Delaware's Forests 2008

Resource Bulletin
NRS-62

United States Department of Agriculture

Forest Service

Northern Research Station

Abstract

The fifth full inventory of Delaware's forests reports an 8 percent decrease in the area of forest land to 352,000 acres, which cover 28 percent of the State's land area and has a volume of approximately 2,352 cubic feet per acre. Twenty-one percent of the growing-stock volume is red maple, followed by sweetgum (13 percent), and loblolly pine (12 percent). All species of oaks combined account for 24 percent of the volume. Red maple is the most abundant species in terms of number of trees and the population had been rising through the 1980s and 1990s, but current data show little change since 1999. Oak species and loblolly pine decreased in numbers of trees and volumes. Seventy-three percent of forest land consists of large-diameter trees and 10 percent is in the small-diameter stand-size classes. Average annual growth as a percentage of total growing-stock volume increased from 2.3 to 3.9 percent between 1999 and 2008, while removals and mortality changed little. Additional information on forest attributes, land-use change, carbon, timber products, and forest health is presented in this report. A DVD included in the report provides information on sampling techniques, estimation procedures, a glossary, tables of population estimates, raw data, and a data summarization and reporting tool.

Acknowledgments

The authors would like to thank the many individuals who contributed both to the inventory and analysis of Delaware's forest resources. Primary field crew and Quality Assurance staff over the 2004-2008 field inventory cycle included Thomas Albright, Jason Gould, William Moir, Stephen Potter, Todd Renninger, Richard Starr, Jr., Chris Tucci, Michael Whitehill, and Thomas Willard. Data management personnel included Carol Alerich, Mark Hatfield, Barbara O'Connell, and Jay Solomakos. Report reviewers and contributors included Michael Valenti, Marcia Fox, and Dacia Meneguzzo.

Cover: Fall foliage reflected in a Delaware stream. Photo by Tonya Lister.

Manuscript received for publication July 2011

Published by:
U.S. FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

For additional copies:
U.S. Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640

March 2012

Visit our homepage at: **http://www.nrs.fs.fed.us**

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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 at work and in our homes. Many species of wildlife depend on forested habitats for 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 2010 Delaware Statewide Forest Strategy (Delaware Forest Service 2010) outlines a number of steps that our foresters, support staff, and cooperating partners will take over the next several 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 which 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, and most recently in 2008. This data enables 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.

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Highlights

On the Plus Side

There are approximately 352,000 acres of forest land in Delaware.

Thirty-four percent of the forest loss in Delaware has been offset by gains in forest land between 2001 and 2006, the majority of which (64 percent) has come from reversion of agricultural lands.

Sussex County has the highest percent of forest land in Delaware (35 percent) and 84 percent of that forest occurs in patches greater than 100 acres in size.

Historic data show that the population of red maple, the most common tree species in Delaware, had been increasing, however current inventory results suggest the population has stabilized.

Delaware forests currently contain almost 29 million tons of carbon. Live trees and saplings represent the largest forest ecosystem carbon stock in the state with more than 14 million tons. Carbon stocks in Delaware's forests have increased substantially over the last several decades.

With an average of 8,416 board feet per acre, there are 2.9 billion board feet of sawtimber in Delaware. Sawtimber volume has increased by nearly 30 percent since 1999.

The volume of growing-stock trees in Delaware is 810 million cubic feet, or 2,352 cubic feet per acre. Volume has increased by 17 percent since 1999.

In Delaware, 60 percent of the sawtimber volume is in grades 1 or 2, the highest quality, and grade 1 volume has increased since the 1999 inventory.

Average annual growth (as a percentage of total growing-stock volume) increased from 2.3 to 3.9 percent between 1999 and 2008.

The overall growth-to-removals ratio (G:R) increased to 4.5 in 2008. The G:R ratio is high for most species, indicating that tree growth is far exceeding removals.

Data suggest that tree mortality has decreased since the 1999 inventory and is now only 0.6 percent of the total growing-stock volume.

The nearly 6 million standing dead trees in Delaware's forests have the potential to provide critical habitat for many forest-associated wildlife species, including the red-headed woodpecker.

The occurrence of poor crowns in Delaware was very low and evenly distributed across the State; no species had greater than 10 percent of its live basal area containing poor crowns.

Problem Areas

Since 1986, over 55,000 acres of forest land have been lost in Delaware, which is just over 2,000 acres per year.

Over the last two decades, forest land area in New Castle and Kent Counties has remained relatively stable. However, significant losses of forest land have occurred in the most heavily forested county of Sussex.

Eighty-three percent of family forest owners have between 1 and 9 acres of forest land and the average parcel size is decreasing, making it more difficult to coordinate consistent and sustainable management of large tracts of forest land.

Hardwood forest. Photo by Glenn Gladders, Delaware Department of Agriculture.

In Delaware, 68 percent of the forest land is less than 300 feet from an agricultural use or developed edge, a distance where edge effects are thought to impact the forest.

The majority of forests (179,000 acres or 51 percent) are fully stocked with live trees but this is a nearly 58,000 acre decrease from the area of fully stocked forests in 1999.

There has been a steady decline in numbers of loblolly pine trees in Delaware with significant decreases from 1986 to 2008. This is a concern since loblolly pine is an important commercial species in Delaware.

The number of oak trees has decreased significantly since 1999, especially in diameter classes less than 14 inches.

Almost 15 percent of harvest residue is from growing-stock sources that could be used to produce wood products.

Area of the small diameter stand-size class on timberland in Delaware decreased from 18 percent in 1986 to 10 percent in the current inventory.

Invasive species are a concern in Delaware. The most commonly occurring nonnative invasive plant species were Japanese honeysuckle and multiflora rose.

A quarter of all trees in Delaware, or 61 million, are susceptible to attack by the Asian longhorned beetle, an exotic wood-boring beetle that is not yet present in the State, but has attacked a variety of hardwood species that are found in Delaware.

Issues to Watch

Sixty-four percent of the gains in forest land are due to agricultural reversion to forest, but gross gains in forest land will likely decrease as the area of land in agriculture continues to diminish.

Data suggest that oak species are continuing to decrease in numbers and volume. Declining oak populations can negatively impact the oak resource for wildlife.

The numbers of trees in the small diameter classes and the area of stands in the small stand-size classes have been decreasing, while the area of forest in the larger stand size and age classes has been increasing. This, coupled with an increase in stand age, may suggest loss of early successional habitat which is important for some wildlife species in decline.

Ninety-two percent of the forests in Delaware are privately owned and much of this forest land will soon be changing hands. It is unclear how these future forest owners will manage and care for their lands.

Pulp mills in other states receive more than half of the total industrial roundwood harvested in Delaware. Saw mills 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.

There is some evidence of lower frequencies of tree seedlings and saplings on plots with higher amounts of invasive plant species.

The emerald ash borer, an exotic beetle found in the New Jersey and Maryland, poses a threat to ash trees in both urban and forested environments in Delaware. Other pests, including gypsy moth and the hemlock wooly adelgid, are also expected to cause damage to Delaware's forests. The spread of these pests needs to be carefully monitored.

Forest fragmentation and forest loss are occurring at a higher rate in the previously more-intact forests of southern Delaware. As population pressures and real estate preferences continue to change, forest loss associated with urbanization will likely have a greater impact on the forests of Delaware.

Background

Forest bordering a backyard stream. Photo by Tonya Lister.

Data Sources and Techniques

Forest Inventory

Information on the condition and status of forests in Delaware was obtained from the U.S. Forest Service, Northern Research Station's Forest Inventory and Analysis (NRS-FIA) program. Previous inventories of Delaware's forest resources were completed in 1957 (Ferguson 1959), 1972 (Ferguson et al. 1974), 1986 (Frieswyk and DiGiovanni 1989), and 1999 (Griffith and Widmann 2001). During the 2004-2008 inventory, hereafter referred to as the 2008 inventory, data were collected on 435 inventory plots (Fig. 1).

The 2008 Delaware inventory was conducted in three phases. In Phase 1 (P1), a geographic information system (GIS) was used to obtain initial land use assessments on each plot, and to obtain stratification information that was used during the estimation process to increase the precision of estimates. In phase 2 (P2), field crews visited field plots to measure inventory variables such as tree species, diameter, and height. In phase 3 (P3), field crews visit a subset of P2 plots to obtain measurements for an additional suite of variables associated with forest and ecosystem health. The three phases of the enhanced FIA program as implemented in this inventory are discussed in greater detail in "Delaware's Forests 2008: Statistics, Methods, and Quality Assurance" on the DVD in the inside back cover of this bulletin.

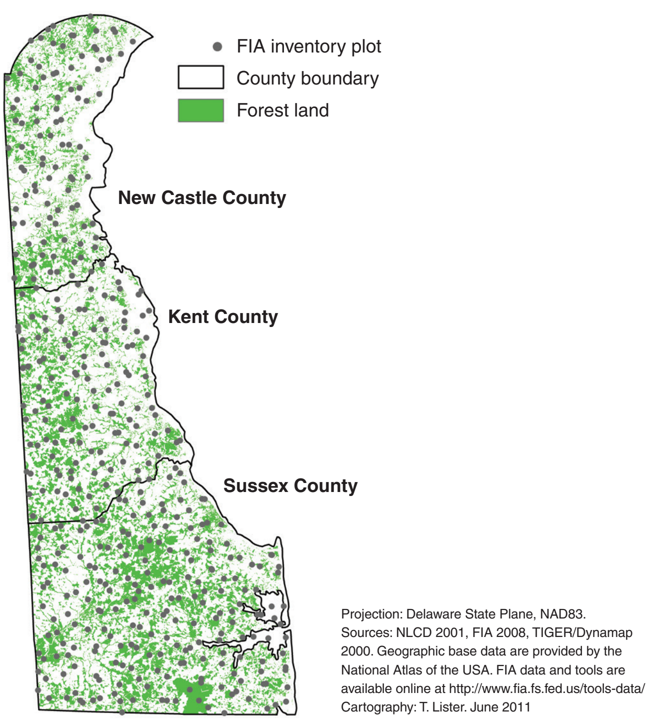


Figure 1.—Distribution of forest land and FIA forest inventory plots in Delaware, 2008. Plot locations are approximate.

National Woodland Owner Survey

Information about family forest owners is collected through the U.S. Forest Service's National Woodland Owner Survey (NWOS). The NWOS was designed to increase our understanding of owner demographics and motivation (Butler et al. 2005). Data presented here are based on survey responses from 88 randomly selected families and individuals who own forest land in Delaware and Maryland. For additional information about the NWOS, visit: www.fia.fs.fed.us/nwos.

Timber Product Output Inventory

This study was a cooperative effort of the Division of Forestry of the Delaware Department of Agriculture and the Northern Research Station (NRS). A questionnaire, designed to determine the size and composition of Delaware's forest products industry, its use of roundwood (round sections cut from trees), and its generation and disposition of wood residues, was filled out for all primary wood-using mills within the State. Completed questionnaires were sent to NRS for editing and processing. As part of data editing and processing, all industrial roundwood volumes reported on the questionnaires were converted to standard units of measure using regional conversion factors. Timber removals by source of material and harvest residues generated during logging were estimated from standard product volumes using factors developed from logging utilization studies previously conducted by NRS.

Frequently Asked Questions

What is a tree?

Trees are perennial woody plants with central stems and distinct crowns. In general, the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service defines a tree as any perennial woody plant species that can attain a height of 15 feet at maturity. A complete list of the tree species measured in this inventory can be found in "Delaware's Forests 2008: Statistics, Methods, and Quality Assurance," on the DVD in the inside back cover pocket of this bulletin.

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 range from very tall, dense, and multi-structured to short, sparsely populated, and single layered. FIA defines forest land as land that is at least 10 percent stocked by trees of any size or formerly having been stocked and not currently developed for nonforest use. The area with trees must be at least 1 acre in size and 120 feet wide. Forest land can exist in urban and agricultural areas as long as it meets the above criteria and doesn't have maintained or mowed understory. Examples of land with tree cover that are not considered forest land by FIA definitions include pasture land under tree cover that has been grazed, urban parks with a maintained understory, and treed residential areas where underlying grass is maintained.

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, reserved forest land, and other forest land. In Delaware, about 98 percent of forest land is classified as timberland, 2 percent is reserved and productive forest land, and less than 1 percent is other forest. Timberland is unreserved forest land that meets the minimum productivity requirement of being capable of growing 20 cubic feet of wood per acre per year. Reserved forest land is land withdrawn from timber utilization through legislation. 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. In earlier inventories, FIA measured trees only on timberland plots and did not report volumes on all forest land. Since the last full inventory in 1999, FIA has been reporting volume on all forest land.

By 2013, FIA will be able to compare two sets of growth, mortality, and removal data using annual inventory data. Much of the trend reporting in this publication is focused on timberland, because comparing current data to data from older periodic inventories requires timberland estimates.

How do we estimate a tree's volume?

The volume for a specific tree species is determined by the use of volume equations developed specifically for a given species. Sample trees were felled and measured for length, diameter, and taper. Volume equations have been developed at the Northern Research Station for each tree species found in the region. Models have been developed from regression analysis to predict volumes within a species group. We produce individual tree volumes based on species, diameter, and merchantable height. Tree volumes are reported in cubic-foot and International ¼-inch rule board-foot scale.

How much does a tree weigh?

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, we add the biomass for stumps (Raile 1982), limbs and tops (Hahn 1984), and belowground stump and coarse roots (Jenkins et al. 2004). We do not currently report live biomass for foliage. 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.

How do we estimate all the forest carbon pools?

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

How do we compare data from different inventories?

Comparing new inventories with older datasets is common to analyze trends or changes in forest growth, mortality, removals, and ownership acreage over time (Powell 1985). A pitfall occurs when the comparisons involve 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 simply an extension of our FIA volume estimates. This allows us to obtain biomass estimates for growth, mortality, and removals of trees from our 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 are 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 especially 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

Oak canopy. Photo by Tonya Lister.

Forest Area

Background

Delaware is located in the fertile Delmarva Peninsula between the Chesapeake and Delaware Bays. It contains a portion of the Chesapeake Bay watershed, which has been designated as a national treasure and a priority area for conservation. Forest land in the State is valued for the ecological, economic, and aesthetic benefits it provides. Located in the northeastern portion of the Delmarva Peninsula, Delaware contain a unique mixture of flora and fauna that are generally associated with coastal plain habitats.

Delaware is dominated by agriculture and urban development, with forests comprising less than a third of the total land area. These forests, however, offer a wide range of benefits including 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. The U.S. Interstate 95 corridor runs through the northern tip of the county. 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 and have a greater concentration of forest land. These counties are also host to the majority of the State's more than 150,000 acres of forested wetlands. Wetland and riparian forests are prominent features in this portion of Delaware. These forests, and those that remain in the more developed northern portions of the state, play a critical role in the protection of water quality, maintenance of biodiversity, generation of wood products, and other ecosystem services that contribute to Delaware's unique role in the mid-Atlantic region.

What we found

Delaware contains 352,000 acres of forest land which cover 28 percent of the State's land area. The State has been losing forest land since the mid 1980s, and data suggest that this is a continuing trend. Since the 1986 inventory, over 55,000 acres of forest land have been lost, which is just over 2,000 acres per year (Fig. 2).

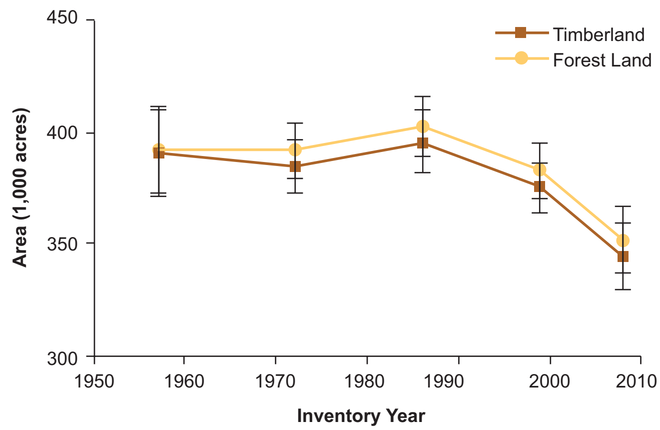


Figure 2.—Area of forest land in Delaware by inventory year. Error bars show 68 percent confidence interval.

The county-level distribution of forest land area shows a gradient of increasing proportions of forest land going from New Castle County in the north to Sussex County in the south. This pattern has persisted since the first FIA inventory in 1956 (Fig. 3). Over the last two decades, forest land area in New Castle and Kent Counties has remained relatively stable. Significant losses of forest land have occurred in the most heavily forested county of Sussex (Fig. 4). This loss is attributed to the increase in urban and residential development during this time period. It is not surprising that forest land conversion in Sussex County is a major driving force behind the net loss of forest in Delaware. According to U.S. Census data, the population in Sussex County increased 23 percent between 2000 and 2009, which is nearly three times the national average of 9 percent and higher than the State population increase of 13 percent (U.S. Census Bureau 2009). Population increases are greatest in the eastern region of Sussex County due its desirable coastal location.

