h. and larger) by species group, Delaware, 2013.

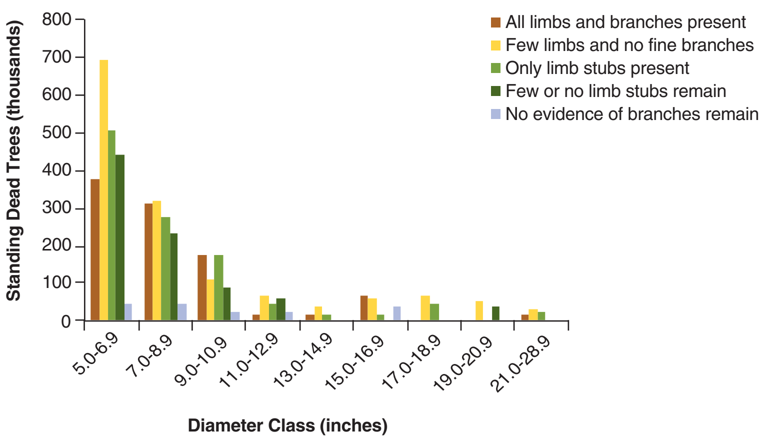


Figure 60.—Distribution of standing dead trees (5 inches d.b.h. and larger) by decay class and diameter class, Delaware, 2013.

What this means

Snags and smaller standing dead trees result from a variety of potential causes, including diseases, insects, weather damage, fire, flooding, drought, and competition. The loblolly and shortleaf pine, other red oaks, soft maple, and other eastern soft hardwoods species groups contained the largest total numbers of standing dead trees, but the other eastern softwoods species group contained the largest number of standing dead trees per 100 live trees of the same species group. On average, 12.7 standing dead trees 5 inches d.b.h. and larger were present for every acre of Delaware forest land; 7.4 standing dead trees were present for every 100 live trees. Recommendations for the density, distribution, and size of snags sufficient to support wildlife in a particular region vary by the species of interest and the location and type of forest land. Some studies suggest that two to three large diameter, quality snags per acre of forest land are recommended. In Delaware, the density of snags 5 inches d.b.h. and larger far exceeds this threshold; however the density of large diameter snags (greater than 17 inches d.b.h.) is only 0.8 per acre, suggesting that more large diameter snags may be needed to support Delaware's wildlife.

Dead trees may contain significantly more cavities per tree than occur in live trees (Fan et al. 2003), thereby providing habitat features for foraging, nesting, roosting, hunting perches, and cavity excavation for wildlife, from primary colonizers such as insects, bacteria, and fungi to birds, mammals, and reptiles. Most cavity nesting birds are insectivores, which help to control insect populations. The availability of very large standing dead trees (snags) may be a limiting habitat feature for some species of wildlife. Providing a variety of forest structural stages and retaining specific features like snags on both private and public lands are ways that forest managers maintain the abundance and quality of habitat for forest-associated wildlife species in Delaware.

Invasive Plant Species

Background

Invasive plant species (IPS) are both native and nonnative species that can cause negative ecological effects. These species can quickly invade forests, changing light, nutrient, and water availability. IPS can form dense monocultures, which not only reduce regeneration but also impact wildlife quality by altering forest structure and forage availability. Invasive species do not only affect forested environments but can also impact agricultural systems. For example, common barberry, an alternate host for wheat stem rust, can cause the complete loss of grain fields. Common buckthorn is another troublesome IPS that is an alternate host for the soybean aphid (*Aphis glycines*). While there are some beneficial uses for these invaders (e.g., culinary, medicinal, and soil contaminant extraction [Kurtz 2013]), the negative effects are worrisome. Each year the inspection, management, and mitigation of IPS costs the United States billions of dollars.

To aid in monitoring invasive species, FIA assesses the presence of 40 IPS, which includes 39 species and one undifferentiated genus (nonnative bush honeysuckles), hereafter referred to as "invasive species," "invasive plants," "invasives," or "IPS" (Table 7). To maintain regional consistency, the species list is not customized for Delaware but represents native and nonnative species of regional concern.

Table 7.—Invasive plant species and genera monitored by the Northern Research Station on Forest Inventory and Analysis P2 invasive plots, 2007 to present

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

What we found

Invasive species were monitored on 30 P2 invasive plots in Delaware from 2009 through 2013. Given the small sample size, it is difficult to make strong conclusions; however the data suggest the presence of some general patterns. Of the 40 IPS monitored (U.S. Forest Service 2010), 14 were observed in Delaware (Table 8). Japanese honeysuckle (Fig. 61) was the most commonly observed species (15 plots; 50.0 percent of P2 Invasive plots) and was found throughout the State. Multiflora rose also grows throughout the State (Fig. 62) and was the second most commonly observed invasive, occurring on

30.0 percent of the plots. Both of these woody invasives were introduced from Japan in the 1800s for ornamental purposes (Kurtz 2013). Nonnative bush honeysuckles were recorded on more than a quarter of the plots (26.7 percent).

Table 8.—Invasive plant species observed on FIA P2 plots, Delaware, 2013

Name	Observances	Percentage of plots
Japanese honeysuckle[a]	15	50
Multiflora rose	9	30
Nonnative bush honeysuckles	8	26.7
Nepalese browntop	6	20
Garlic mustard	3	10
Oriental bittersweet	3	10
Japanese barberry	2	6.7
Tree of heaven	2	6.7
Black locust	2	6.7
Reed canarygrass	1	3.3
Autumn olive	1	3.3
Japanese knotweed	1	3.3
Common reed	1	3.3
Common buckthorn	1	3.3

[a] See Table 7 for scientific names

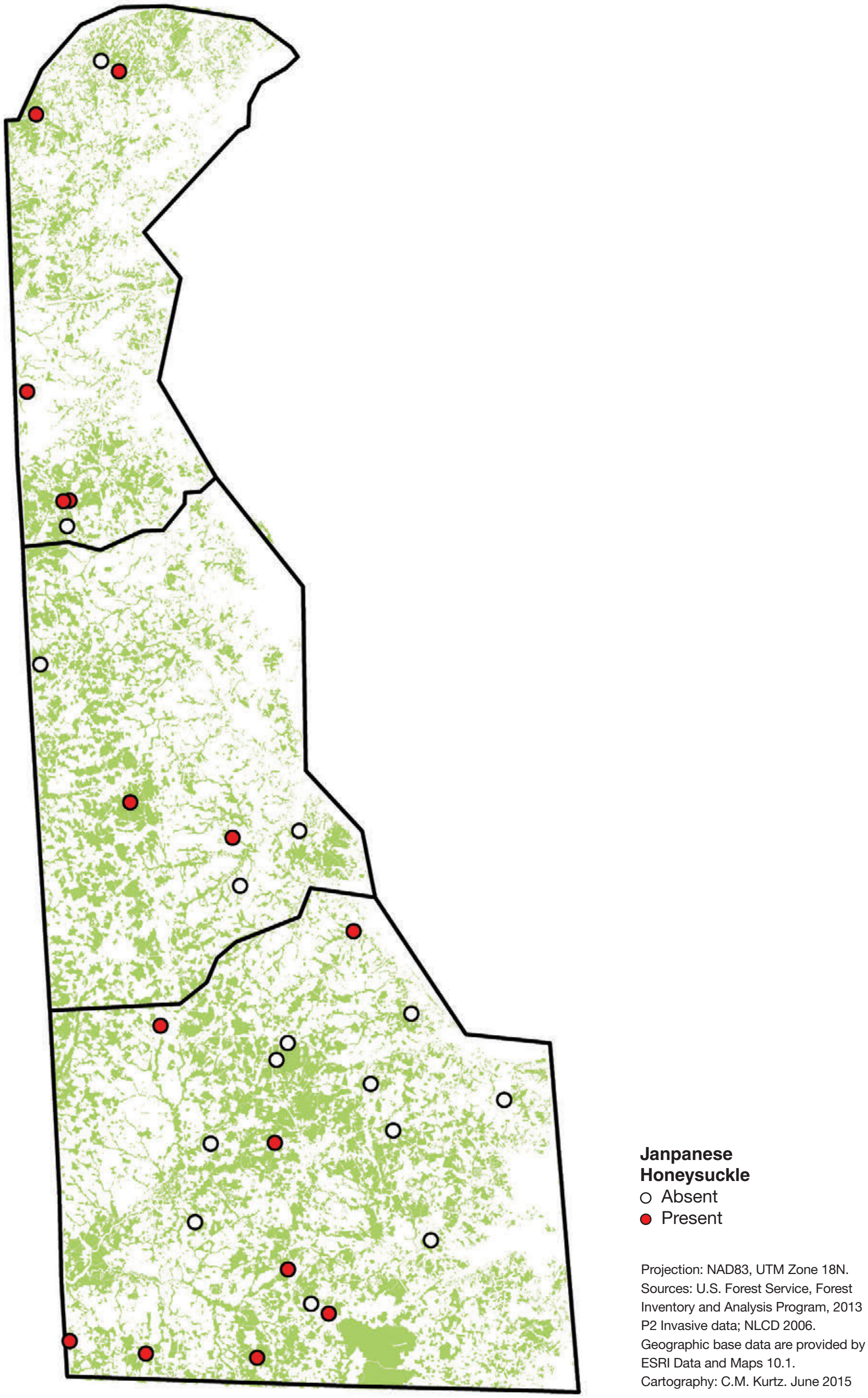


Figure 61.—Distribution of Japanese honeysuckle on P2 invasive plots, Delaware, 2013.

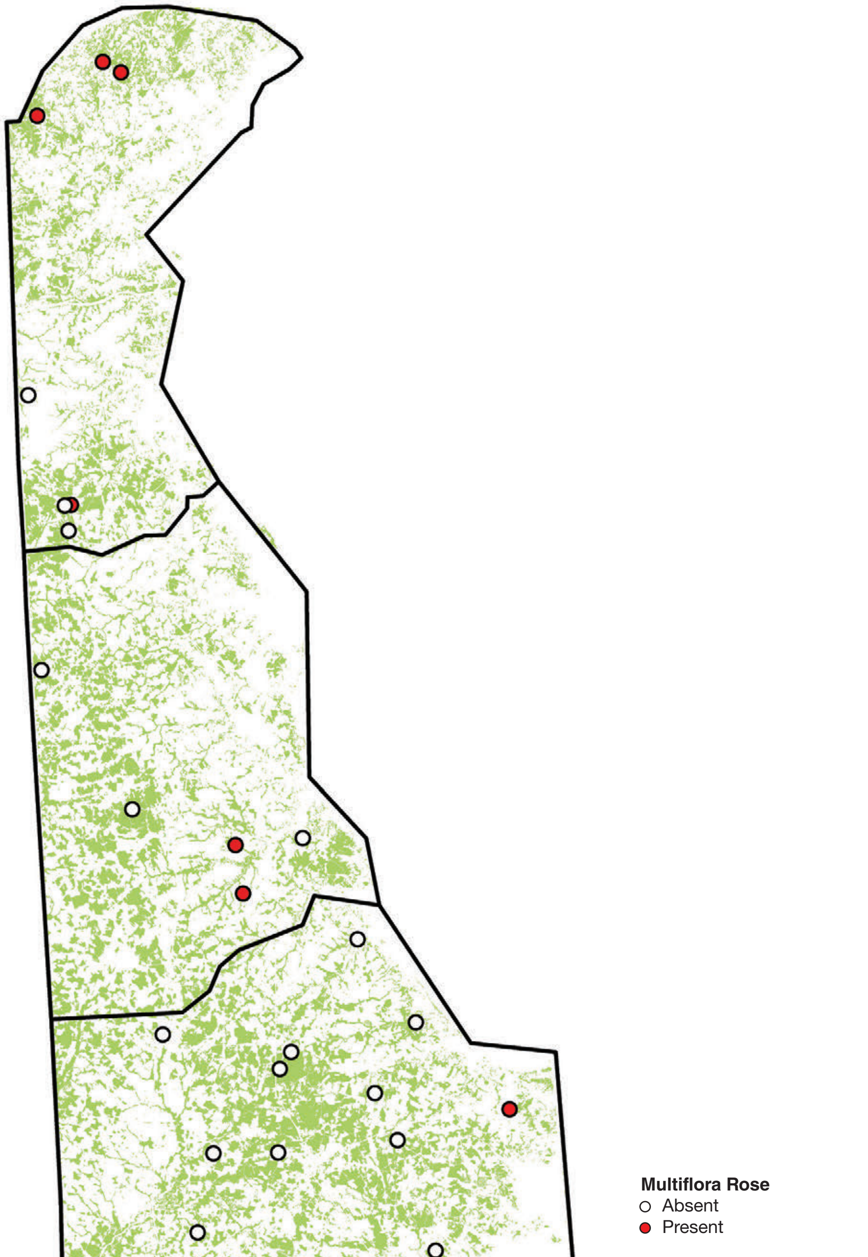


Figure 62.—Distribution of multiflora rose on P2 invasive plots, Delaware, 2013.

One or more of the monitored IPS were present on more than three quarters (76.7 percent) of the plots, with the number of IPS per plot ranging from 0 to 9 (Fig. 63). The distribution of plots with invasive species present was fairly homogeneous throughout Delaware (Fig. 64), but the plots with the greatest number of invasive plants were clustered in the northern part of the State. When reviewing these figures one must remember that the inventory takes place only on forested land, so areas with less forest have fewer plots.