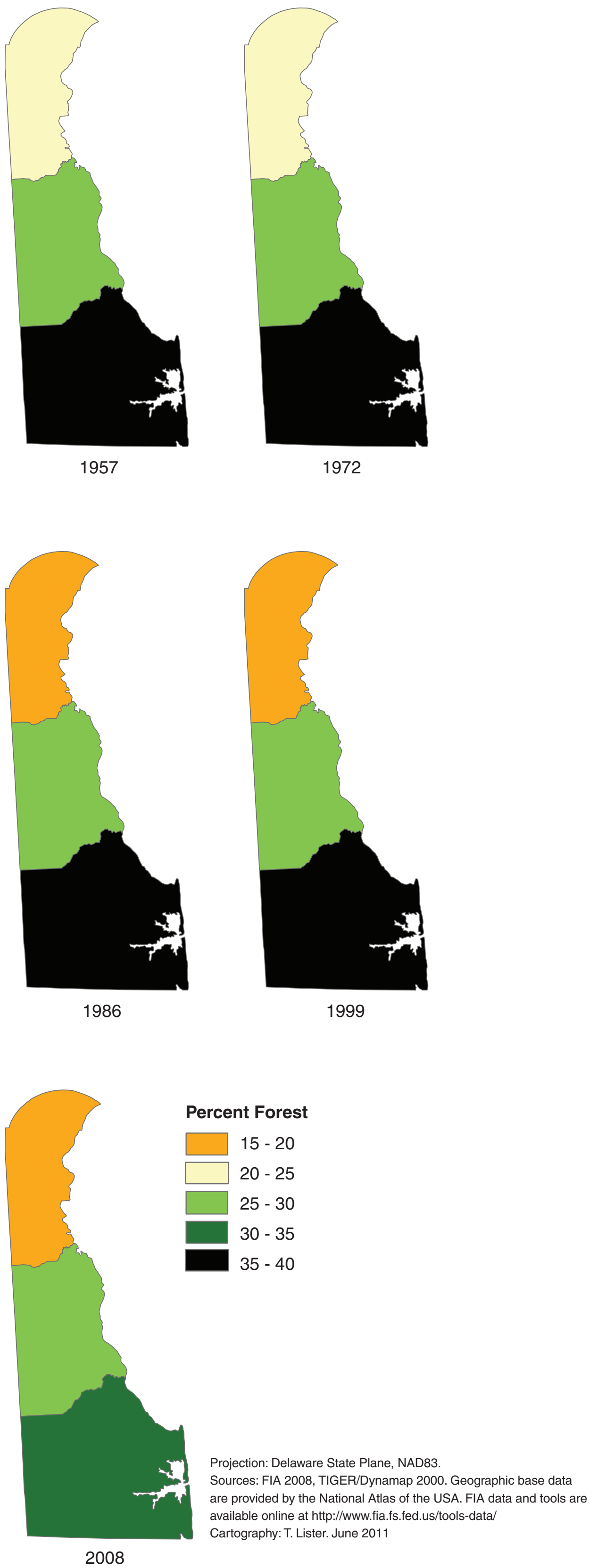


Figure 3.—Forest land area as a percent of total land area by county and inventory year, Delaware, 1950-2008.

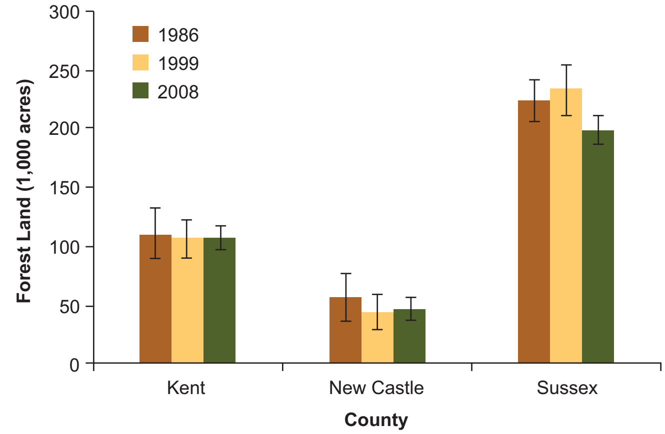


Figure 4.—Trends in forest land area by county, Delaware, 1986, 1999, and 2008. Error bars show 68 percent confidence interval.

What this means

Forest change dynamics in Delaware are due to a complex interaction of patterns of population growth, land development, reversion of agricultural land to forest, conservation policies, and the availability of land open for development. The increase in development rates in Sussex County over the past 10 years is due in part to population growth and real estate preferences, and makes this county, which has the largest blocks of contiguous forest in the state, vulnerable to habitat fragmentation and associated impacts on wildlife, water quality, and aesthetic value. There are a number of programs and legislative initiatives that are designed to promote wise stewardship of Delaware's forest resources.

Land-use Change

Background

Eastern forests offer habitat for forest-dwelling species, protect drinking water, serve as buffers for rivers and bays against sedimentation and nutrient enrichment, and provide socio-economic and other benefits for humans (Sprague et al. 2006). They are, however, under increasing pressure as the demand for residential development increases (Claggett et al. 2004). Urban development is occurring at a rapid pace. Nowak et al. (2005) predicted that the area of urban land in the United States will nearly triple between 2000 and 2050.

Delaware has experienced a loss of forest land area over the past 20 years due in part to population growth and urban development. Figure 2 shows this trend of decreasing forest area but the dynamics of forest change are more complicated. When we compare forest land estimates between inventories, the difference between the two estimates is the net change in forest land area. The gross amount of forest loss is actually higher but some of these losses have been offset by gains in forest land.

In an effort to explore the dynamics of these gross changes in land use, data from the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) program were used (NOAA 2007). C-CAP provides land cover and land-use change estimates for coastal and adjacent upland areas of the United States, and land cover maps are updated every 5 years. Delaware falls completely within the C-Cap monitoring area and land-cover change data between 2001 and 2006 were analyzed for a better understanding of gross land-use and land-cover change dynamics in Delaware.

What we found

Based on the C-CAP data, there were 7,000 acres of gross forest lost between 2001 and 2006, 34 percent of which was offset by gains in forest land from previous nonforest uses (Fig. 5). The gross forest loss was primarily due to conversion to other nonforest uses which include water, shore, wetland, bare land, and grassland. Forest conversion to developed uses is nearly equal to forest conversion to agricultural. Sixty-four percent of gains in forest land came from reversion of agricultural uses.

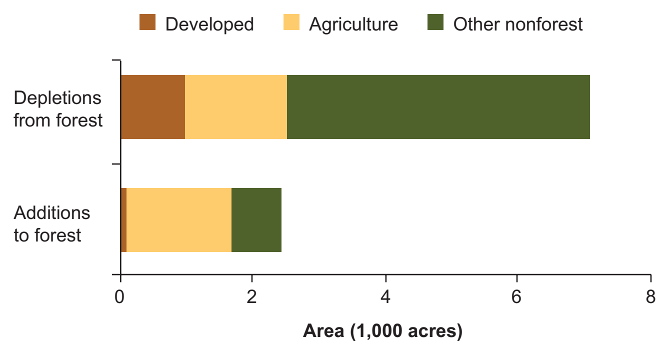


Figure 5.—Estimates of areas of different land-use change categories, Delaware, 1998-2007.

Figure 6 shows the distribution of net forest loss and gain in Delaware based on an aggregation of the C-Cap data. All counties show a net loss of forest land area. Kent County has the least amount of forest loss and Sussex County has both the greatest loss of forest and the greatest gain in forest land area. In general, the C-CAP

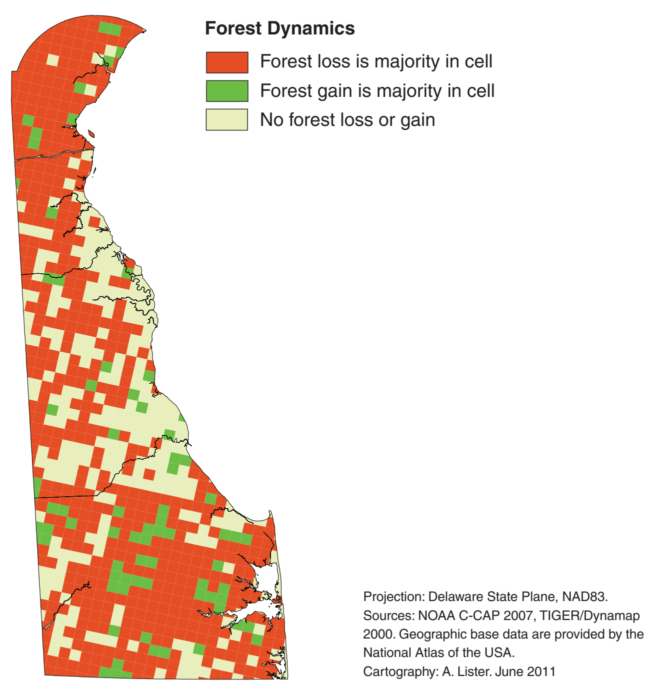


Figure 6.—Forest land dynamics in Delaware, 1998-2007.

and FIA data show similar results for the distribution of forest loss among the three counties in Delaware. Both datasets estimate that 65 percent of the net forest loss in the state occurs in Sussex County.

What this means

As the population of Delaware continues to grow, forest and agricultural land is likely to be converted to developed uses. The majority of this new development is occurring on agricultural land uses, but given the fact that agricultural land area is decreasing in Delaware, forest land is at even greater risk of being developed. In neighboring Maryland, inventory results indicate that new development is now more likely to occur on forest land than agricultural land. This situation is compounded by the fact that some of the gains in forest land are coming from agricultural reversion, so not only is there less agricultural land available for development, there is also less available for conversion to forest. The end result may be greater net loss of forest land.

There are many policies and programs in place in Delaware to promote forest sustainability. Delaware's Forest Legacy and Forest Land Preservation programs allow forest land to be purchased by the State or protected through a conservation easement. Delaware also encourages private land owners to develop Forest Stewardship Plans and offers educational opportunities to landowners to help promote sustainability. In addition, a portion of Delaware is within the Chesapeake Bay watershed, and there are several initiatives, including the Chesapeake Bay Critical Areas Program, that include forest protection guidelines aimed at improving water quality. Understanding land-use dynamics helps planners ensure that Delaware's forests and the associated ecosystem services they provide are managed sustainably.

Forest Ownership

Background

It is the owners of the forest land who ultimately control its fate and decide if and how it will be managed. By understanding the motivations of forest land owners, leaders of the forestry and conservation communities can better help these owners meet their needs, and in so doing, help conserve the region's forests for future generations. FIA conducts the National Woodland Owner Survey (NWOS) to better understand who owns the forests, why they own them, and how they use them (Butler 2008). NWOS data for Maryland and Delaware are combined here because of the small sample size in the states.

What we found

The forests of Maryland and Delaware are mostly privately owned—76 percent in Maryland and 92 percent in Delaware (Fig. 7). Of these private acres, 74 percent are owned by families, individuals, and other unincorporated groups, collectively referred to as family forest owners.

One hundred and fifty-six thousand family forest owners in Maryland and an additional 28,000 family forest owners in Delaware control 1.7 million forested

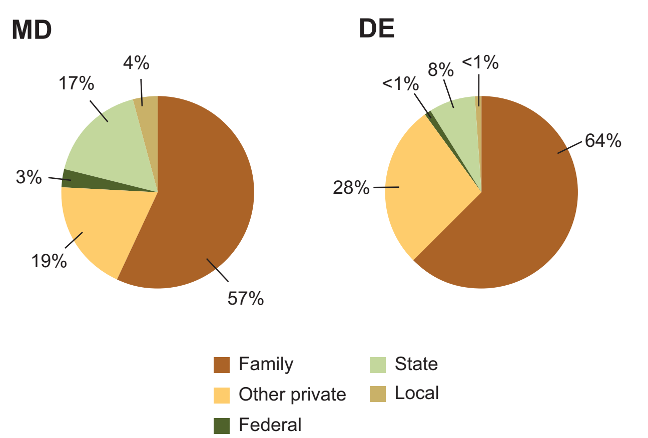


Figure 7.—Forest ownership, Maryland and Delaware, 2006.

acres across the two states. Eighty-three percent of these owners have between 1 and 9 acres of forest land (Fig. 8); the average holding size is 9 acres. The primary reasons for owning forest land are related to aesthetics, the forest land being part of a home site, and nature protection (Fig. 9).

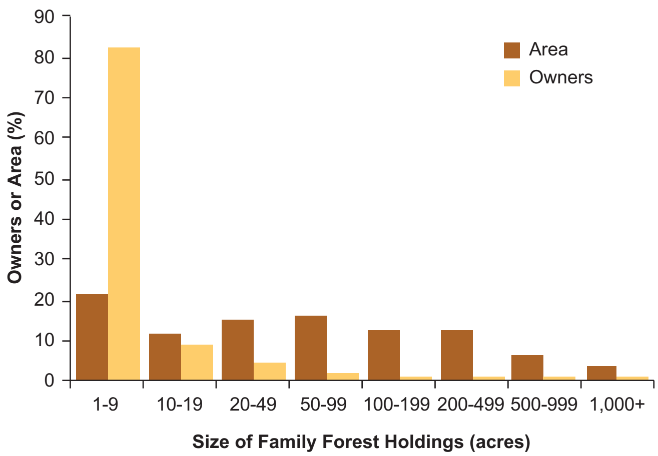


Figure 8.—Percent of total forest land and number of owners distributed across family forest holding size classes, Maryland and Delaware, 2006.

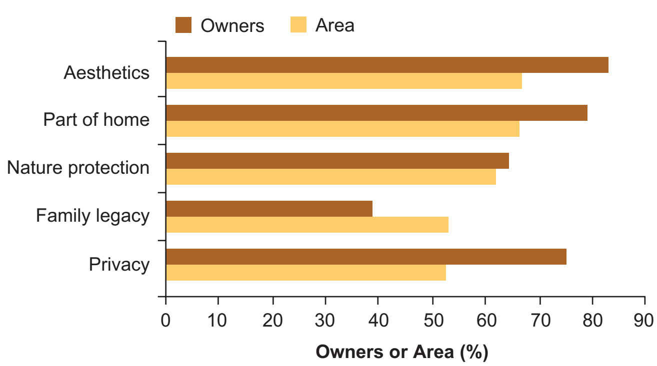


Figure 9.—Primary ownership objectives of family forest owners by percent forest land, Maryland and Delaware, 2006.

Although timber production is not a major ownership objective, 44 percent of the family forest land is owned by people who have commercially harvested trees. Thirty-three percent of the land is owned by people who have a written management plan, and 41 percent of the land is owned by people who have received management advice.

What this means

The average parcel size is decreasing and some of this forest land will soon be changing hands. Thirteen percent of the family forest acres is owned by someone who plans to pass the land onto heirs or sell it in the near future. Family legacy is a major ownership objective and it is also a major concern. It is important to develop an understanding of forest owner perspectives and objectives in order to develop appropriate programs that promote wise stewardship of Delaware's forest resources.

Urbanization and Fragmentation

Background

The expansion of urban lands that accompanies human population growth often results in the fragmentation of natural habitat (Wilcox and Murphy 1985). Forest fragmentation and habitat loss is recognized as a major threat to animal populations worldwide (Rosenberg et al. 1999), particularly for species that require interior forest conditions for all or part of their life cycle (Donovan and Lamberson 2001), and species that are wide-ranging, slow-moving, or slow-reproducing (Forman et al. 2003). Forest fragmentation can also affect forest ecosystem processes through changes in micro-climate conditions and the ability of tree species to move in response to climate change (Iverson and Prasad 1998).

The physical fragmentation of habitats is only one of the human-induced processes affecting natural habitats and their biodiversity. Urbanization and other anthropogenic pressures can also lead to habitat deterioration, changes in hydrology, and the introduction of exotic species. In addition to the negative effects on forested ecosystems, the fragmentation and urbanization of forest land may have direct economic and social effects as well. For example, smaller patches of forest or those in more populated areas are less likely to be managed for forest products (e.g., Wear et al. 1999, Kline et al. 2004) and are more likely to be "posted" (i.e., not open for public use) (Butler et al. 2005), potentially affecting local forest industry, outdoor recreation opportunities, and local culture. Forest land is also a significant factor in the protection of surface and groundwater, and fragmentation and urbanization of that forest land has been observed to affect both water quality and quantity (e.g., Hunsaker et al. 1992, Riva-Murray et al. 2010).

The metrics presented here relate to some aspect of urbanization or fragmentation that is suspected of, or has been documented to have an effect on the forest, its management, or on its ability to provide ecosystem services and products (Riemann et al. 2008). These measures are forest edge versus interior, proximity to roads, patch size, local human population density, and the extent of houses intermixed with forest.

What we found

In Delaware, less than a third of the forest land is greater than 295 feet from an agricultural use or developed edge. This ranges from 22 percent in New Castle County in the north to 36 percent in Sussex County at the southern end of the State (Table 1).

Figures 10 and 11 show where and to what extent forest land is affected by roads. As both Forman (2000) and Riitters and Wickham (2003) reported, this can be quite extensive, even in areas that appear to be continuous forest land from the air. In Delaware, for example, 27 percent of the forest land is within 330 feet of a road and 62 percent is within 980 feet.

Forest land in Delaware occurs largely as remnant patches and corridors within a primarily urban and agricultural matrix. In Sussex County, only 35 percent of the land is forested, yet 84 percent of that forest still occurs in patches greater than 100 acres in size. Forested areas containing higher proportions of small patches (patches <100 acres) occur in the more urbanized north and along the coast where nonforest vegetation historically dominated (Figure 12). New Castle County has over 30 percent of its remaining forest land in patches less than 100 acres in size (Figure 13).

The wildland-urban interface (WUI) is commonly described as the zone where human development meets or intermingles with undeveloped wildland vegetation, and is associated with a variety of human-environment conflicts (Radeloff et al. 2005). Radeloff et al. (2005) define this area in terms of housing density (greater than 15.5 houses per square mile), the percentage of

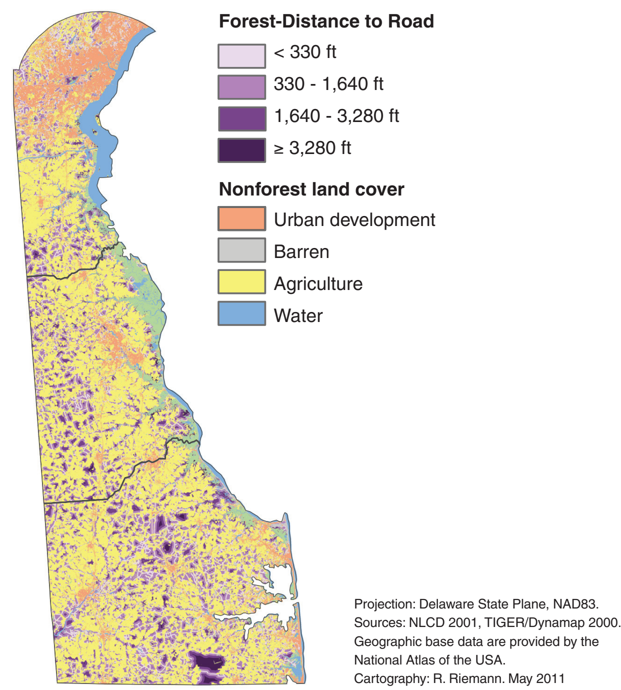


Figure 10.—Spatial distribution of forest land in distance to the nearest road classes, Delaware, 2000.