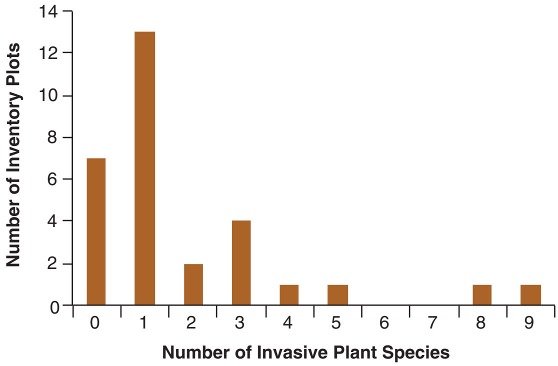


Figure 63.—Number of invasive plant species per P2 Invasive plot, Delaware, 2013.

In the 2008 inventory, 2 years of invasive plant data were reported for 44 P2 Invasive plots. Thirteen species were found (12 species plus nonnative bush honeysuckles), and Japanese honeysuckle was the most commonly observed invasive plant species, occurring on 54.5 percent of plots (Lister et al. 2012). In the 2013 data, 14 species were found, and there were no large changes in the percentage of plots where each invasive species occurred. However, with the small sample size in both 2008 and 2013, it is important to use caution in comparison and analysis. Over time it will be important to monitor the plots where these species are observed and also watch for the presence of new invasive species.

What this means

Delaware forests had a higher percentage of plots invaded (76.7 percent) than neighboring Maryland where 61.5 percent of plots had one or more of the monitored invasive plant species. However there were fewer of the monitored invasive plants in Delaware (14 species) than there were in Maryland (19 species). The presence of IPS within Delaware forests is troublesome, and it is important that these species continue to be monitored over time to ensure that managers and the general public are aware of their occurrence and spread.

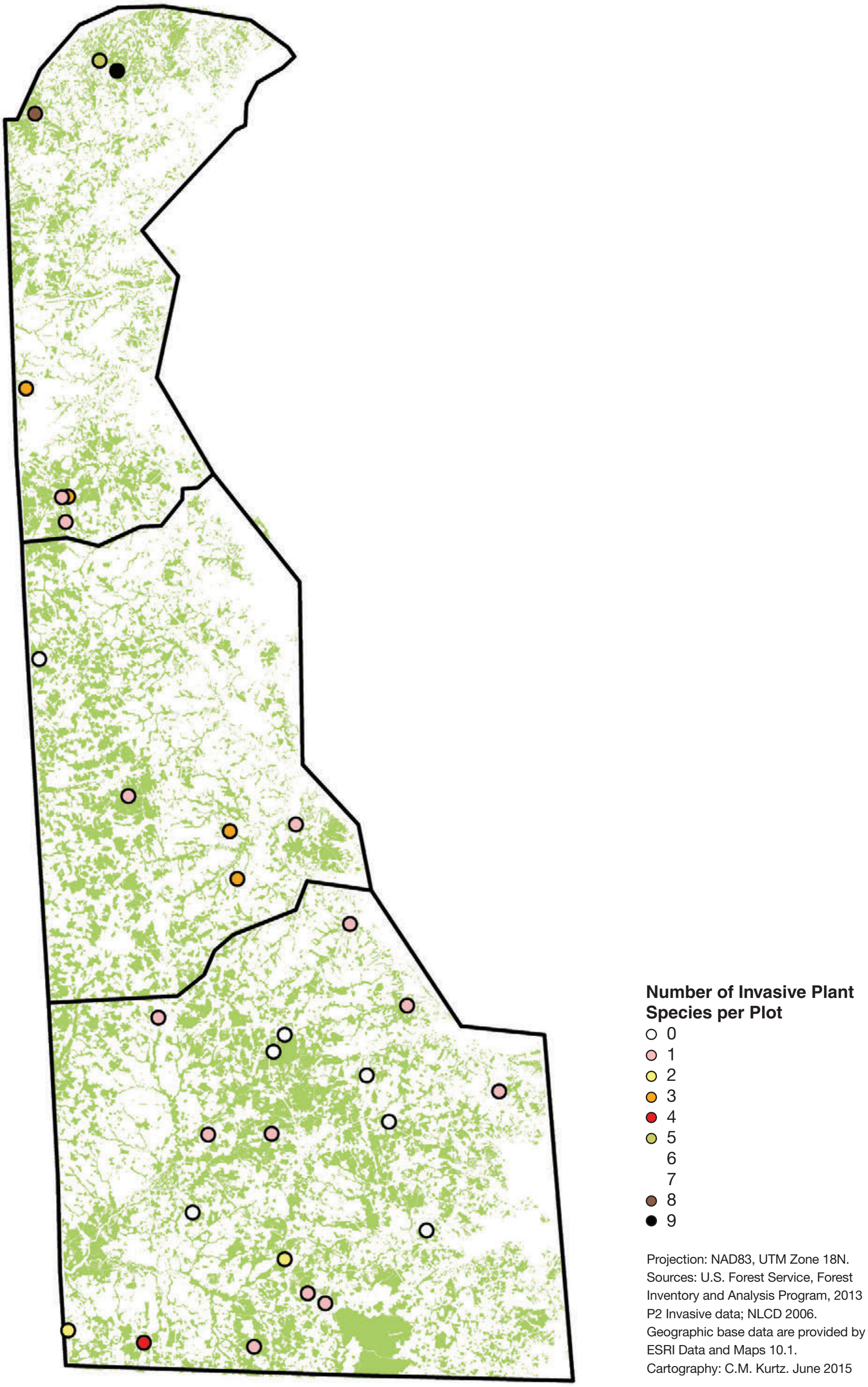


Figure 64.—Distribution and abundance of invasive plant species per P2 invasive plot, Delaware, 2013.

Invasive plants are good competitors and are able to change forested ecosystems by displacing native species and altering forage. Several characteristics contribute to their success, including prolific seed production, rapid growth rate, ability to propagate vegetatively, and the ability to survive in harsh conditions. Many factors contribute to forest invasion, including ungulates, development, fragmentation, and timber harvesting; however some IPS are able to take hold with little to no disturbance. Additional investigation of the inventory data may help to reveal influential site and regional trends, as well as how the forest changes due to an evolving plant community.

Forest Insect Pests

Invasive insects impact the structure and composition of forest ecosystems. Monitoring the status of these organisms provides a measure of forest health and is crucial in assessing the current state and changing trends in Delaware's forests. A number of insect pests were active in or around Delaware between 2009 and 2013, and the major species are discussed below.

Emerald ash borer

Background

A wood-boring beetle native to Asia, emerald ash borer (*Agrilus planipennis;* EAB) is a pest of all North American ash (*Fraxinus* spp.) and has recently been found to attack white fringetree (*Chionanthus virginicus*), an understory shrub native to Delaware but not tallied by FIA (Cipollini 2015; Herms and McCullough 2014; NRCS 2015). While EAB shows some preference for stressed trees, all trees greater than 1 inch in diameter are susceptible regardless of vigor (Herms and McCullough 2014). Since its 2002 discovery in southeastern Michigan, EAB has been identified in 25 states as of July 2015. EAB was not found in Delaware during the 2013 inventory period, but it was present in all neighboring states and has since been found in New Castle County, Delaware.

What we found

In Delaware, ash trees make up a small fraction (less than 1 percent) of total species composition; however, they are widely distributed across the State (Fig. 65). Of the estimated 2.1 million white and green ash trees (greater than 1 inch diameter) present, white ash is the most prevalent, representing 69 percent of all ash. The net volume of live ash trees (5 inches in diameter and larger) has remained consistent since 2008 and currently totals 20.2 million cubic feet (Fig. 66).

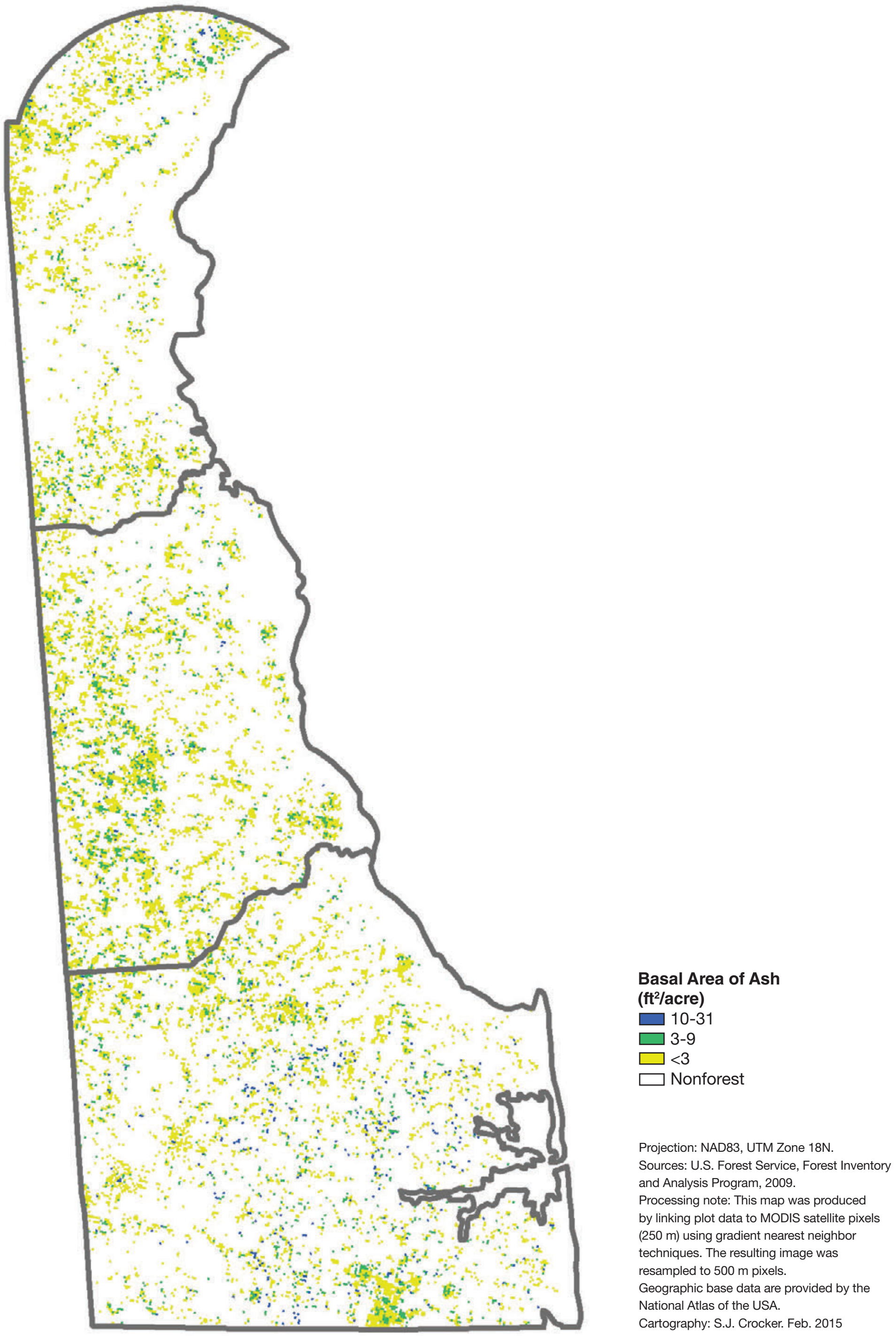


Figure 65.—Ash density on forest land, Delaware, 2009.

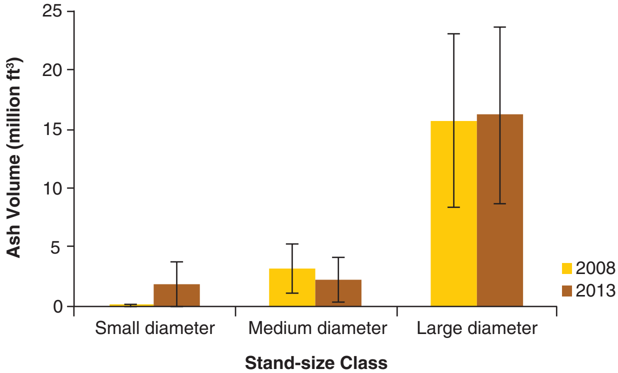


Figure 66.—Live-tree ash volume on forest land by stand-size class and inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

What this means

Even though ash is a relatively small component of overall forest land, its predominance in riparian and urban forests makes the potential introduction of EAB a significant threat to the health and composition of these areas. Ash trees occur in greater proportions in urban areas; however in Delaware, urban trees on nonforest land are not currently measured by FIA. Beginning in 2018, FIA will initiate an urban forest inventory in the State, which will include intensified sampling in the city of Dover. The results from the urban forest inventory will help scientists and managers better monitor Delaware's threatened ash resource. As EAB continues to spread throughout the eastern United States, forest monitoring will become an increasingly important tool to help quantify any future impacts due to EAB.

Asian longhorned beetle

Background

Asian longhorned beetle (*Anoplophora glabripennis*; ALB) is another exotic, wood-boring beetle whose potential introduction represents a threat to Delaware's forests. Tree mortality is caused by larval activity that girdles the trunk. ALB attacks a variety of hardwood species found in Delaware, but maple (most favored), birch, willow, and elm are the preferred hosts. Occasional hosts include poplar and ash (U.S. Forest Service 2008).