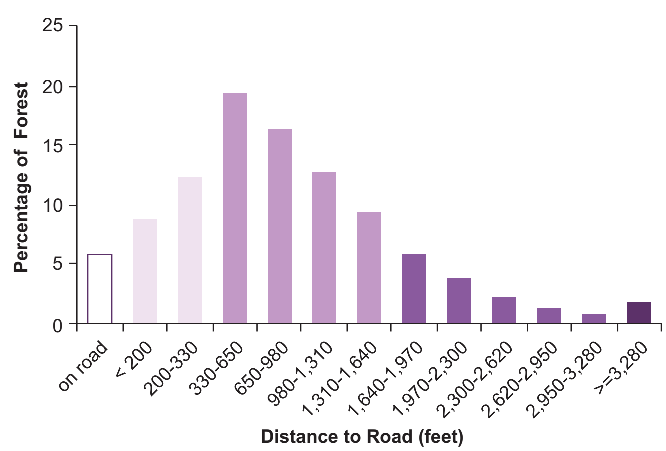


Figure 11.—Distribution of forest land by distance to the nearest road classes, Delaware, 2000.

Table 1. The distribution of forest land by urbanization and fragmentation factors, expressed as a percent of the total forest land area in each county.

County	Forest land in county [a]	Forest land with house density > 15.5/mi² [b]	Forest land > 295 ft (90 m) from an ag or developed edge [c]	Forest land > 980 ft from a road [d]	Forest land located in patches > 100 acres in size [e]	Forest land located in a block with population densities > 150/mi² (57.9/km²) [f]
		---percent---				
Kent	27	58	30	44	82	18
New Castle	26	66	22	28	67	38
Sussex	35	54	36	38	84	15
Delaware total	31	57	32	38	80	20

[a] Percent forest estimate based on NLCD 2001. Values are generally higher than estimates from FIA plot data.
[b] Approximating the forest land potentially affected by underlying development.
[c] Approximating the forest land undisturbed by edge conditions.
[d] Approximating the forest land outside the effects of roads.
[e] Approximating the forest land with potentially enough core area for sustainable interior species populations.
[f] Approximating the forest land not available for commercial forestry.

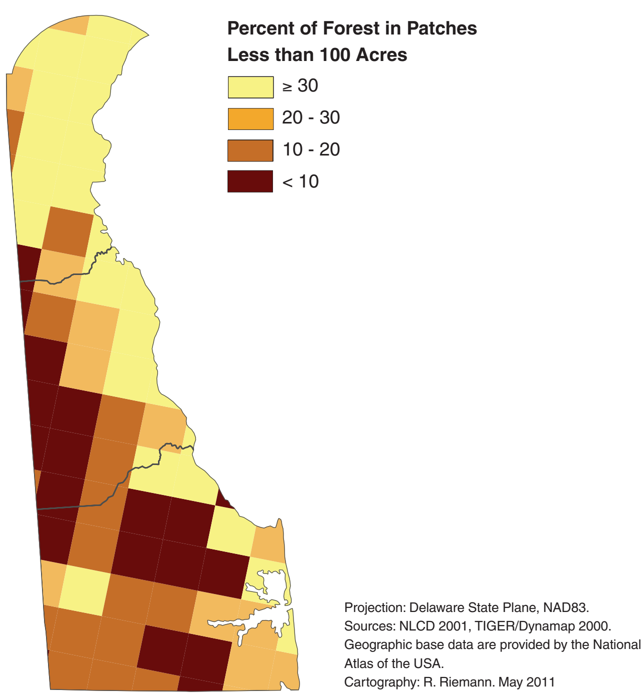


Figure 12.—Forest cover (percent) in patches less than 100 acres, by 62-square-mile grid cell, Delaware, 2000.

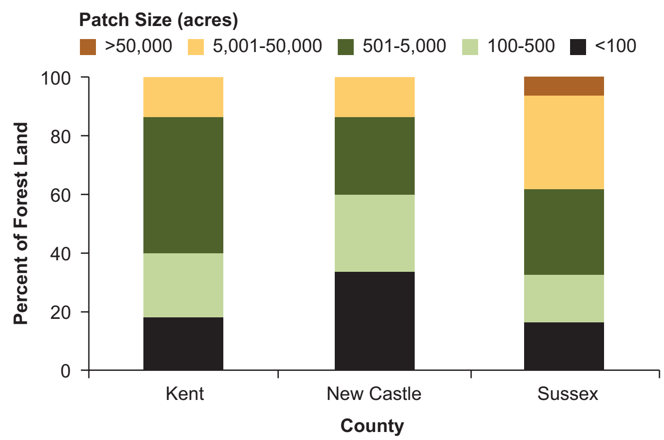


Figure 13.—Distribution of forest land by patch size and by county, Delaware, 2000.

vegetation coverage present, and proximity to developed areas. Figure 14 illustrates that 57 percent of the forest land in Delaware is affected by house densities greater than the threshold of 15.5 houses per square mile. Individual counties range from 54 percent (Sussex) to 66 percent (New Castle) of the forest intermixed with house densities of greater than 15.5 per square mile. Close proximity of humans to forest land has also been observed to affect the viability of commercial forestry in the area. (Wear et al. 1999). In Delaware, 20 percent of the forest land is located in areas with a population

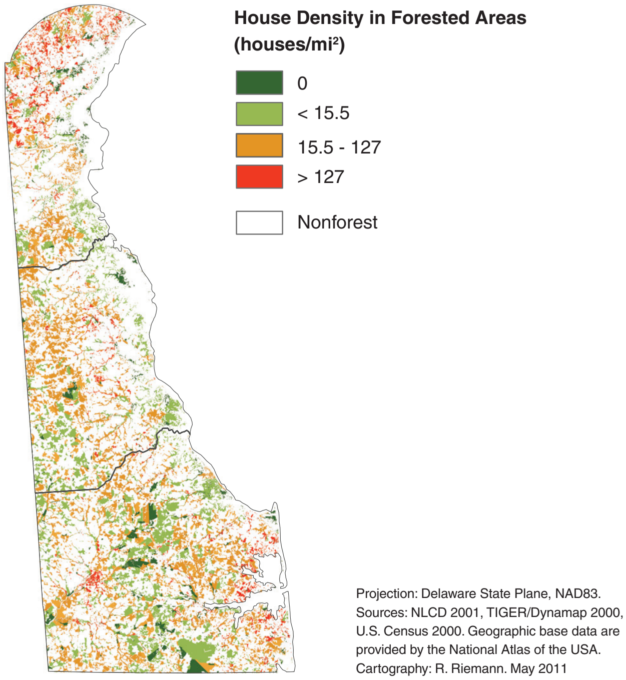


Figure 14.—Housing density, by class, in forested areas of Delaware, 2000.

density greater than 150 people per square mile (Table 1; U.S. Census 2009), however this varies across the region, from 15 percent in southern Delaware to 38 percent in New Castle county.

Table 1 brings together many of the factors discussed in this section and presents the extent to which the current forest land base is being influenced by one or more of the factors. For example, in Sussex County, which is 35 percent forested, 54 percent of that forest land is potentially affected by house densities greater than 15.5 per square mile, while only 36 percent of the forest land is far enough from an edge to be considered interior forest conditions. Eighty percent of the forest land is in large patches (>100 acres), but only 32 percent is greater than 980 feet from a road.

What this means

Edge effects vary with distance from forest edge, depending on the type of effect and species of vegetation or wildlife, (e.g., Chen et al. 1992, Flaspohler et al. 2001, Rosenberg et al. 1999), but 100 to 300 feet is frequently used as a general range for the 'vanishing distance' or the distance into a patch where the edge effect disappears and interior forest conditions begin.

Figures 10 and 11 depict the pervasiveness of roads in the landscape. The presence of roads can cause changes in: hydrology, chemistry (salt, lead, nutrients, etc.), noise, habitat fragmentation, prevalence of invasive species, and level human access. These effects impact forest ecosystem processes, wildlife movement and mortality, and human use of the surrounding area. Road effects diminish when distances range from about 330 feet for secondary roads (a rough estimate of a highly variable zone), 1,000 feet for primary roads in forest (assuming 10,000 vehicles traverse the road per day), and 2,650 feet from roads in urban areas (assuming 50,000 vehicles traverse the road per day) (Forman 2000). Delaware falls within an area of high road densities, with more than 60 percent of forest land area located within 1,000 feet of the nearest road (Riitters and Wickham 2003). Actual ecological impacts of roads will vary by the width of the road and its maintained right-of-way, number of cars, level of maintenance (salting, etc.), number of wildlife-friendly crossings, hydrologic changes made, how pervious road surfaces are, location with respect to important habitat features, etc. These variables also suggest some changes that can be made to alleviate the impact of roads on the forest (Forman 2000, Forman et al. 2003).

Habitat requirements for wildlife vary by species, but for reporting purposes it is often helpful to summarize forest patch data using general guidelines. Many wildlife species prefer contiguous forest patches that are at least 100 acres (Hoover et al. 1995, Riemann et al. 2008). This patch area is often used as a minimum size still containing enough interior forest to be a source rather than a sink for populations of some wildlife species. Without considering the impact of roads or houses that don't substantially break the tree canopy, 80 percent of Delaware's forest land is in patches larger than 100 acres. However, given the pervasiveness of houses and roads within the forest landscape in Delaware and the high proportion of forest land that is less than 300 feet from an agricultural or developed edge, patch size alone will not be a good indicator of wildlife habitat quality.

Human population is generally recognized as having a negative effect on the viability and practice of commercial forestry (Barlow et al. 1998, Kline et al. 2004, Munn et al. 2002, Wear et al. 1999). Working in Virginia, Wear et al. (1999) identified a threshold of 150 people per square mile as the population density at which the probability of commercial forestry dropped to practically zero. In Delaware, 20 percent of forest land occurs in areas that exceed this threshold.

With population pressures and urban growth increasing in Delaware, it is important to continue to monitor forest fragmentation and urbanization to ensure that the State's forest resources will continue to provide important ecological benefits.

Forest Resource Attributes

Hardwood forest. Photo by Glenn Gladders, Delaware Department of Agriculture.

Forest Structure and Density

Background

In order to understand the ecology and economic value of a forest, it is common to describe the structure of the forest in terms of the area in different stand-size, stocking, and age classes. Foresters typically use stem diameter at breast height (d.b.h.), or diameter at 4.5 feet above the ground, as a measure of tree size, and trees per acre as a metric of stem density. FIA defines stand-size class as the dominant d.b.h. class of trees in the stand: small diameter (less than 5.0 inches d.b.h.), medium diameter (5.0 to 8.9 inches d.b.h. for softwoods and 5.0 to 10.9 inches d.b.h. for hardwoods), or large diameter (≥ 9.0 inches for softwoods and 11.0 d.b.h. for hardwoods).

Similarly, stocking, or a measure of site occupancy by trees, is another measure of forest structure that, depending upon how it is calculated, can integrate size and stem density to provide an index of how close to fully utilized the site is by trees. Stocking tables and charts have been created by foresters to aid in the calculation of this index. Five values of the stocking index are reported by FIA: nonstocked (0 to 9 percent), poorly stocked (10 to 34 percent), moderately stocked (35 to 59 percent), fully stocked (60 to 100 percent) and overstocked (>100 percent). As stands become overstocked, trees become crowded, productivity decreases, more trees die, and stem quality often decreases. Poorly stocked stands are not fully occupied by trees, and might benefit from some silvicultural treatment that improves site occupancy and value. Economically valuable trees are called "growing-stock trees". Analyses of stocking values for growing-stock trees, as well as the ratio of growing stock to all live stocking, can help resource specialists manage forests for economic value.

What we found

Large-diameter stands dominate the forest land area (73 percent) in Delaware. While differences are not statistically significant, data suggest a trend of decreasing area of small- and medium-diameter forest stands and increasing area of large-diameter stands between 1986 and 2008 (Fig. 15).

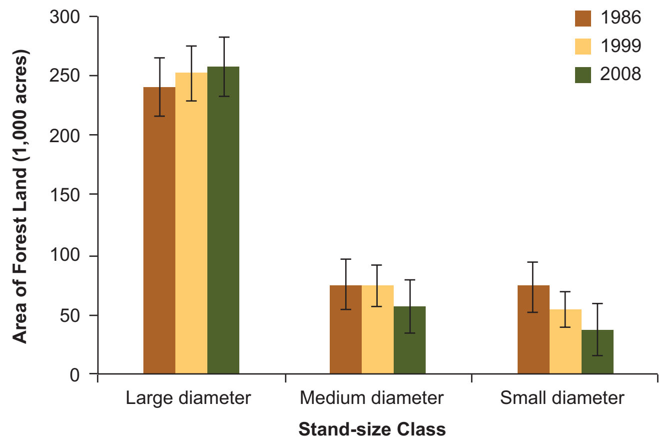


Figure 15.—Area of forest land by stand-size class, Delaware, 1986, 1999, and 2008. Error bars show 68 percent confidence interval.

Data indicate that since 1999, Delaware's forests have become less fully stocked (Fig 16). An estimated 179,000 acres (51 percent) of the forests are fully stocked with live trees, which is a nearly 58,000 acre decrease from the area of fully stocked forest in 1999 (Fig. 16). The area of forest in the medium stocking class, increased by 56 percent, and the acreage of nonstocked and poorly stocked stands showed little change since 1999. The acreage in the poorly and nonstocked class is relatively small (36,000 acres).

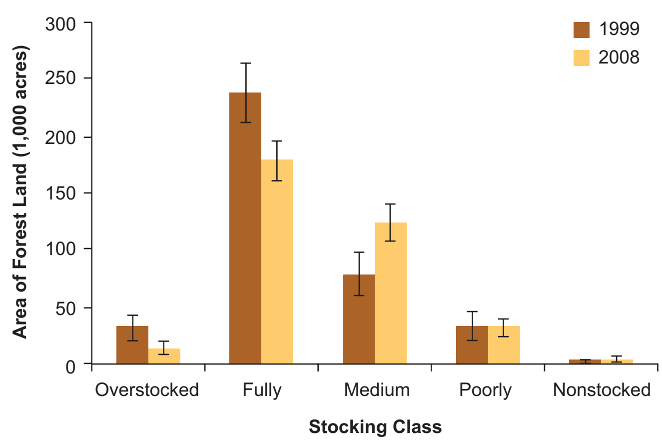


Figure 16.—Area of forest land by stocking class of all live trees, Delaware, 1999 and 2008. Error bars show 68 percent confidence interval.

The age class distribution in Delaware is shifting to the older age classes – relatively more forest area appears to be in the higher classes compared to the 1999 inventory (Fig. 17). The only statistically significant difference in age class area, however, is for the 0-20 year age class, in which there is a greater than 50 percent reduction in area. According to the 2008 inventory, 51 percent of forest stands are at least 61 years old. Nearly all of the nonstocked stands are young (less than 20 years old) (Fig. 18) and small-diameter stands are more likely to be overstocked than medium- or large-diameter stands (Fig. 19).

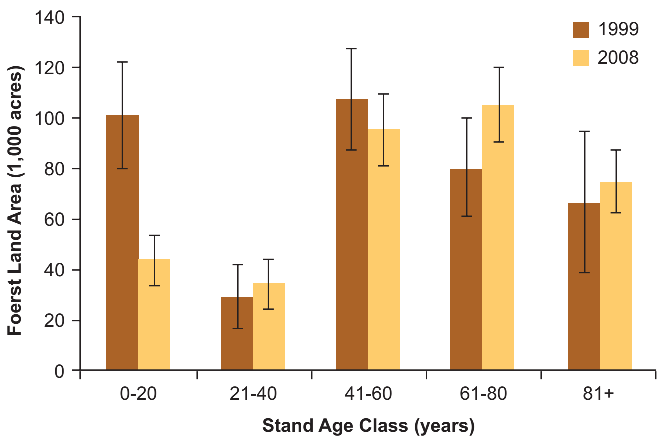


Figure 17.—Distribution of forest land by age class, Delaware, 1999 and 2008. Error bars show 68 percent confidence interval.

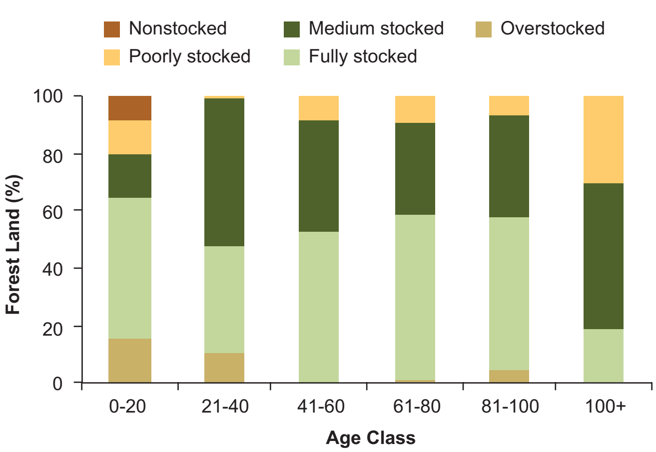


Figure 18.—Distribution of forest land (percent) by stocking class and age class, Delaware, 2008.