What we found

Nearly one quarter (24 percent) of all trees greater than 1 inch diameter in Delaware forests, or 57.7 million trees, are susceptible to ALB. Maples, largely red maple, are the most abundant and account for 94 percent of available hosts (Fig. 67). Susceptible hosts are present across the State but are more abundant in Kent and Sussex counties (Fig. 68).

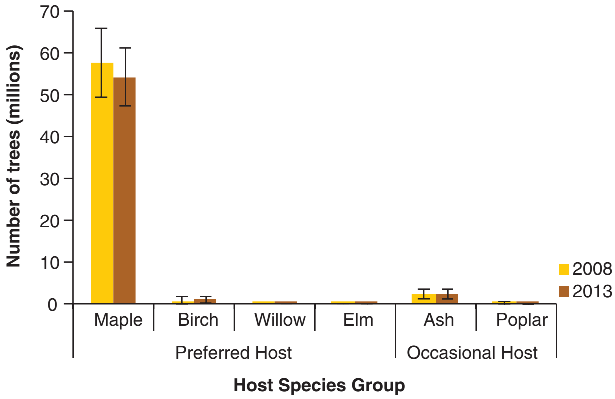


Figure 67.—Number of ALB-susceptible trees by level of host preference, species group, and inventory year, Delaware. Error bars represent 68 percent confidence intervals around the estimated means.

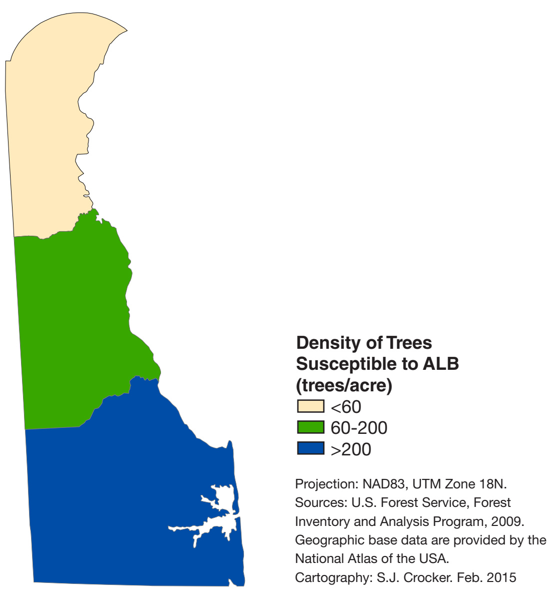


Figure 68.—Density of ALB-susceptible trees by county, Delaware, 2009.

What this means

ALB has been a significant source of urban tree mortality in many cities in the eastern United States. Because there is a wide range of susceptible hosts, ALB could have a substantial impact on hardwood forests across Delaware.

Sirex woodwasp

Background

Native to Europe, Asia, and the northern part of Africa, Sirex woodwasp (*Sirex noctilio*) was first identified in North America in 2005, where it was found in Oswego County, New York (APHIS 2008, Haugen and Hoebeke 2005). This insect attacks a number of pine species, including loblolly pine. Sirex woodwasp has not been detected in Delaware; however, infestations have occurred in Michigan, Ohio, and neighboring Pennsylvania.

What we found

Loblolly pine forest types make up 77,000 acres, or 21 percent of the total forest land in Delaware. Eighty-four percent of loblolly stands are high density, where the basal area is greater than 120 square feet per acre (Fig. 69). An estimated 23 million loblolly pine are distributed across Delaware; however, the bulk of these trees are concentrated in Sussex County (Fig. 70). Loblolly pine is the third most voluminous species in the State, with 120.3 million cubic feet of growing-stock volume and 452.9 million board feet of sawtimber volume.

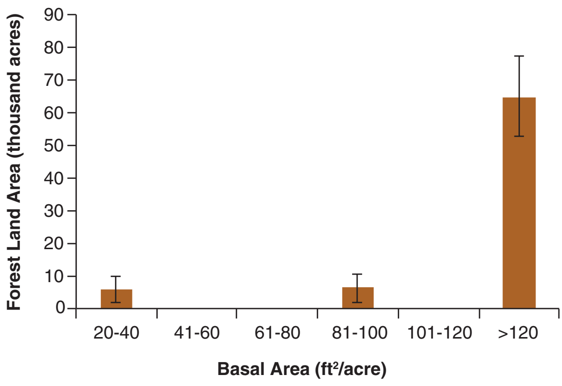
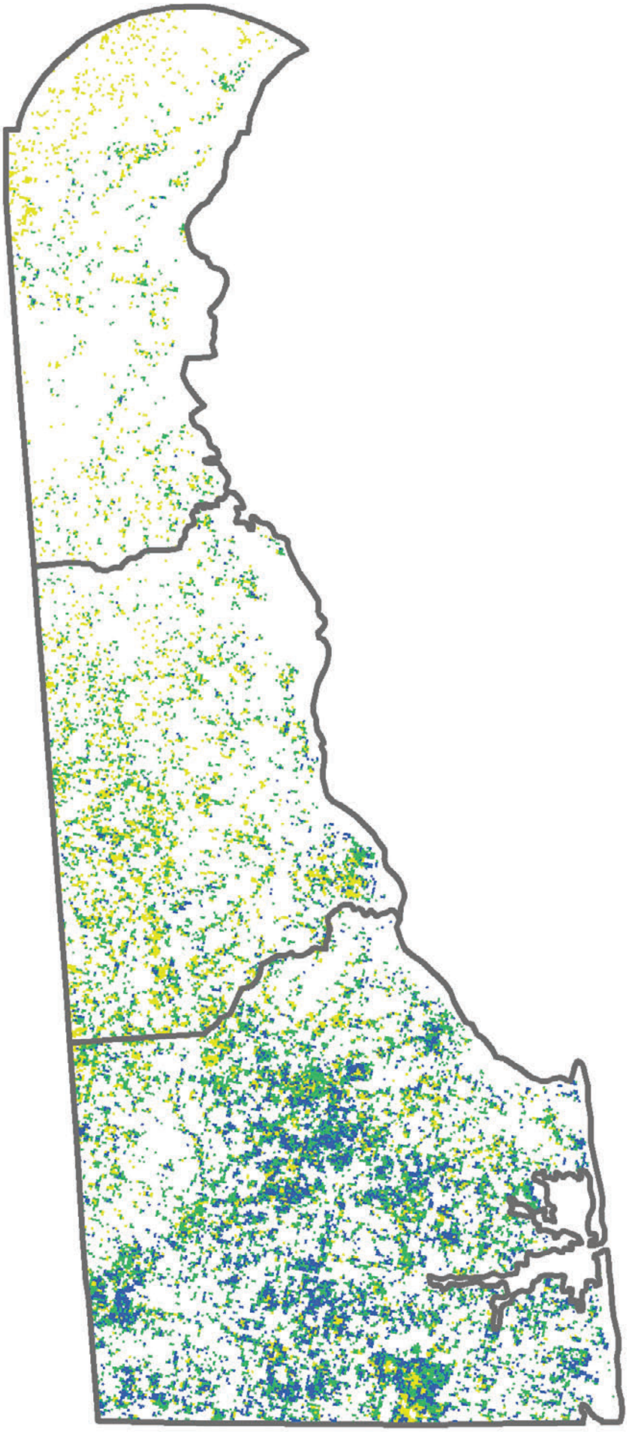


Figure 69.—Area of forest land by basal area for loblolly pine and loblolly/hardwood forest types, Delaware, 2013. Error bars represent 68 percent confidence intervals around the estimated means.



Basal Area of Loblolly Pine (ft²/acre)

35-116
5-34
<5
Nonforest

Projection: NAD83, UTM Zone 18N.
Sources: U.S. Forest Service, Forest Inventory and Analysis Program, 2009.
Processing note: This map was produced by linking plot data to MODIS satellite pixels (250 m) using gradient nearest neighbor techniques. The resulting image was resampled to 500 m pixels.
Geographic base data are provided by the National Atlas of the USA.
Cartography: S.J. Crocker. Feb. 2015

Figure 70.—Loblolly pine density on forest land, Delaware, 2009.

What this means

Previous introductions of Sirex woodwasp have resulted in high pine mortality, which makes this insect a major threat to the loblolly pine resource in Delaware. In addition to being an important component of forest land, loblolly pine is a major commercial species. Therefore, damage resulting from the potential introduction of Sirex woodwasp could have major economic and ecological impacts.

Southern pine beetle (*Dendroctonus frontalis*) is another insect that attacks loblolly pine, and even though its activity was very low throughout the survey period, it may have combined future effects on the resource. Continued monitoring of forest resources will help to identify the long-term impacts of the aforementioned insects and new arrivals, including thousand cankers disease, in Delaware.

Forest Products

Background

The harvesting and processing of timber products provides a stream of income that is shared by the timber owner, managers, marketers, loggers, truckers, and processors. In 2013, the wood products and paper manufacturing industries in Delaware employed almost 1,100 people, with an average annual payroll of $36.0 million (Bureau of Labor Statistics 2015). To better manage the State's forests, it is important to know the species, amounts, and locations of timber being harvested. Surveys of Delaware's wood-processing mills are conducted periodically to estimate the amount of wood volume that is processed into products. This is supplemented with recent surveys conducted in the surrounding states that also process wood harvested from Delaware. In 2011, six active primary wood-processing mills were surveyed to determine the species that were processed and where the wood material came from.

What we found

In 2011, six active sawmills in Delaware processed 2.1 million board feet (350,000 cubic feet) of logs into lumber. When trees that were harvested and processed in other states are included, a total of 3.5 million cubic feet of industrial roundwood was harvested from Delaware in 2011, an increase of 7 percent from 2008. Pulpwood accounted for 59 percent of the total industrial roundwood harvested, and saw logs accounted for 34 percent (Fig. 71). Other products were excelsior, posts, poles, and pilings. All of the timber harvested for pulpwood was shipped to mills in other states.

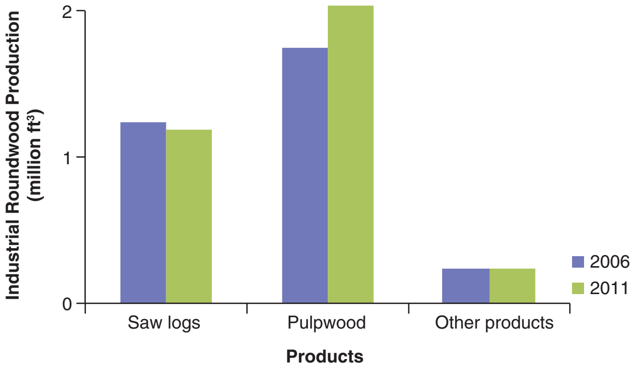


Figure 71.—Industrial roundwood production by product and year, Delaware.

Loblolly pine accounted for 59 percent of the total industrial roundwood harvest. Other important species harvested were Virginia pine, soft maple, red oaks, and white oaks (Fig. 72). In the process of harvesting industrial roundwood, 1.8 million cubic feet of harvest residues were left on the ground. More than 80 percent of the logging residue came from nongrowing stock sources such as crooked or rotten trees, tops and limbs, and noncommercial species. The processing of industrial roundwood in the State's primary wood-using mills generated another 222,800 cubic feet (5,600 green tons) of wood and bark residues. Seventy-seven percent of the mill residues were used for mulch, 15 percent were used for other miscellaneous products such as animal bedding and small dimension products, and 7 percent were used for residential fuelwood (Fig. 73). Only 1 percent of the mill residues produced were not utilized further into other secondary uses.

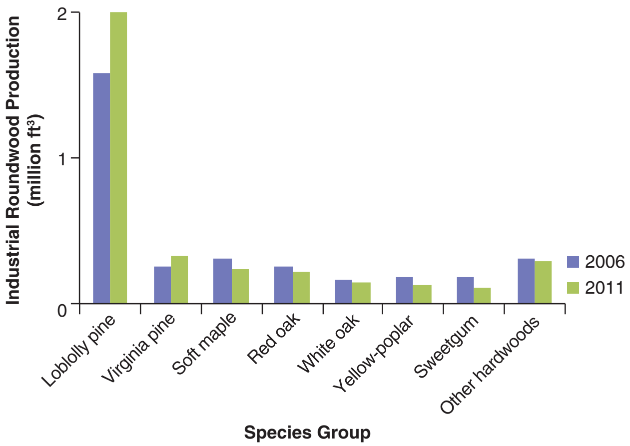


Figure 72.—Industrial roundwood production by species group and year, Delaware.

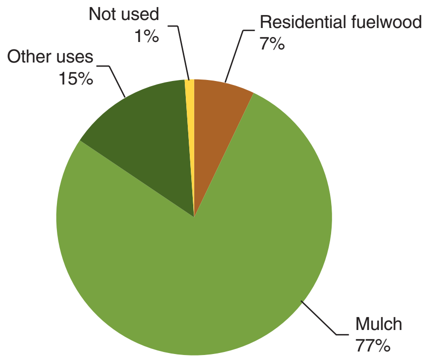


Figure 73.—Disposition of mill residues generated by primary wood-using mills, Delaware, 2011.