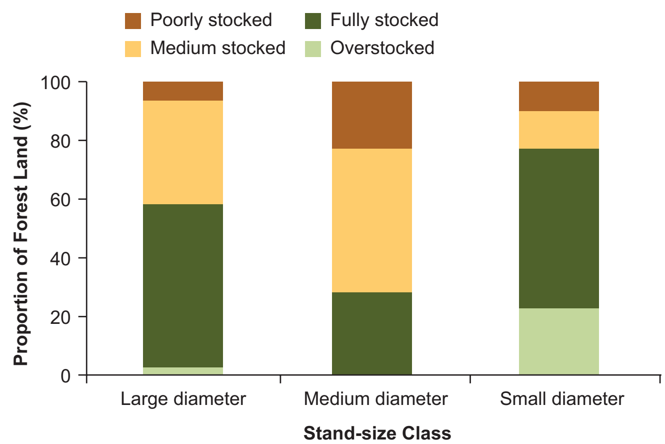


Figure 19.—Proportional distribution of forest area in stocking classes by diameter-size class, Delaware, 2008.

What this means

The forests of Delaware are maturing in terms of age and stand-size class distributions. At the same time, there has been a slight shift from forest land dominated by fully and overstocked stands to forest land dominated by medium stocked stands, reflecting the loss of area of young, small-diameter stands which tend to be dense and often overstocked. The data suggest that the amount of early successional habitat in Delaware may be decreasing. This will be discussed in more detail in the Forest Habitat section of this report.

Numbers of Trees

Background

Summaries of the number of trees by diameter class and species are useful to forest managers. Not only do they provide information on forest sustainability, but they also inform ecologists interested in topics such as species diversity indices. Changes in diameter distributions lead to changes in forest structure and composition as cohorts of similar-sized trees move through the successional process. If, for example, there are not an adequate number of small-diameter trees of a certain species, it is less likely that the species will play a prominent role in the future forest.

What we found

There are nearly 235 million live trees 1-inch or larger (d.b.h.) on Delaware's timberland, or an average of 681 trees per acre. The overall number of trees has not changed significantly since the last inventory; however, there are differences when comparing changes in numbers of trees by diameter class. The number of trees greater than 13 inches d.b.h. has increased significantly since 1986 while trees less than 11 inches d.b.h. appear to be decreasing in number (Figs. 20, 21). This trend of decreasing number of small-diameter class trees and increasing numbers of larger sized trees has been observed in each successive inventory since 1976.

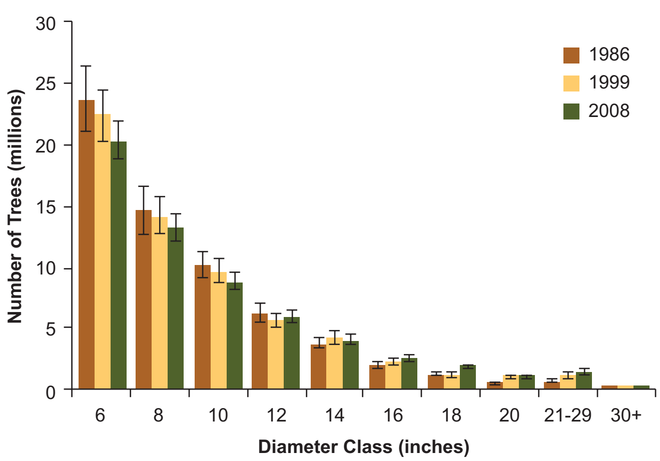


Figure 20.—Number of growing-stock trees on timberland by diameter class, Delaware, 1986, 1999, and 2008. Error bars show 68 percent confidence interval.

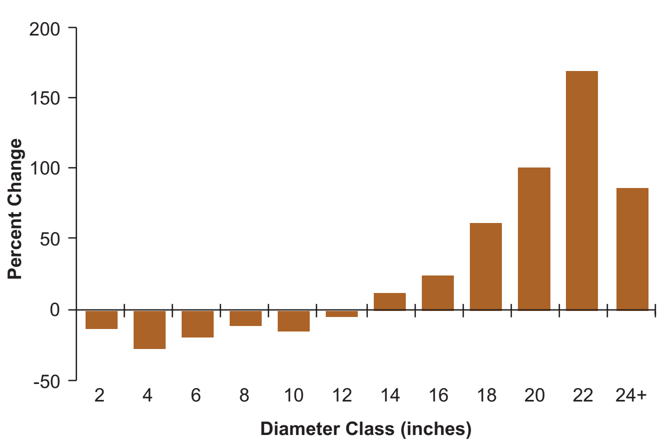


Figure 21.—Percent change in the numbers of growing-stock trees by diameter class, Delaware, 1999-2008.

There are 595,000 (173 trees per acre) live trees 5 inches d.b.h. or greater and 175 million saplings (508 trees per acre) on timberland in Delaware. Red maple (*Acer rubrum*) is the most common tree species in Delaware, accounting for 21 percent of all saplings and 22 percent of the live trees 5 inches and larger in d.b.h. (Fig. 22). When considering all live trees 1inch d.b.h. or larger, American holly (*Ilex opaca*) is the second most common tree in Delaware. This is due to the abundance of sapling-sized trees of this species (91 percent are less than 5 inches in diameter). Sweetgum (*Liquidambar styraciflua*) and blackgum (*Nyssa sylvatica*) are the third and fourth most common tree species. There is the same proportion of sweetgum among sapling-size trees as in trees 5 inches and greater (13 percent). Blackgum is more common among the sapling diameter size class (accounting for 10 percent of total live trees), than among live trees 5 inches and greater (comprising 6 percent of live trees). Loblolly pine is the fifth most common species with 4 percent of the saplings and 14 percent of live trees 5 inches and larger. Although the sampling errors are high when looking at tree data by species, there was a notable increase in the number of black cherry (*Prunus serotina*) trees greater than 5 inches d.b.h. in Delaware since 1999. Red maple, which

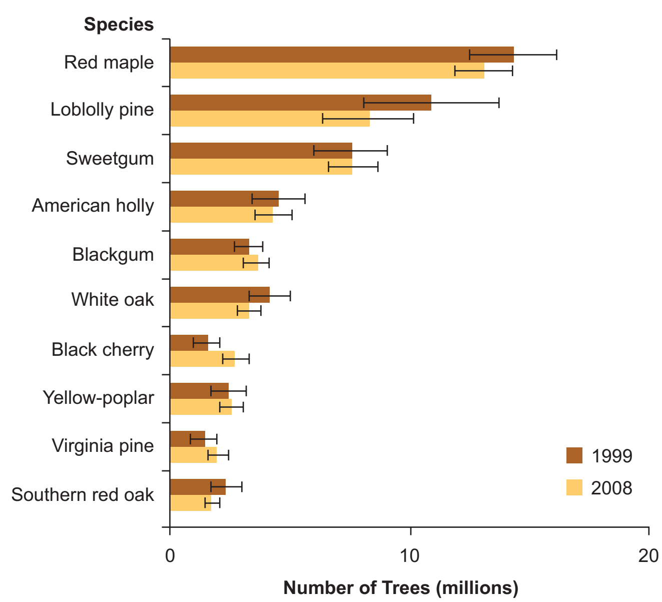


Figure 22.—Number live trees 5 inches d.b.h. and greater on timberland by species, Delaware, 1999 and 2008. Error bars show 68 percent confidence interval.

according to past inventories had been increasing in frequency in Delaware and in other areas of the country, has remained stable in terms of number of trees from 1999 to 2008.

What this means

A shift in the numbers of trees away from saplings toward trees within the larger diameter classes can be a result of several factors, including natural forest maturation in the absence of disturbance, the implementation of conservation practices aimed at protecting forests, changes in harvesting rates, predation of young trees by white-tailed deer (*Odocoileus virginianus*) and the conversion of early successional forests to nonforest land uses. The data suggest that the forests of Delaware are maturing. Changes in development patterns and conservation practices are playing strong roles in the maintenance of larger diameter stands. In the absence of either natural or anthropogenic stand replacing events, this trend of increase in the relative numbers of large-diameter trees will continue.

Species Composition and Distribution

Background

Forest species composition is the result of a number of processes: seed dispersal patterns, the distribution of microsites suitable for seed germination, soil nutrient and moisture status, competition between other plant species for light and resources, predation, and macro-scale environmental patterns such as climate and topography. Ecologists and forest managers are interested in species composition because of the effects it has on wildlife, forest productivity, timber values, and forest health characteristics. The relative volume of oaks has been in decline in many areas of the Northeast, and this is of particular concern because of their economic and wildlife values.

What we found

Red maple is by far the most abundant species in Delaware in terms of number of trees, and occurs in roughly the same proportion across all diameter classes (Fig. 23). Oak species dominate in the larger diameter classes and, although there are fewer yellow-poplar (*Liriodendron tulipifera*) trees, their diameter distribution is similar to that of the oak species, having a much higher proportion of large-diameter trees. Loblolly pine has relatively more middle-size trees than small- or large-diameter trees.

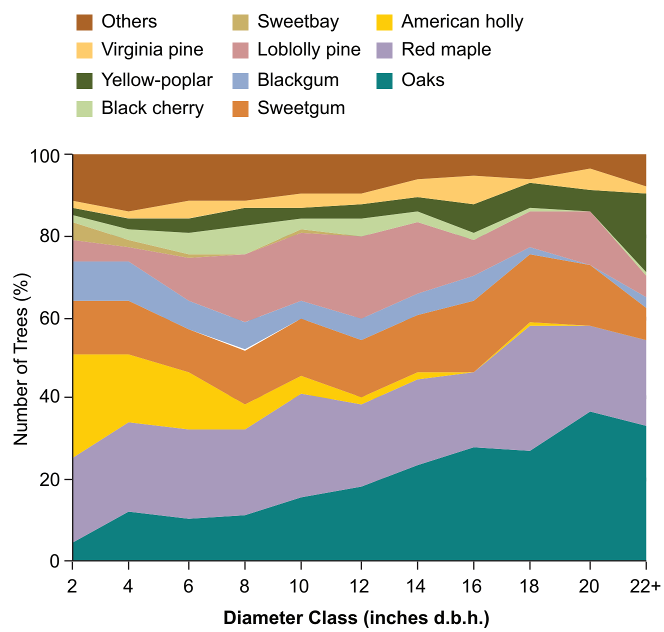


Figure 23.—Relative species abundance by diameter class, Delaware, 2008.

The relative frequency of several important tree species has changed over the years (Fig. 24). The most dramatic changes are in oak species and loblolly pine for which the relative abundance has been decreasing. The proportion of American beech (*Fagus grandifolia*) and yellow-poplar trees has increased since 1986, however, the 2008 estimates show relatively little change from 1999.

Loblolly pine and oak species also show declines in terms of overall number of trees (Fig. 25). There has been a steady decrease in numbers of loblolly pine trees in Delaware since 1986. Decreases occurred in all size classes with the most significant decreases observed in

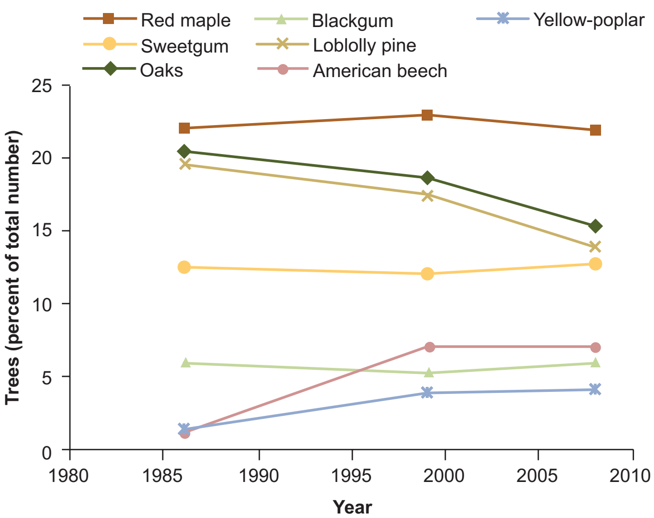


Figure 24.—Change in relative proportion of trees for select species and species groups in Delaware by inventory year.

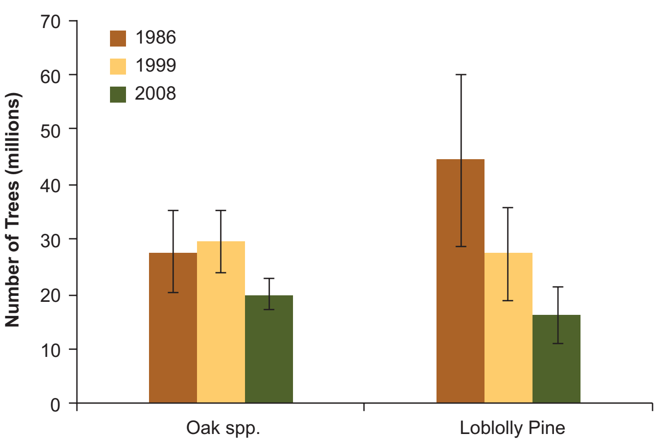


Figure 25.—Number of loblloly pine and oak species on timberland by inventory year, Delaware. Error bars show 68 percent confidence interval.

the 2- to 12-inch diameter classes. There has been a considerable decline in the number of oak trees between 1999 and 2008, with estimated decreases in all diameter classes less than 14 inches.

Distribution maps of the top six species are shown in Figure 26. Red maple is clearly a generalist, with relatively more basal area distributed throughout the forested parts of the state. The oak species, though not as widespread as red maple, appear to be generalists as well, with a relatively high likelihood of occurrence in the north and central regions of the state and a lower likelihood of occurrence in the south. In southern Sussex County, loblolly pine is a prominent species and associated species such as sweetgum and blackgum are also relatively dominant. Yellow-poplar is more prevalent in the northern part of New Castle County where there is a transition from low-lying coastal plain to eastern broadleaf forest.

What this means

Studying trends in the relative frequency or volume of tree species by diameter class can provide clues about the composition of the future forest. In Delaware, it appears that as large oaks are claimed by mortality or cutting, the gaps created will be susceptible to colonization by red maple, blackgum, and sweetgum, which comprise a relatively large proportion of trees in the small-diameter classes. Decreases in the abundance of oak species over time might be attributed to a combination of inadequate regeneration (due to predation by white-tailed deer, competition in the understory by shade-tolerant, generalist species, and lack of fire) and selective cutting of larger, more valuable trees.

Loblolly pine was once the most prevalent species in Delaware in terms of both volume and number of trees. Trends in forest inventory data indicate that around 1990, red maple surpassed loblolly pine in total volume. Decreasing abundance of loblolly pine is a major concern because it is an important commercial species.

Biomass of Live Trees and Forest Carbon

Background

Collectively, forest ecosystems represent the largest terrestrial carbon sink on earth. The accumulation of carbon in forest biomass through sequestration helps to mitigate emissions of carbon dioxide to the atmosphere from sources such as forest fires and burning of fossil fuels.

Projection: Delaware State Plane, NAD83.
Sources: FIA 2008, TIGER/Dynamap 2000. Geographic base data are provided by the National Atlas of the USA. FIA data and tools are available online at http://www.fia.fs.fed.us/tools-data/
Cartography: D. Griffith. May 2011

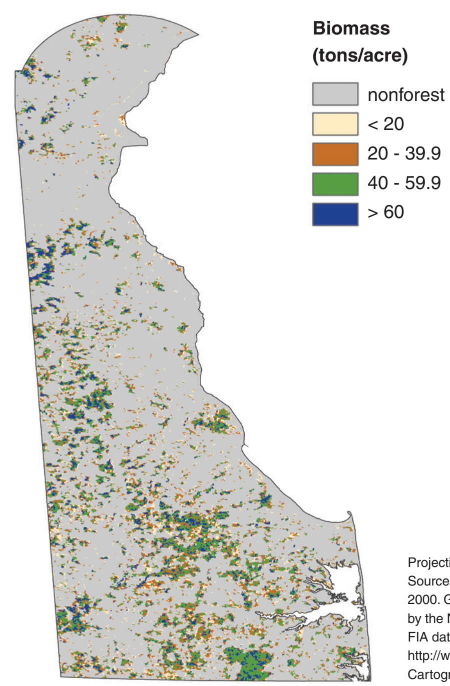
Figure 26.—Species distribution of common trees in terms of basal area (ft^2/acre), Delaware, 2008.

Total aboveground tree biomass is calculated as the sum of the weights of different components of the tree: the bole, stump, top, and limbs. Biomass is a measure of dominance similar to tree volume and is sometimes used as an index of ecological importance. In particular, biomass is of interest to scientists and policy makers who wish to characterize the local, regional, and global carbon cycle and its effect on climate change. Since the FIA program does not directly measure forest biomass, it is estimated using mathematical models as described by Smith et al. (2006). The carbon content of wood and bark is approximately 50 percent of dry biomass, so live tree carbon estimates are thus derived by dividing the dry biomass weight in half. Other components of forest carbon are also described in Smith et al. (2006).

What we found

Aboveground tree biomass is distributed in fragmented patches across Delaware (Fig. 27). Many of the smaller, linear patches are riparian forests bordering streams and wetlands. The patches of greatest tree biomass are contained within some of the State's Forest Legacy areas,

Aboveground biomass



Projection: Delaware State Plane, NAD83.
Sources: FIA 2008, TIGER/Dynamap 2000. Geographic base data are provided by the National Atlas of the USA.
FIA data and tools are available online at http://www.fia.fs.fed.us/tools-data/
Cartography: D. Griffith. May 2011

Figure 27.—Distribution of aboveground live biomass in Delaware, 2008.

which are areas that are protected from development due to a land purchase or conservation easement. Aboveground tree biomass is greatest in the Redden/Ellendale legacy area in central Sussex County and the Cypress Swamp legacy area in southern Delaware.

Delaware's forests currently contain almost 29 million tons of carbon. Live trees and saplings represent the largest forest ecosystem carbon stock in the State at more than 14 million tons, followed by soil organic matter (SOM) at nearly 11 million tons (Fig. 28). Within the live tree and sapling pool, merchantable boles contain the bulk of the carbon (8.6 million tons) followed by roots (2.3 million tons) and tops and limbs (2.0 million tons).