What this means

All of the wood-processing facilities in Delaware are sawmills processing primarily State-grown saw logs, but Delaware sawmills only process about 7 percent of the industrial roundwood that is harvested from the State. Pulp mills in other states receive almost 60 percent of the total industrial roundwood harvested in Delaware, and sawmills in surrounding states receive most of the remaining volume that is harvested. Although these mills provide Delaware woodland owners with an outlet to sell timber, most of the timber processing jobs and economic values are realized outside the State. The need for wood products is likely to increase, placing a greater demand on the resource. An important consideration for the future of the primary wood-products industry is its ability to retain industrial roundwood processing facilities. The number of wood processing mills has been steadily declining. The loss of processing facilities makes it harder for landowners to find markets for the timber harvested from management activities on their forest land.

Projections for the Future

Ash tree infected with emerald ash borer (EAB), showing signs of crown damage. Photo by Tonya Lister, U.S. Forest Service.

Projections For The Future

Background

This section focuses on anticipated changes to the forests of Delaware between 2010 and 2060. The Northern Forest Futures study (Shifley and Moser 2016) examined several alternative future scenarios that cover a range of different assumptions about the economy, population, climate, and other driving forces that will affect the future conditions of forests. The assumptions were incorporated into seven scenarios that consider how different alternative future climate conditions, demographic changes, and economic policies will impact forests. Additional details on methodology can be found in Shifley and Moser (2016).

Just as in the past, a large component of future forest change will be the result of normal forest growth, aging, natural regeneration, and species succession. A range of external forces is also expected to drive forest change:

- Population increases will cause millions of acres of forest land to be converted to urban land.
- Economic conditions will affect forest products consumption, production, and harvest rates.
- The spread of invasive species will worsen the effects of other disturbances on forest ecosystems.
- Changes in human population, the economy, energy consumption, and energy production will affect future climate change.
- Climate change will affect patterns of forest growth and species succession.

The seven scenarios that were considered are briefly described below. The cryptic naming system is a link back to the more detailed scenario descriptions that originated from the Intergovernmental Panel on Climate Change (IPCC 2001):

1) A1B-C—Rapid economic globalization

2) A1B-BIO—Rapid economic globalization including the potential impact of increased harvest and utilization of woody biomass for energy

3) A2-C—Consolidation into economic regions

4) A2-BIO—Consolidation into economic regions including the potential impact of increased harvest and utilization of woody biomass for energy

5) A2-EAB—Consolidation into economic regions including the potential impact of continued spread of the emerald ash borer with associated mortality of all ash trees in the affected areas

6) B2-C—A trend toward local self-reliance and stronger communities

7) B2-BIO—A trend toward local self-reliance and stronger communities including the potential impact of increased harvest and utilization of woody biomass for energy

What we found

Anticipated declines in forest land, which total in the tens of thousands of acres, continue the half century-long trend of decreasing forest area in Delaware (Fig. 74). Specifically, over the next 50 years forest land area is projected to decline from an estimated 352,000 acres in 2010 to 287,000 acres (-18 percent) in 2060 under scenario A1B-C; to 285,000 acres (-19 percent) under scenario A2-C; and to 311,000 acres (-12 percent) under scenario B2-C. Only three scenarios are represented in Figure 74 because the choice of climate model and variations on the storylines do not impact the projected area of forest land. The projected losses of forest land from 2010 to 2060 are relatively small compared to the cumulative increase in forest area since the beginning of the 20th century. In 2010, 28 percent of Delaware was forested, and forests are projected to remain a significant land cover in Delaware, with 23 to 25 percent remaining forested in 2060.

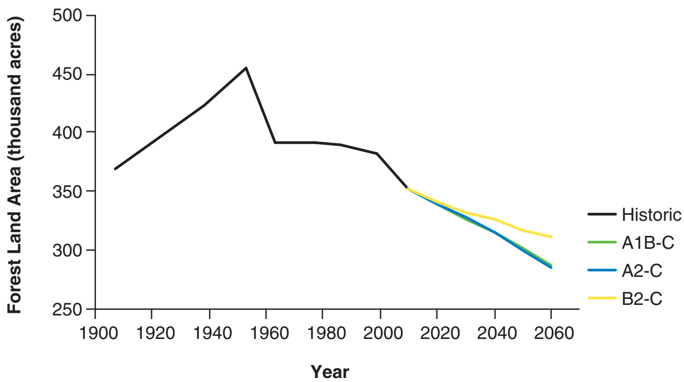


Figure 74.—Projected forest land area by scenario, Delaware, 2010-2060.

At the time of the inventory, emerald ash borer (EAB) had not been detected in Delaware but was present in all neighboring states. Ash species make up 2 percent of the total live-tree volume on forest land in Delaware and 10 percent of the volume in the elm/ash/

cottonwood forest-type group. Under scenario A2-EAB, ash species volume is projected to decline from 19 million cubic feet in 2010 to zero by 2030. Under scenario A2-C, ash volume is expected to decrease from 19 million cubic feet in 2010 to 12 million cubic feet by 2060. However, the area of elm/ash/cottonwood is predicted to increase from 2010 to 2060 under both scenario A2-C (15 percent) and A2-EAB (5 percent) (Fig. 75). The loss of the ash component in the elm/ash/cottonwood forest-type group in these two scenarios will be partially offset by increases in other associated species in this forest-type group. The area in the maple/beech/birch forest-type group is also expected to increase over the next 50 years. The negative impacts of EAB are more apparent when looking at predicted changes in volume (Fig. 76). Under scenario A2-EAB, live-tree volume is projected to be 10 percent less than the volume under scenario A2-C in 2060.

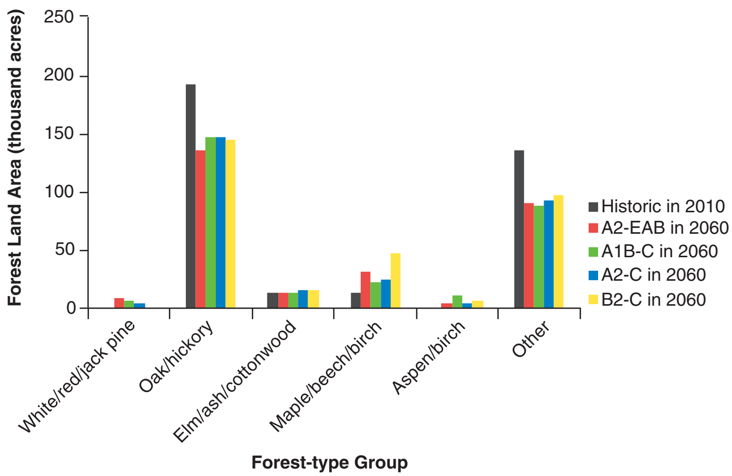


Figure 75.—Current (2010) and projected (through 2060) forest land area by forest-type group and scenario, Delaware.