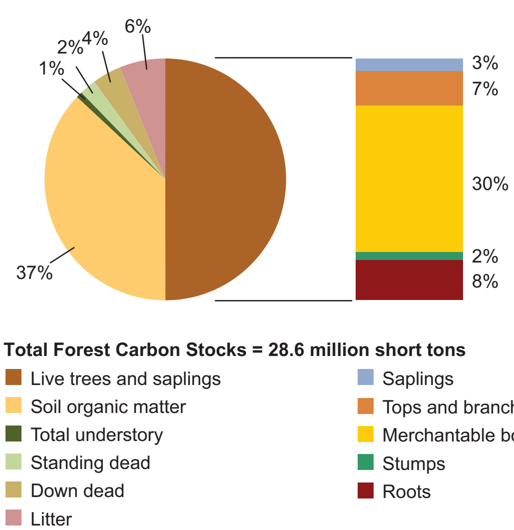


Figure 28.—Estimated carbon stocks on forest land by forest ecosystem component, Delaware, 2008.

A more detailed breakdown of the aboveground biomass distribution of the live trees and saplings in Delaware is given in Figure 29. There is much more hardwood biomass than softwood biomass across all diameter classes in Delaware (Fig. 30).

The majority of Delaware's forest carbon stocks are found in medium-aged stands 41 to 100 years old (Fig. 31). Early in stand development, most of forest ecosystem carbon is in the SOM and belowground tree components. As forest stands mature, the ratio of aboveground to belowground carbon shifts and by age

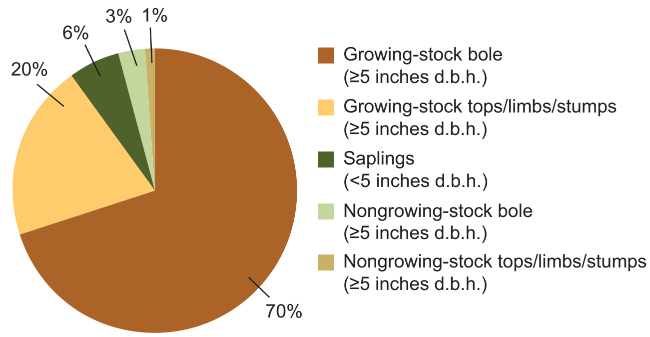


Figure 29.—Percentage of live-tree biomass (trees 1 inch d.b.h. and larger) on forest land by aboveground component, Delaware, 2008.

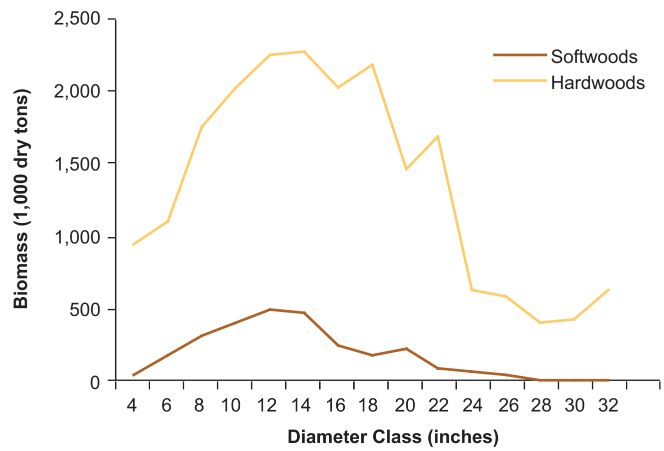


Figure 30.—Live-tree biomass (trees 1 inch d.b.h. and larger) on timberland by species group and diameter class, Delaware, 2008.

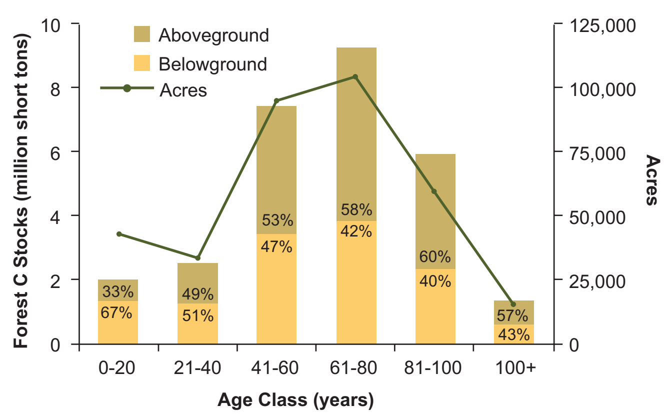


Figure 31.—Above- and belowground carbon stocks on forest land by stand age class, Delaware, 2008.

41 to 60 years, the aboveground components represent the majority of ecosystem carbon. This trend continues well into stand development as carbon accumulates in live and dead aboveground components.

A look at carbon by forest-type group on a per-unit-area basis found that five of the eight types have between 78-102 tons of carbon per acre (Fig. 32). Despite the similarity in per-acre estimates, the distribution of forest carbon stocks by forest type is quite variable. In the oak/hickory group, for example, 58 percent (46 tons) of the forest carbon is in live biomass, whereas in the maple/beech/birch group, only 29 percent is in live biomass.

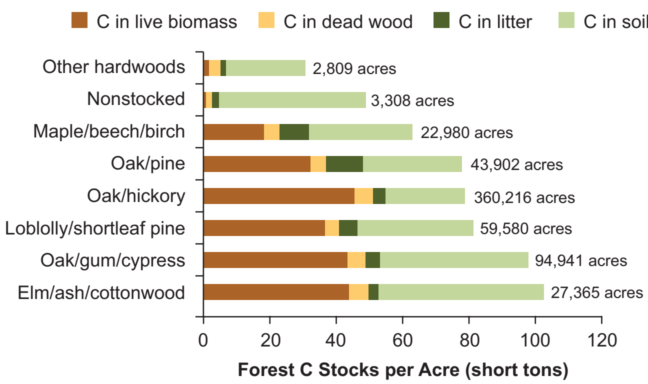


Figure 32.—Carbon stocks on forest land by forest-type group and carbon pool per acre, Delaware, 2008.

What this means

Carbon stocks in Delaware's forests have increased substantially over the last several decades. Most forest carbon in the State is found in medium-aged stands dominated by relatively long-lived species. This suggests that Delaware's forest carbon will continue to increase as stands mature and accumulate carbon in above- and belowground components. Biomass carbon accumulation has implications for acquiring carbon credits through the framework established by the Regional Greenhouse Gas Initiative (of which Delaware is a member), climate change research, and biofuel and other wood product development potential.

Volume of Growing-stock Trees

Background

Growing-stock volume is the amount of sound wood in live, commercially valuable trees. It is a measure of wood that could be put to commercial use and thus gives an indication of potential financial value. Forest owners and managers need to understand the potential value of forests when evaluating management plans and inventory results with respect to economic implications.

What we found

Ninety-seven percent of the live volume in Delaware is in growing-stock trees, which are trees with good form and the species that are commercially important. The remaining volume is in cull trees, classified as either rough (3 percent) or rotten (<1 percent) (Fig. 33). The volume of growing-stock trees in Delaware is 810 million cubic feet, or 2,352 cubic feet per acre. Volume has increased by 17 percent since 1999. This is an estimated annual increase of 1.8 percent per year, which is more than the rate of increase experienced from 1972 to 1986 (0.6 percent per year). Hardwood species dominate, accounting for 85 percent of the total growing-stock volume in Delaware and are also responsible for the overall growing-stock increases as softwood volume has remained relatively constant for the past 30 years (Fig. 34).

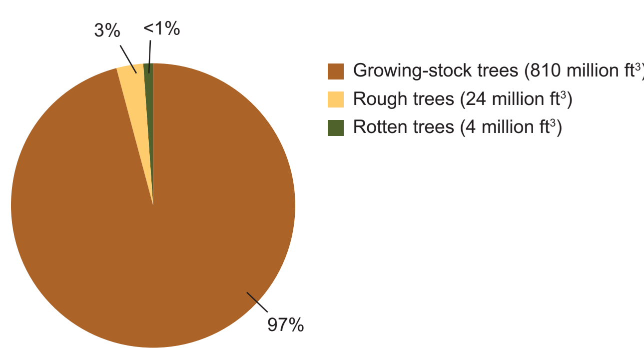


Figure 33.—Percent volume by tree condition, Delaware, 2008.

Figure 34.—Growing-stock volume on timberland by species group and inventory year, Delaware. Error bars show 68 percent confidence interval.

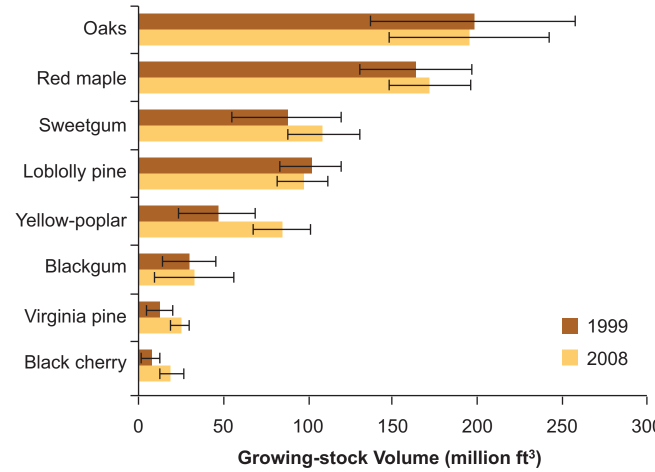


Figure 36.—Growing-stock volume on timberland by species, Delaware, 1999 and 2008. Error bars show 68 percent confidence interval.

Since 1976, there has been a shift in growing-stock volume toward larger trees (Fig. 35). Substantial increases have occurred in the 14- to 32-inch diameter classes. From 1986 to 1999, the growing-stock volume in these diameter classes increased by 34 percent; from 1999 to 2008, there was a 30 percent increase. These changes are consistent with changes in the number of trees by diameter class discussed in the section "Number of Trees".

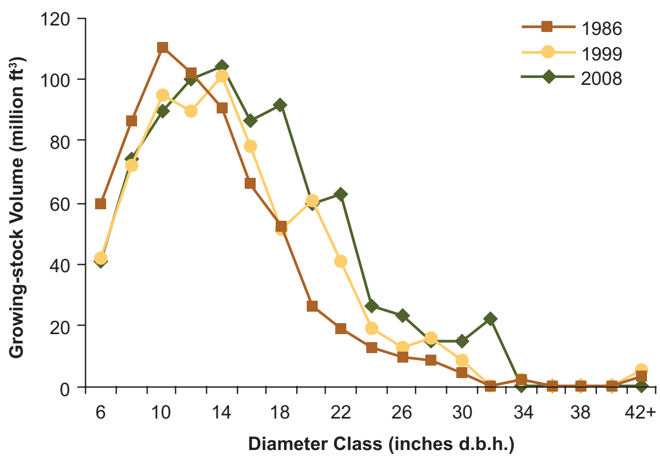


Figure 35.—Growing-stock volume on timberland by diameter class and inventory year, Delaware.

When all oak species are combined into one class, it is the leading species group in growing-stock volume, with 195 million cubic feet, or 24 percent of the total. Red maple accounts for 21 percent of the total volume, or 172 million cubic feet, sweetgum accounts for 109 million cubic feet and loblolly pine ranks fourth with 12 percent (97 million cubic feet) of the total (Fig. 36).

What this means

The total volume of hardwood trees in Delaware's forests has increased steadily since 1976, while that of softwoods has remained relatively steady. Total softwood volume, which consists mostly of loblolly pine, is holding constant due to the combination of timber management strategies, forest loss to development, and increases in volume. The stability of softwood volume through time could be perturbed, however, with unsustainable forest management or increasing forest loss.

An examination of the shift in volume by diameter class from one time period to another reveals that Delaware's forests are maturing. In general, relatively more volume is accumulating in the larger diameter classes. Hardwood sawtimber-size trees (those greater than 11 inches in d.b.h.) are generally found in the canopy and contain most of the volume. Although volume changes at the species level are not significant, there have been some changes in the relative abundance in terms of growing-stock volume. Yellow-poplar is increasing in relative volume, mostly in the canopy stratum due to its competitive advantage and its frequency in the population within the larger diameter (and volume) size classes. Oak species and loblolly pine have decreased in relative volume. Changes in species composition may lead to changes in the value of Delaware's forests for wildlife and for the production of timber products.

Management of species composition can have an impact on the value of the future forest as Delaware's forests continue to mature and the next generation of trees develops in the understory.

Sawtimber Quality and Volume

Background

The amount and quality of merchantable sawtimber in the State has a far-reaching impact on the economics of the State's forest industry. To understand sawtimber quality in Delaware, FIA generates estimates of total volume by tree grade, which is an index of wood quality. Tree grade depends upon the species, the amounts of knot-free bole and cull, tree form, and tree diameter, and is typically used to help assess the potential value of the sawtimber resource. Trees of grades 1 or 2 yield the highest quality wood for lumber. High quality timber is typically used for making cabinets, furniture, flooring, or other millwork, while lower quality timber is used for pallets, pulpwood, or fuelwood.

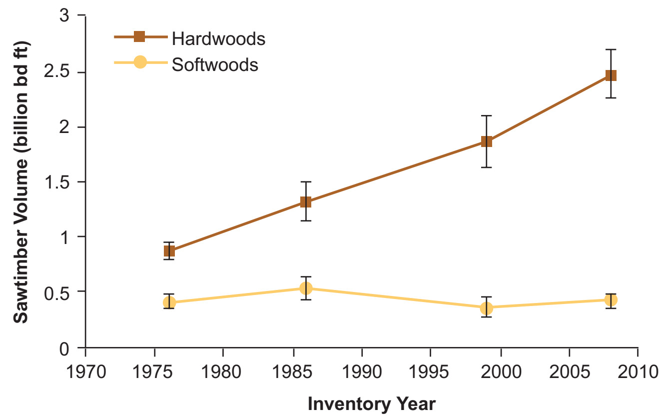


Figure 37.—Sawtimber volume on timberland by species group and inventory year, Delaware. Error bars show 68 percent confidence interval.

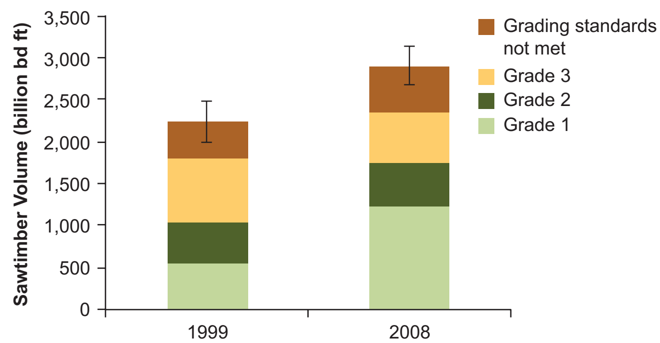


Figure 38.—Sawtimber volume on timberland by tree grade, Delaware, 1999 and 2008. Error bars show 68 percent confidence interval.

What we found

There are 2.9 billion board feet of sawtimber in Delaware, or an average of 8,416 board feet per acre. Sawtimber volume has increased by nearly 30 percent since 1999, a greater increase than was estimated between 1986 and 1999 (20 percent). Hardwood species comprise the majority of the sawtimber volume and also account for its increase (Fig. 37). Figure 38 shows the breakdown of sawtimber volume by tree grade. In Delaware, 60 percent of the current sawtimber volume is in grades 1 or 2. The board foot volume in grades 2 and 3 has changed very little since 1999, however, the volume of the highest quality, grade 1, increased.

Sawtimber volume is greatest for all oak species combined with 814 million board feet, or 28 percent of the total sawtimber volume, a 4 percent decrease since 1999 (Fig. 39). Figure 40 shows the percent of sawtimber volume by tree grade for select tree species. In Delaware, loblolly pine has the largest volume in tree grades 1 and 2, followed by yellow-poplar and oak species. These species, as well as sweetgum, have at least half of their sawtimber volume in tree grade 2 or better. Of the other major species in the State, American beech had no sawtimber volume in grades 1 or 2, and black cherry, red maple, and Virginia pine (*Pinus virginiana*) each had less than half their sawtimber volumes in grades 1 or 2 (26, 34, and 40 percent, respectively). Many beech trees in Delaware are degraded because of large amounts of rotten wood. Red maple is graded lower than other species because it typically has more defects and smaller diameters. Beech and red maple also do not self prune as well as other species such as yellow-poplar which can result in poor form and decreased value.

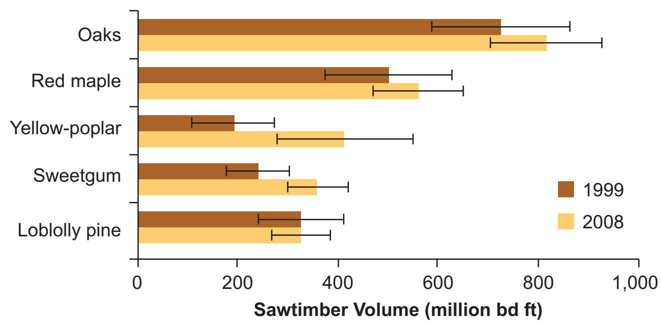


Figure 39.—Volume of sawtimber on timberland for major species, Delaware 1999 and 2008. Error bars show 68 percent confidence interval.

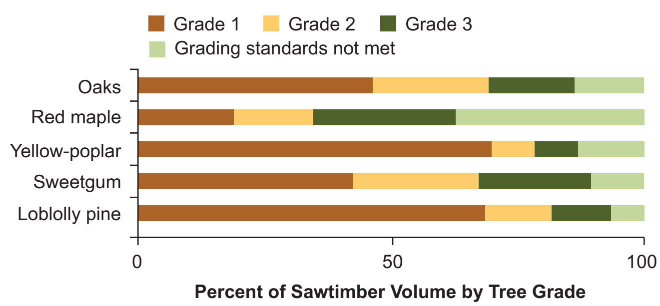


Figure 40.—Percentage of sawtimber volume on timberland by tree grade for select tree species, Delaware, 2008.