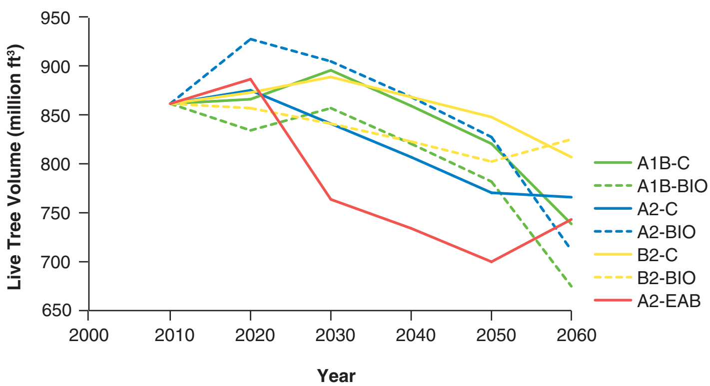


Figure 76.—Projected live tree volume on forest land by scenario, Delaware, 2010-2060.

All seven scenarios result in lower levels of live-tree volume in 2060 than in 2010. Two of the three high biomass utilization scenarios (A1B-BIO and A2-BIO) result in significantly less live-tree volume in 2060 than do their corresponding normal biomass utilization scenarios (A1B-C and A2-C). This is due to much higher harvesting rates for A1B-BIO and A2-BIO (Fig. 77).

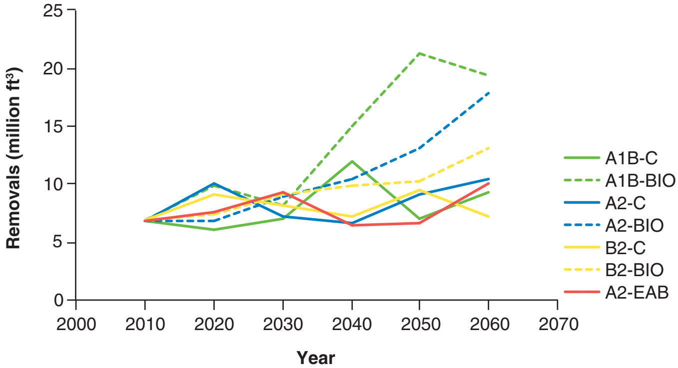


Figure 77.—Projected average annual growing-stock removals on timberland by scenario, Delaware, 2010-2060.

What this means

The projected scenarios presented here show the area of forest land and tree volume decreasing in the future. Over the past 50 years, forest managers have seen increasing forest volume, with growth greatly exceeding removals. If these projections hold true, that will not be the case for future generations. Changing trends result from the combined effects of gradually decreasing forest area and an aging forest resource. These projections should be considered as possible trends. The future forest will be shaped by actual future climate conditions, demographic changes, and changing economic policies.

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Appendix

List of tree species, greater than or equal to one inch in diameter, found on FIA inventory plots, Delaware, 2013

Common name	Genus	Species
Eastern redcedar	*Juniperus*	*virginiana*
Loblolly pine	*Pinus*	*taeda*
Virginia pine	*Pinus*	*virginiana*
Baldcypress	*Taxodium*	*distichum*
Boxelder	*Acer*	*negundo*
Norway maple	*Acer*	*platanoides*
Red maple	*Acer*	*rubrum*
Silver maple	*Acer*	saccharinum
Ailanthus	*Ailanthus*	*altissima*
Sweet (black) birch	*Betula*	*lenta*
River birch	*Betula*	*nigra*
American hornbeam (musclewood)	*Carpinus*	*caroliniana*
Mockernut hickory	*Carya*	*alba*
Pignut hickory	*Carya*	*glabra*
Sand hickory	*Carya*	*pallida*
Catalpa spp.	*Catalpa*	spp.
Flowering dogwood	*Cornus*	*florida*
Common persimmon	*Diospyros*	*virginiana*
American beech	*Fagus*	*grandifolia*
White ash	*Fraxinus*	*americana*
Green ash	*Fraxinus*	*pennsylvanica*
American holly	*Ilex*	*opaca*
Black walnut	*Juglans*	*nigra*
Sweetgum	*Liquidambar*	*styraciflua*
Yellow-poplar	*Liriodendron*	*tulipifera*
Sweetbay	*Magnolia*	*virginiana*
Apple spp.	*Malus*	spp.
White mulberry	*Morus*	*alba*
Red mulberry	*Morus*	*rubra*
Mulberry spp.	*Morus*	spp.
Blackgum	*Nyssa*	*sylvatica*
American sycamore	*Platanus*	*occidentalis*
Bigtooth aspen	*Populus*	*grandidentata*
Black cherry	*Prunus*	*serotina*
White oak	*Quercus*	*alba*
Swamp white oak	*Quercus*	*bicolor*

(Appendix continued on next page.)

(Appendix continued)

Common name	Genus	Species
Scarlet oak	*Quercus*	*coccinea*
Southern red oak	*Quercus*	*falcata*
Overcup oak	*Quercus*	*lyrata*
Swamp chestnut oak	*Quercus*	*michauxii*
Water oak	*Quercus*	*nigra*
Pin oak	*Quercus*	*palustris*
Willow oak	*Quercus*	*nigra*
Chestnut oak	*Quercus*	*prinus*
Northern red oak	*Quercus*	*rubra*
Post oak	*Quercus*	*stellata*
Black oak	*Quercus*	*velutina*
Black locust	*Robinia*	*pseudoacacia*
Black willow	*Salix*	*nigra*
Sassafras	*Sassafras*	*albidum*
American elm	*Ulmus*	*americana*
Siberian elm	*Ulmus*	*pumila*
Slippery elm	*Ulmus*	*rubra*

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This report summarizes the 2013 results of the annualized inventory of Delaware's forests conducted by the U.S. Forest Service, Forest Inventory and Analysis program. Results are based on data collected from 389 plots located across the State. There are an estimated 362,000 acres of forest land in Delaware with a total live- tree volume of 936 million cubic feet. There has been no change in the area of forest land since 2008, however, live-tree volume in Delaware has been increasing. Forest land is dominated by the oak/hickory forest-type group, which occupies 53 percent of total forest land area. Seventy-four percent of the forest land area is in large diameter stands, 12 percent in medium diameter stands, and 13 percent in small diameter stands. The volume of growing stock on timberland has been rising since the 1950s and currently totals 811 million cubic feet. Between 2008 and 2013, the average annual net growth of growing-stock trees on timberland was approximately 16 million cubic feet per year. Additional information is presented on forest attributes, ownership, carbon, timber products, species composition, regeneration, and forest health. Detailed information on forest inventory methods, data quality estimates, and summary tables of population estimates are available online at https://doi.org/10.2737/NRS-RB-115.

KEY WORDS: forest resources, forest health, forest products, volume, biomass, carbon, habitat

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