What this means

Since tree diameter is one of the factors influencing tree grade, the maturing of Delaware's forests has led to a simultaneous increase in tree grades and thus potential value. The yellow-poplar resource is increasing in grade and volume at a higher rate than other species due to its rapid growth rate and straight form, especially for trees that have reached codominant status. Softwood sawtimber volume, most of which is loblolly pine, has stayed relatively flat since 1976. This is due in part to several factors: forest loss in areas where loblolly pine dominates, increase in volume in large-diameter classes, and timber management practices that promote sustainable harvests. Changes in species distribution and tree grade of sawtimber-sized trees will affect the economics of the forest industry in Delaware.

Growth, Removals, and Mortality

Background

The concept of forest sustainability has many parts: the maintenance of forest cover, ecological and economic value, and forest productivity. One way to understand the status of forest sustainability is to look at the components of volume change: growth, removals, and mortality. Growth is the net increase in volume over a specific time period. Removals include harvested trees, trees on timberland that have been reclassified to reserved forest land (e.g., by the establishment of a protected area), or trees on forest land lost to a nonforest landuse. Mortality is the loss of live volume that occurs when a tree dies due to natural causes. Growth, removals, and mortality data are collected on each remeasured tree in each inventory cycle, so trends in these metrics can be calculated over time.

What we found

In Delaware, tree growth exceeds losses from mortality and removals. Figure 41 shows the components of annual volume change. The average annual net growth of growing stock on timberland is 36 million cubic feet, or 91 cubic feet per acre per year. Losses due to mortality average 5 million cubic feet annually, and removals averaged 7 million cubic feet per year. These components

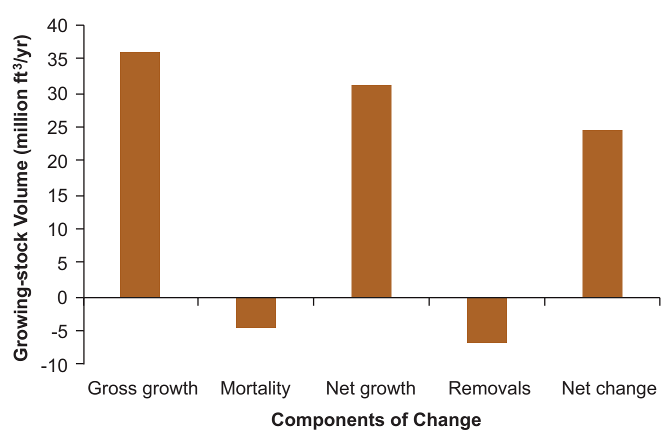


Figure 41.—Average annual components of change in growing-stock volume, Delaware, 1999-2008.

resulted in an annual net gain of 24 million cubic feet. Removals include tree volume that was harvested, but will likely remain in forest (85 percent) and tree volume lost due to a change to nonforest use (15 percent).

Figure 42 shows how growth (as a percentage of total growing-stock volume) increased from 2.3 to 3.9 percent between 1999 and 2008, while removals decreased and mortality changed little. The overall growth-to-removals ratio (G:R) increased from 1.1 in 1999 to 4.5 in 2008. Red maple has one of the highest G:R at 25.3 (Fig. 43). Loblolly pine, the species with the second highest growth rate (and representing 60 percent of all removals), has a G:R of only 1.4, indicating that the population is relatively stable. Oaks as a group, which represent 18 percent of all removals, has a G:R of 4.8.

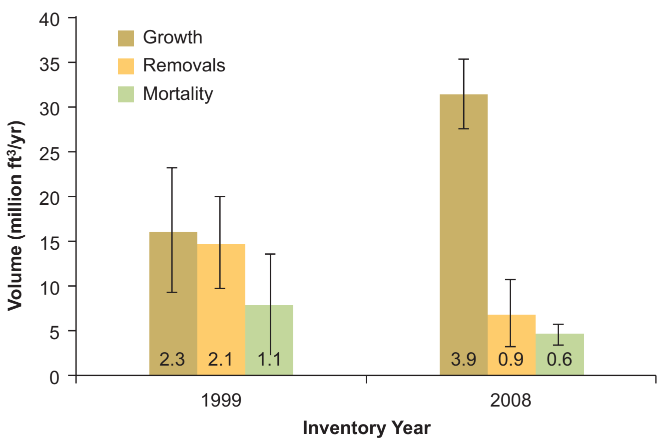


Figure 42.—Annual net growth, removals, and mortality on timberland and as a proportion of total growing-stock volume, Delaware, 1999, and 2008. Error bars show 68 percent confidence interval.

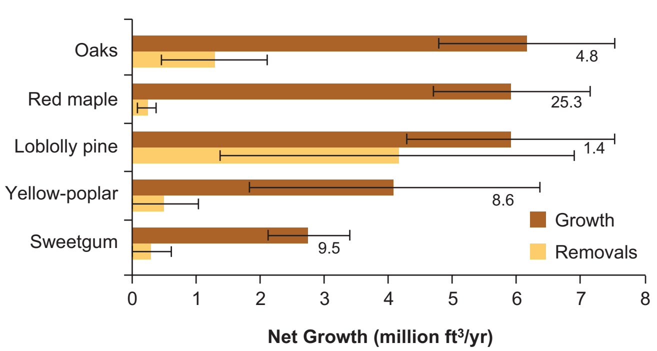


Figure 43.—Average annual net growth and removals for major species, Delaware, 1999-2008. Number at end of bar pair indicates growth-to-removal ratios. Error bars show 68 percent confidence interval.

What this means

The annual net growth of Delaware's forests increased since the last inventory due, in part, to the impressive growth of loblolly pine, which is an important commercial species in Delaware. A useful metric for comparing growth rates among species is growth relative to the total volume of the species. Loblolly pine had the highest rate of growth relative to growing-stock volume (6.1), followed by yellow-poplar (4.8) and red maple (3.4).

The G:R ratio is high for most species in Delaware, indicating that tree growth is far exceeding removals. Harvest activities in the State are dominated by loblolly pine removals. The current inventory results indicate that Delaware's loblolly pine resource is being harvested at a sustainable rate.

Mortality

Background

The loss of tree volume to mortality is a natural process. Excessive mortality, however, can be an indicator of poor forest health and can be caused by insects, disease, animals, competing vegetation, weather events, old age, or a combination of these factors. In very dense stands, trees die due to competition for resources. In open, sparse stands, trees might be more susceptible to extremes in wind and precipitation, or prone to damage by animals. In addition to per-species diameter class and volume distributions, per-species mortality estimates can provide a clue to the composition of the future forest.

What we found

In Delaware, the average annual mortality for the current inventory was 4.5 million cubic feet, or 13 cubic feet per acre per year (Fig. 44). Data suggest that mortality has decreased since the 1999 inventory and is now only 0.6 percent of the total growing-stock volume.

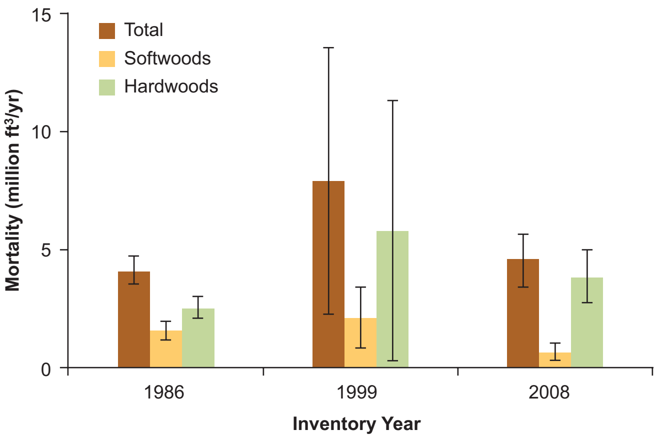


Figure 44.—Average annual mortality on timberland by species group and inventory year, Delaware, 1986, 1999, and 2008. Error bars show 68 percent confidence interval.

Softwood mortality relative to the total amount of softwood growing-stock volume is similar to relative hardwood mortality.

Of the dominant species, oaks and yellow-poplar were the species with the greatest mortality in 2008, (1.5 and 0.9 million cubic feet, respectively) (Fig. 45). The only dominant species that showed significant changes in mortality between 1999 and 2008 were yellow-poplar and loblolly pine. Yellow-poplar increased from nearly zero mortality and loblolly pine mortality decreased during this time period. Of the five most dominant species, yellow-poplar showed the largest mortality relative to growing-stock volume (relative mortality) (1.1 percent) followed by oak species combined (0.8 percent), both of which were greater than the average relative mortality for all species combined (0.7 percent) (Fig. 46).

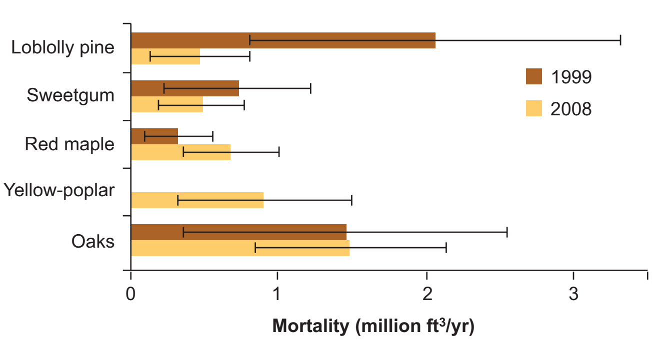


Figure 45.—Average annual mortality for major species, Delaware 1999 and 2008. Error bars show 68 percent confidence interval.

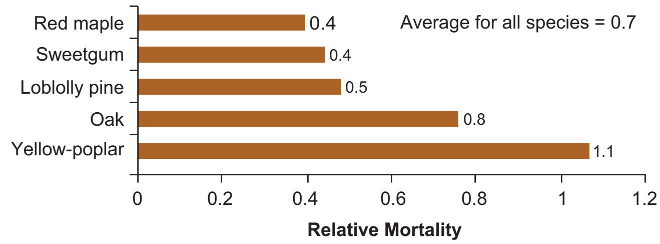


Figure 46.—Relative mortality for major species, Delaware, 1999 and 2008.

What this means

Mortality levels of Delaware's trees do not indicate any dramatic deviations from that expected from natural processes such as succession, periodic loss of vigor and death from insect or physical damage, or competition with other individuals for resources. The higher relative level of mortality of yellow-poplar and oak species is not surprising. Yellow-poplar is susceptible to physical damage such as weather events; once this damage occurs, the trees becomes more vulnerable to insect or other disease attack, loss of vigor, and death. With respect to the oaks, their distribution tends toward the large diameter classes. Collectively, these larger, more mature trees might be reaching the end of their natural life span and are becoming more susceptible to the aforementioned damaging agents. As insect and disease threats emerge, managers should continue to monitor mortality rates of susceptible species.

Timber Products Output

Background

The harvesting and processing of timber products produces a stream of income shared by timber owners, managers, foresters, loggers, truckers, and processors. The wood products and paper manufacturing industries in Delaware employ more than 1,000 people, with an average annual payroll of more than $17 million (U.S. Census 2007). To properly manage the State's forests, it is important to know the species, amounts, and locations of timber being harvested.

What we found

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 the most recent surveys conducted in surrounding states that processed wood harvested from Delaware. In 2005, four active primary wood-processing mills were surveyed to determine the species that were processed and where the wood material came from. These mills processed over 3.4 million board feet.

A total of 8.8 million cubic feet of industrial roundwood was harvested from Delaware in 2005. Pulpwood accounted for 54 percent of the total industrial roundwood harvested, and saw logs for 46 percent (Fig. 47). All of the timber harvested for pulpwood is shipped to mills in other states. Loblolly pine accounted for 72 percent of the total industrial roundwood harvest. Other important species harvested were Virginia pine, yellow-poplar, white oaks, red oaks, red maple, and sweetgum (Fig. 48). An additional 392,000 cubic feet of wood was harvested for residential fuelwood.

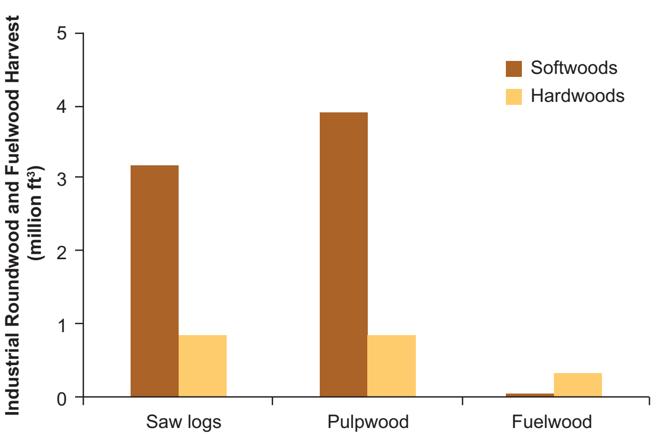


Figure 47.—Industrial roundwood and fuelwood production by product, Delaware, 2008.

In the process of harvesting industrial roundwood, 3.8 million cubic feet of logging residues were left on the ground (Fig. 49). More than 85 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 1.4 million cubic feet (21,500 dry tons) of wood and bark residues (Fig. 50). Eighty-eight percent of the mill residues were used for miscellaneous products such as animal bedding and mulch. The remainder was used for industrial and residential fuelwood.

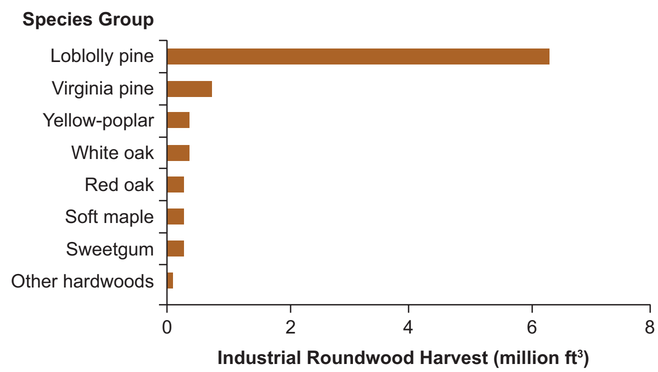


Figure 48.—Industrial roundwood harvested by species group, Delaware, 2008.

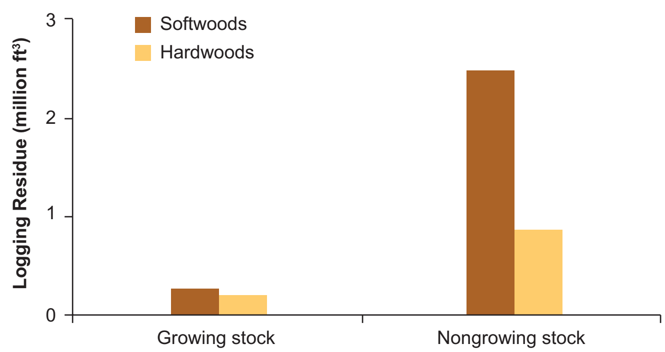


Figure 49.—Logging residue by species group and for growing-stock and nongrowing-stock trees, Delaware, 2008.

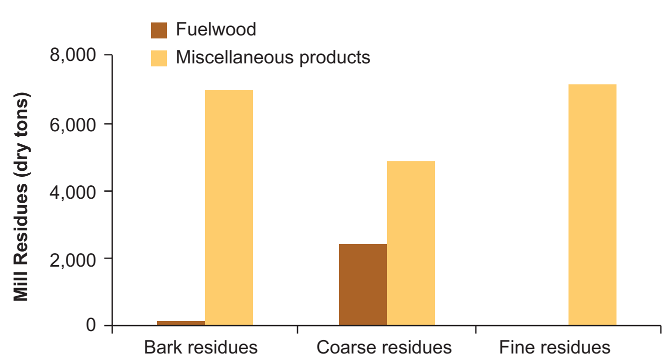


Figure 50.—Disposition of mill residues generated by primary wood-using mills, Delaware, 2008.

What this means

All of the wood-processing facilities in Delaware were sawmills processing primarily saw logs grown in the State, but Delaware sawmills only process about 6 percent of the industrial roundwood that is harvested from the State. Pulp mills in other states receive more than half of the total industrial roundwood harvested in Delaware. Saw mills 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 demand 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.

Another important issue is the volume of harvest residues that are generated in the State that go unused. Almost 15 percent of the harvest residue is from growing-stock sources that could be used to produce products. Improved pulpwood markets could lead to better utilization of merchantable trees. The use of logging slash and mill residues for industrial fuelwood at cogeneration facilities and pellet mills could also result in better utilization of the forest resource.

Forest Health

Down woody material. Photo by Tonya Lister.

Young Forest Habitat

Background

Forests provide habitat for numerous species of mammals, birds, reptiles, and amphibians, as well as for fish, invertebrates, and plants. Several indicators of wildlife habitat abundance can be derived from FIA data. Forest composition and structure affect the suitability of habitat for each species. Some species depend upon early successional forests or the ecotone (edge) between different forest stages. Yet other species require old growth forests or interior forests. Many species require multiple structural stages of forests to meet different phases of their life history needs. Abundance and trends in these structural and successional stages serve as indicators of population carrying capacity for wildlife species (Hunter et al. 2001).

Delaware developed a State Wildlife Action Plan (SWAP) (Allen et al. 2006) that identifies species of greatest conservation need (SGCN), and threats to their habitats. Example SGCN species for forest habitats of conservation concern include American woodcock (*Scolopax minor*)—early successional upland habitats; Delmarva fox squirrel (*Sciurus niger cinereus*)—coastal plain upland forests; and broad-winged hawk (*Buteo platypterus*)—coastal plain forested floodplains and riparian swamps. And, because of their importance to area-sensitive species, large blocks of unfragmented forests are considered to provide key wildlife habitat for forest interior-dwelling birds such as cerulean warbler (*Dendroica cerulean*), Northern parula (*Parula americana*), and black-and-white warbler (*Mniotilta varia*). Forest characteristics related to fragmentation and patch size are discussed in the section "Urbanization and Fragmentation."

What we found

Area of the small-diameter stand-size class on timberland in Delaware decreased from 18 percent in 1986 to 11 percent in the current inventory (Fig. 51). Concurrently, the distribution of the large-diameter stand-size class increased steadily from 62 percent to 74 percent, with medium-diameter class decreasing from 20 to 15 percent. Twelve percent of all Delaware forest land is age 20 years or younger, 74 percent is between 41 and 100 years of age. Only 4 percent is older than 100 years, with almost none older than 150 years. Small-diameter stand-size class predominates in forests of 0 to 20 years and large-diameter predominates in forests over 60 years of age (Fig. 52).

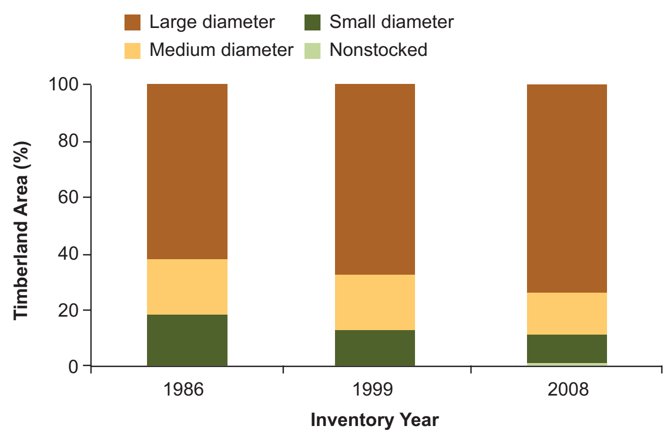


Figure 51.—Percent of forest land area by stand-size class and inventory year, Delaware.

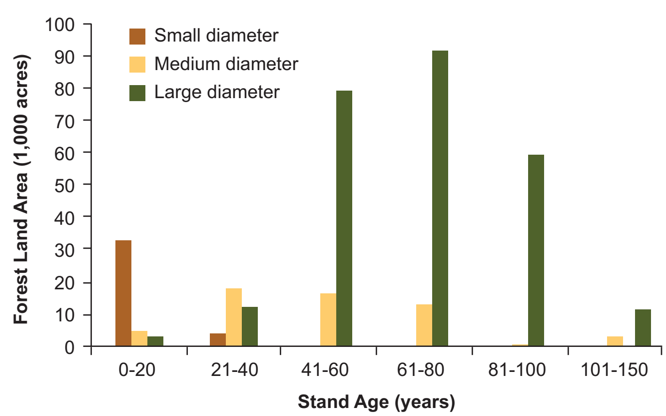


Figure 52.—Area of forest land by age class and stand-size class, Delaware, 2008.

What this means

Decreasing abundance of both small- and medium-diameter stand-size classes is offset by increasing abundance in the large-diameter class. However, 95 percent of forest in the large-diameter class is less than 100 years of age. Although both stand-size class and stand-age class provide indicators of forest successional and structural stage, the two attributes are not exactly interchangeable and are best viewed in combination. There is a need to monitor and maintain forest conditions in multiple stand-size and stand-age classes, including both early (young) and late (old) successional stages to provide habitats for all forest-associated species.

Standing Dead Trees

Background

Specific features such as nesting cavities and standing dead trees (at least 5 inches d.b.h.) provide critical habitat components for many forest-associated wildlife species, including red-headed woodpecker (*Melanerpes erythrocephalus*), a Deleware SGCN. Standing dead trees contain significantly more cavities than live trees (Fan et al. 2003). Standing dead trees that are large enough to meet habitat requirements for wildlife are referred to as 'snags'. Standing dead trees serve as important indicators not only of wildlife habitat, but also for past mortality events and carbon storage. And, they serve as sources of down woody material (discussed in the "Down Woody Material" section), 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 forests.

What we found

Between 2004 and 2008, FIA collected data on standing dead trees of numerous species and sizes in varying stages of decay. According to the current inventory data, almost 6 million standing dead trees are present on Delaware's forest land. This represents an overall density of 16.3 standing dead trees per acre of forest land. Loblolly and shortleaf pine, soft maple, other yellow pines, and other eastern soft hardwoods species groups each contained more than half a million standing dead trees (Fig. 53). Four species groups exceeded 5 standing dead trees per 100 live trees of the same species group: other yellow pines (11.8), cottonwood and aspen (11.6), select white oaks (6.8), and loblolly and shortleaf pine (6.6) (Fig. 54). Across Delaware, more than 79 percent of standing dead trees were smaller than 11 inches d.b.h., with 45 percent between 5 and 6.9 inches d.b.h. (Fig. 55). Decay class 5 (most decay) had the fewest number of standing dead trees across almost all diameter classes (Fig. 55).

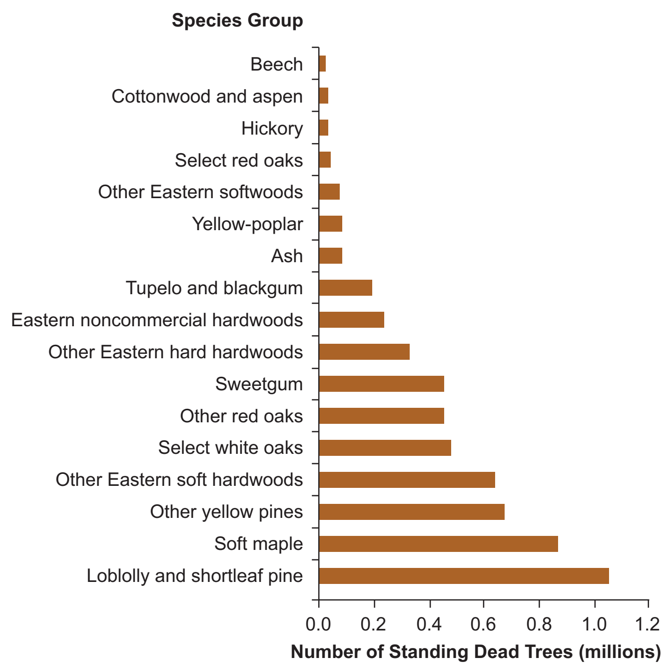


Figure 53.—Number of standing dead trees by species group Delaware, 2008.

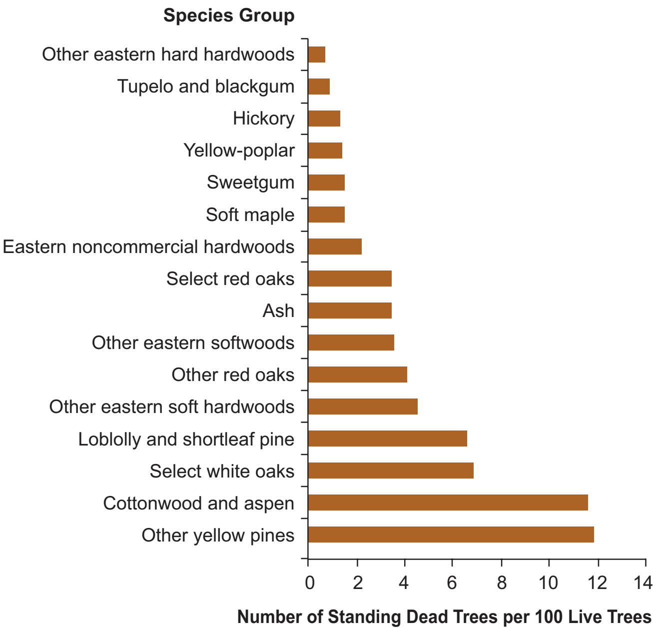


Figure 54.—Number of standing dead trees per 100 live trees by species group, Delaware, 2008.

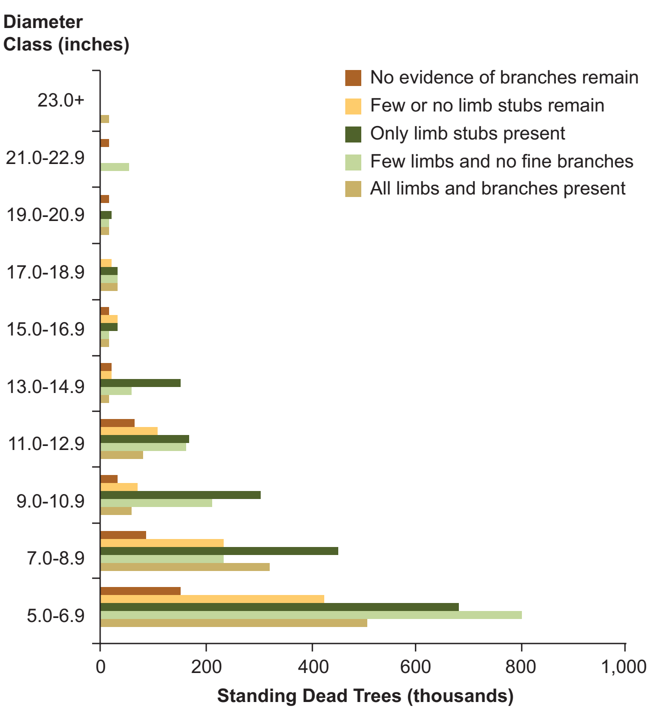


Figure 55.—Number of standing dead trees by decay and diameter class, Delaware, 2008.

What this means

Standing dead trees result from a variety of potential causes, including diseases and insects, weather damage, fire, flooding, drought, competition, and other factors. Loblolly and shortleaf pine, and soft maple species groups contained the largest total number of standing dead trees, comprised entirely of loblolly pine and red maple tree species, respectively. Standing dead trees provide areas 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. The state endangered red-headed woodpecker is an SGCN that excavates nesting cavities in snags. Most cavity nesting birds are insectivores and help to control insect populations. Providing a variety of forest structural stages and retaining specific features like snags are ways that forest managers maintain the abundance and quality of habitat for forest-associated wildlife species.

Down Woody Materials

Background

Down woody materials, in the form of fallen trees and branches, fulfill a critical ecological niche in Delaware's forests. Down woody materials provide both valuable wildlife habitat in the form of coarse woody debris and contribute towards forest fire hazards via surface woody fuels. Since dried wood is a greater fire hazard risk, one way to determine down woody material's fire hazard potential is to classify it by the amount of time it take for the material to dry out. These classes are called time-lag fuel classes.

Larger coarse woody debris takes longer to dry out than smaller fine woody pieces. For example, time-lag fuel classes for small fine woody debris equal 1 hour, medium woody debris equal10 hours, large fine woody debris equal 100 hours, and coarse woody debris equal 1,000+ hours (Woodall and Monleon 2008).

What we found

The fuel loadings of down woody materials (time-lag fuel classes) are not exceedingly high in Delaware (Fig. 56). When compared to the neighboring states of New Jersey and Maryland, Delaware's fuel loadings of all time-lag fuel classes are not substantially different. The size-class distribution of coarse woody debris appears to be heavily skewed (82 percent) toward pieces less than 8 inches in diameter at point of intersection with plot sampling transects (Fig. 57A). With regard to decay class distribution of coarse woody debris, there appears to be a fairly uniform distribution of stages of coarse woody decay across the State, except for decay class 3 and 4 logs (71 percent) (Fig. 57B). Decay classes 3 and 4 coarse woody pieces are typified by moderate- to heavily decayed logs that are sometimes structurally sound but missing most/all of their bark with extensive sapwood decay. There is no strong trend in coarse woody debris volumes per acre among classes of live tree density (basal area/acre); however, forests with the lowest amounts of coarse woody debris volume (approximately 100 cubic feet/acre) also had the lowest live tree basal area (Fig. 58).

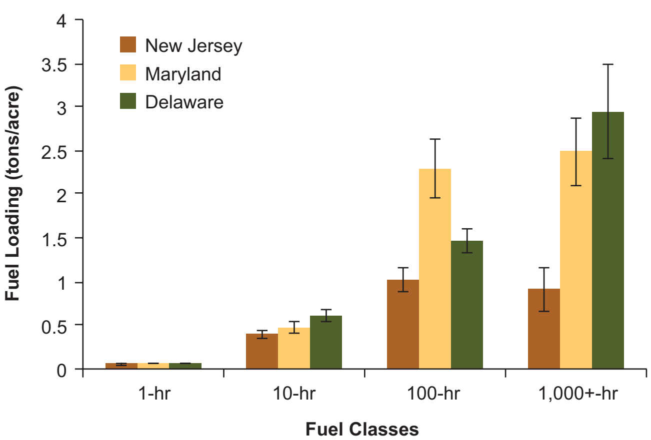


Figure 56.—Average fuel loadings by fuel class on forest land in Delaware and neighboring states, 2008. Error bars show 68 percent confidence interval.

Figure 57.—Percent of coarse woody debris by woody diameter (A) and decay classes (B) on forest land in Delaware, 2008.

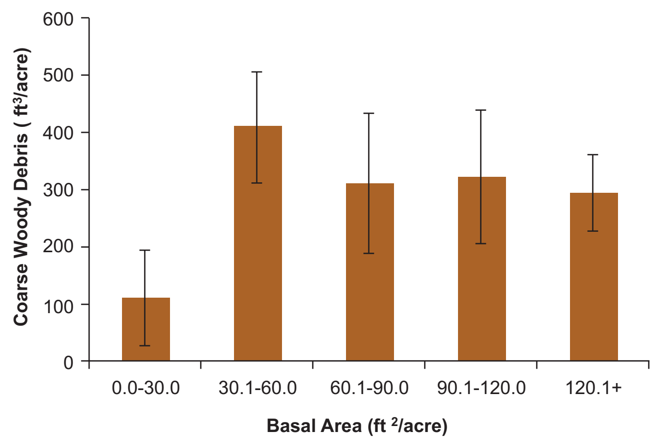


Figure 58.—Average coarse woody debris volume on forest land in Delaware, 2008. Error bars show 68 percent confidence interval.

What this means

Only in times of extreme drought would the low amounts of fuel loadings in Delaware's forests pose a hazard across the State. Of all down woody components, coarse woody debris (i.e., 1,000+ hr fuels) comprised the largest amounts. However, coarse woody debris volumes were still relatively low and were represented by small, moderately decayed pieces. The scarcity of large coarse woody debris resources may also indicate a lack of high quality wildlife habitat. Because fuel loadings are not exceedingly high across Delaware, potential fire dangers are outweighed by the down woody material benefits of wildlife habitat and carbon sinks.

Lichen Communities

Background

Lichens are symbiotic, composite organisms made up from members of as many as three kingdoms. The dominant partner is a fungus. Fungi are incapable of producing their own food, so they typically provide for themselves as parasites or decomposers. The lichen fungi (*kingdom Fungi*) cultivate partners that manufacture food by photosynthesis. Sometimes the partners are algae (*kingdom Protista*), other times cyanobacteria (*kingdom Monera*), formerly called blue-green algae. Some enterprising fungi associate with both at once (Brodo et al. 2001).

A close relationship exists between lichen communities and air pollution, especially acidifying or fertilizing nitrogen- and sulfur-based pollutants. A major reason lichens are so sensitive to air quality is their total reliance on atmospheric sources of nutrition. By contrast, it is difficult to separate tree-growth responses specific to air pollution (McCune 2000).

Lichen community monitoring is included in the FIA Phase 3 inventory to address key assessment issues such as the impact of air pollution on forest resources, or spatial and temporal trends in biodiversity. This long-term lichen monitoring program in the United States dates back to 1994. The objectives of the lichen indicator are to determine the presence and abundance of lichen species on woody plants and to collect samples. Lichens occur on many different substrates (e.g., rocks) but FIA sampling is restricted to standing trees or branches/twigs that have recently fallen to the ground. Samples are sent to lichen experts for species identification.

What we found

Seventy-seven lichen species were sampled on the lichen plots in Delaware (Table 2). The most common lichen genus, *Physcia*, was present on 18 percent of the plots (Table 3). The genus with the highest number of species sampled was *Parmotrema* (11 species).

The easiest way to measure species diversity is to count the number of species at a site; this measure is called species richness. However, species richness does not provide a complete picture of diversity in an ecosystem because abundance is excluded. Richness values fell into the low to medium categories across Delaware (Table 2). The spatial distribution of lichen species richness scores is shown in Figure 59. In general, species richness scores were highest in the central portion of the State. The lichen species richness and diversity scores reported here will serve as baseline estimates for future monitoring at the State and regional level.

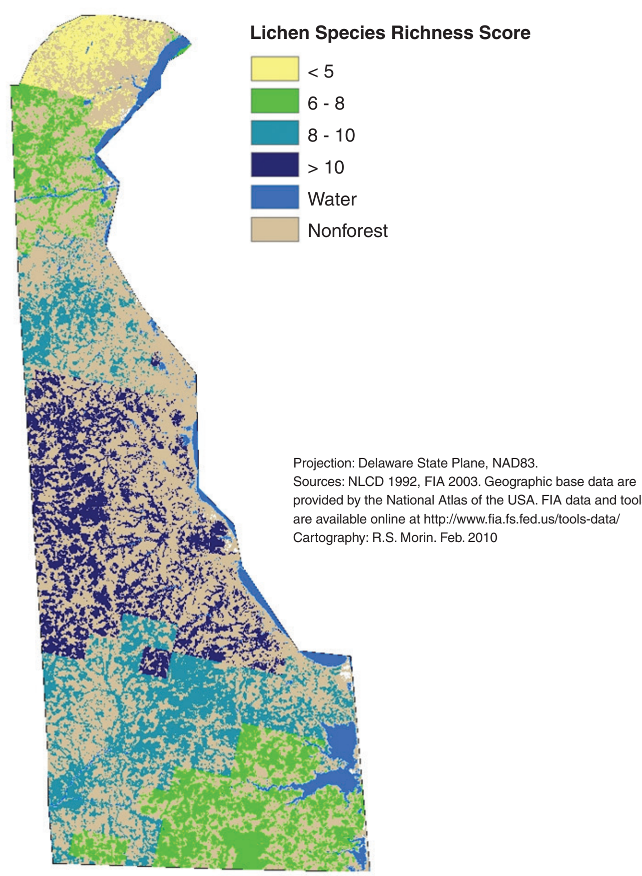


Figure 59.—Estimated lichen species richness scores, Delaware, 2000-2003.

Table 2.—Lichen communities summary table for southern Delaware, 2001-2003

Parameter	
Number of plots surveyed	20
Number of plots by species richness category	
0-6 species (low)	7
7-15 species (medium)	13
16-25 species (high)	0
Median	9
Range of species richness score per plot (low-high)	4-15
Average species richness score per plot (alpha diversity)	9
Standard deviation of species richness score per plot	3.9
Species turnover rate (beta diversity)[1]	8.6
Total number of species per area (gamma diversity)	77

[1] Beta diversity is calculated as gamma diversity divided by alpha diversity.

Table 3.—Percentage of specimens and number of species for lichen genera sampled, Delaware, 2001-2003

Genus	All Specimens (percent)	Species (count)
Physcia	18.2	5
Punctelia	15.9	4
Parmotrema	13.3	11
Flavoparmelia	10.0	1
Phaeophyscia	6.6	4
Cladonia	4.4	7
Canoparmelia	4.0	4
Hypotrachyna	3.8	5
Parmelinopsis	3.6	2
Usnea	3.6	5
Myelochroa	3.4	3
Pyxine	3.2	3
Rimelia	3.2	4
Candelaria	2.1	1
Parmelia	1.1	4
Physciella	0.9	2
Heterodermia	0.8	2
Xanthoria	0.6	3
Unknown	0.2	1
Anaptychia	0.2	1
Bryoria	0.2	1
Hyperphyscia	0.2	1
Leptogium	0.2	1
Lobaria	0.2	1
Pseudoparmelia	0.2	1
Total	100	77

What this means

Showman and Long (1992) reported that mean lichen species richness was significantly lower in areas of high sulfate deposition than in low deposition areas. Sulfate deposition levels have been relatively homogenous across Delaware and are moderate compared to other areas in the northeastern United States (Fig. 60). A general pattern of lower lichen species richness scores in high deposition areas and vice versa is evident by comparing areas in Figures 60 and 61, but other factors may affect the distribution of lichen species, including intrinsic forest characteristics and long-term changes in climate.

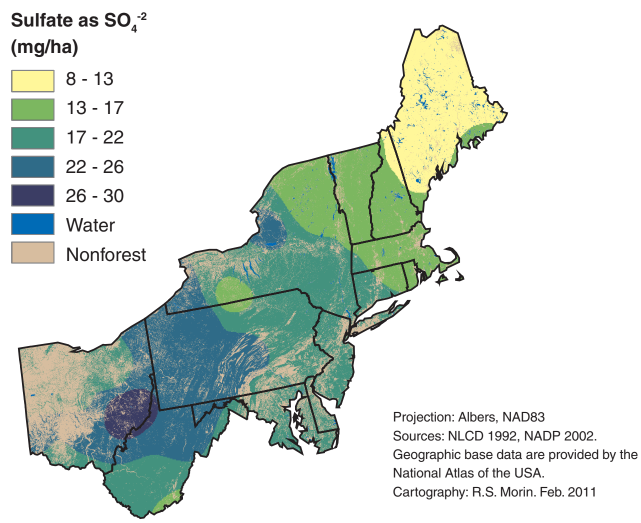


Figure 60.—Mean sulfate ion wet deposition, northeastern United States, 1994-2002.

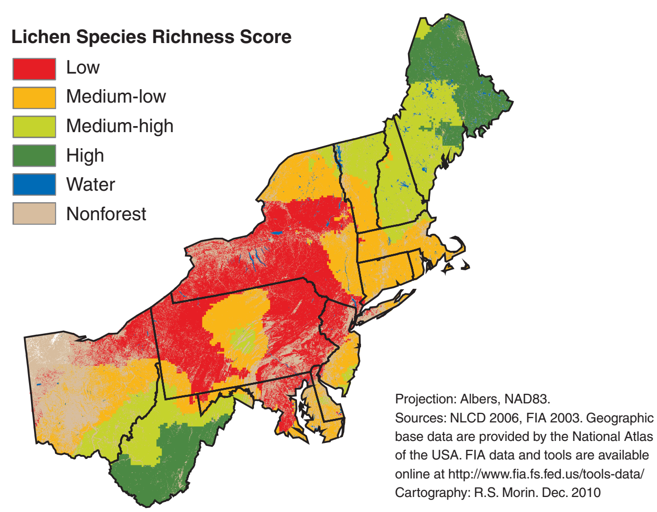


Figure 61.—Estimated lichen species richness, northeastern United States, 2000-2003.

Crown Health

Background

A tree's crown condition is influenced by various biotic and abiotic stressors. Abiotic stressors include drought, flooding, cold temperatures or freeze injury, nutrient deficiencies, soil physical properties affecting soil moisture and aeration, or toxic pollutants. Biotic stressors include native or introduced insects, diseases, competition from native and invasive plant species, and animals. Seasonal or prolonged drought periods have long been a significant and historical stressor in Delaware. Droughts occurred in some regions of the State during 1999 and 2002; alternatively, one of the wettest years on record was 2003 (NCDC 2010). These extreme events can produce conditions that facilitate insect and/or disease outbreaks and can be even more devastating to trees that are stressed by pest damage or other agents.

Tree-level crown measurements are collected on P3 plots. They include vigor class, crown ratio, light exposure, crown position, crown density, crown dieback, and foliage transparency. Three factors are used to determine the condition of tree crowns: crown dieback, crown density, and foliage transparency. Crown dieback is defined as recent mortality of branches with fine twigs and reflects the severity of recent stresses on a tree. Crown density is defined as the amount of crown branches, foliage, and reproductive structures that block light visibility through the crown and can serve as an indicator of expected growth in the near future. Foliage transparency is the amount of skylight visible through the live, normally foliated portion of the crown. Changes in foliage transparency can also occur because of defoliation or from reduced foliage resulting from stresses during preceding years. A crown was rated as 'poor' if crown dieback was greater than 20 percent, crown density was less than 35 percent, or foliage transparency was greater than 35 percent. These three thresholds were based on preliminary findings by Steinman (2000) that associated crown ratings with tree mortality.

What we found

Poor crowns in Delaware were infrequent and evenly distributed across the State (Fig. 62). Red maple had the greatest number of trees with poor crowns, however this accounted for only 7 percent of its live basal area. No species had greater than 10 percent of its live basal area containing poor crowns (Table 4).

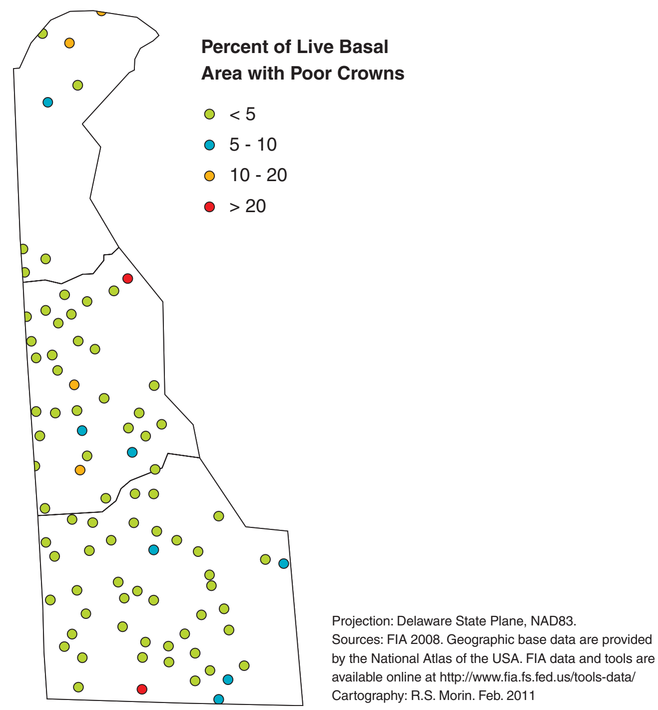


Figure 62.—Percent of live basal area with poor crowns, Delaware, 2008. Plot locations are approximate.

Table 4.—Percent of live basal area with poor crowns, Delaware, 2008

Species	Percent of Basal Area with Poor Crowns
Red maple	7
Sweetgum	4
Blackgum	4
White oak	2
Loblolly pine	2
Black cherry	1
Southern red oak	<1
Virginia pine	<1
Willow oak	<1
Yellow-poplar	<1

What this means

Tree crowns are generally healthy across Delaware and among all tree species; however, continued monitoring of crown health is important due to its potential to provide an early warning prior to a potential forest health problem. Invasions by exotic diseases and insects are one of the most serious threats to the productivity and stability of forest ecosystems around the world (Liebhold et al. 1995, Pimentel et al. 2000, Vitousak et al. 1996). Over the last century, Delaware's forests have suffered the effects of well known exotic and invasive agents such as Dutch elm disease (*Ophiostoma ulmi*), chestnut blight (*Cryphonectria parasitica*), European gypsy moth (*Lymantria dispar*), and hemlock woolly adelgid (*Adelges tsugae*). Another important exotic insect that is currently spreading near Delaware's forests is emerald ash borer (*Agrilus planipennis*). Data on tree crown condition helps scientists monitor tree health and track potential forest problems.

Ozone Bioindicator Plants

Background

Ozone (O_3) is a byproduct of industrial activities and is found in the lower atmosphere. Ozone forms when nitrogen oxides and volatile organic compounds go through chemical transformation in the presence of sunlight (Brace et al. 1999). Ground-level ozone is known to have detrimental effects on forest ecosystems. Certain plant species exhibit visible, easily diagnosed foliar symptoms to ozone exposure. Ozone stress in a forest environment can be detected and monitored by using these plants as indicators. The FIA program uses these indicator plants to monitor changes in air quality across a region and to evaluate the relationship between ozone air quality and the indicators of forest condition.

The degree of ozone-induced foliar injury is assessed on indicator plants throughout a natural system of sites and this information is used to estimate the impact of ozone on the greater forest environment (Smith et al. 2003, Smith et al. 2007). These sites are not collocated with FIA plots. Ozone plots are chosen for ease of access and optimal size, species, and plant counts. As such, the ozone plots do not have set boundaries and vary in size. At each plot, between 10 and 30 individual plants of three or more indicator species are evaluated for ozone injury. Each plant is rated for the proportion of leaves with ozone injury and the mean severity of symptoms using break points that correspond to the human eye's ability to distinguish differences. A state-level biosite index is calculated based on amount and severity ratings where the average score (amount * severity) for each species is averaged annually across all species at each site and multiplied by 1,000 to allow risk to be defined by integers (Smith et al. 2007).

What we found

The majority of the plants sampled in Delaware were blackberry (*Rubus* spp.), sweetgum, or black cherry (Table 5). Biosite index results in the State indicate that risk of foliar injury due to ozone was at its highest level in the late 1990s and has since been decreasing (Table 6 and Fig. 63). Ozone exposure levels also appear to be highest in the late 1990s as indicated by the SUM06 index data that is defined as the sum of all valid hourly O_3 concentrations that equal or exceed 0.06 ppm (Fig. 64).

Table 5.—Number of plants sampled for ozone injury by species, Delaware, 1995-2007.

Common Name	Scientific Name	Number
Blackberry	*Rubus fruticosus*	2,892
Sweetgum	*Liquidambar styraciflua*	2,726
Black cherry	*Prunus serotina*	2,386
Sassafras	*Sassafras albidum*	1,167
Milkweed	*Asclepias syrica*	687
Yellow-poplar	*Liriodendron tulipifera*	666
Spreading dogbane	*Apocynum androsaemifolium*	498
White ash	*Fraxinus americana*	286
Unknown		141

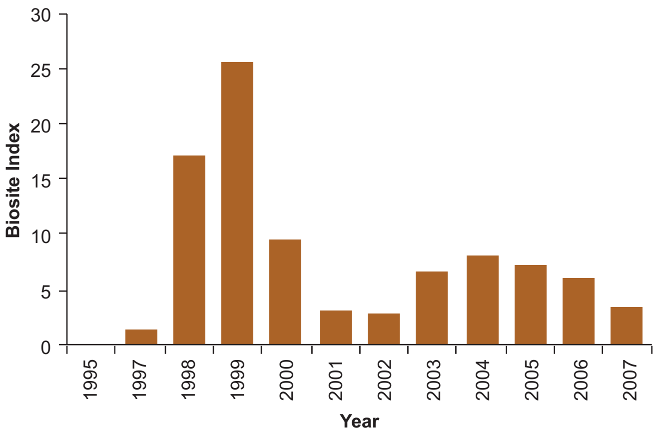


Figure 63.—Biosite index, Delaware.

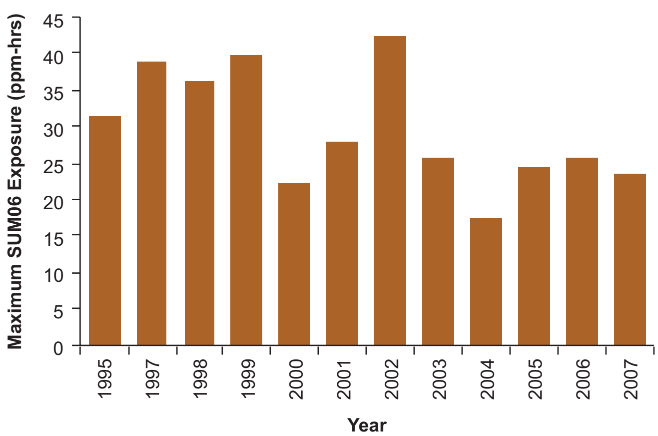


Figure 64.—Maxiumum SUM06 exposure levels, Delaware, 1994-2007.

What this means

Ozone exposure rates have been decreasing slightly with corresponding decreases in foliar injury, however despite these decreases, ozone injury is still a concern in the Mid-Atlantic region. Figure 65 shows a typical summer O_3 exposure pattern for the 20 states of the Forest Service's Eastern Region. Delaware is shown to be at medium to high risk for O_3 exposure (Coulston et al. 2003). Controlled studies have found that high O_3 levels (shown in orange and red) can lead to measurable growth suppression in sensitive tree species (Chappelka and Samuelson 1998). Other factors including temperature and moisture regimes, however, can influence a tree's response to elevated O_3 levels. Smith et al. (2003) reported that even when ambient O_3 exposures are high, the percentage of injured plants can be reduced sharply in dry years.

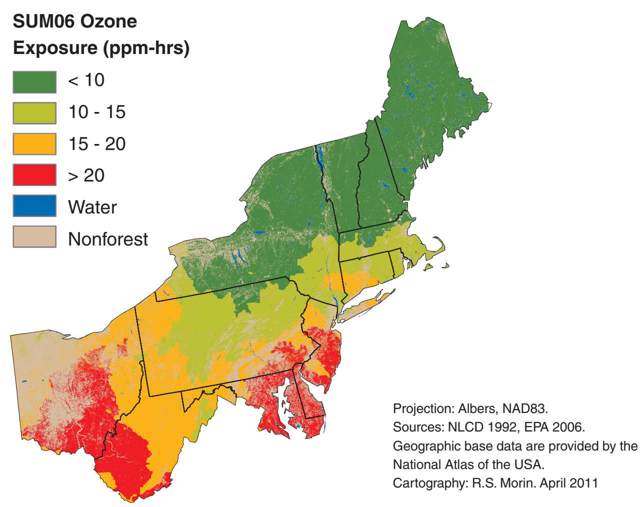


Figure 65.—Typical June through August 12-hour SUM06 ozone exposure rates in the northeastern United States, 2000-2006.

Table 6.—Regional summary statistics for ozone bioindicator program, Delaware, 1995-2007

Parameter	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Number of biosites evaluated	1	3	3	11	9	10	11	11	11	8	11	11
Number of biosites with injury	0	2	3	10	6	8	4	11	8	6	8	7
Average biosite index score	0	1.35	17.2	25.56	9.41	3.02	2.78	6.67	7.93	7.28	6.14	3.46
Number of plants evaluated	30	244	211	864	283	825	1,065	1,298	1,176	845	1,215	1,235
Number of plants injured	0	16	68	159	34	80	29	212	143	80	99	73
Maximum SUM06 value[a] (ppm-hr)	31.46	38.66	36.19	39.57	22.25	28.08	42.24	25.88	17.4	24.53	25.56	23.56

[a] Averaged from State values

Forest Soils

Background

FIA collects data to evaluate soil physical and chemical properties on P3 plots. Soils are an important component of the forest ecosystem. They supply water, oxygen, heat, and physical support to vegetation. Soils also play a role in cycling carbon through the forest. Carbon stocks in soils are important long-term stores of carbon. Accumulating and decaying leaf litter stores carbon on the forest floor. Measurements of current carbon stocks help managers understand the importance of different forest types and landscapes in the carbon cycle.

The soils that sustain forests are influenced by a number of factors, including: climate; the trees, shrubs, herbs, and animals living there; landscape position; elevation; and the passage of time. Climate-soil interactions are one significant way that humans influence the character and quality of the soil and indirectly affect the forest. For example, industrial emissions of sulfur and nitrogen oxides lead to "acid rain." The deposition of acids strips the soil of important nutrients, notably calcium and magnesium. The loss of calcium and magnesium results in a shifting balance of soil elements toward aluminum, which is toxic to plants in high concentrations. We can use the ratio of aluminum to calcium (Al:Ca) and aluminum to magnesium (Al:Mg) as measures of the impact of acid deposition on forest soils; larger ratios suggest a shift toward more aluminum.

What we found

Carbon stocks in the forest soil were estimated by mathematical models using data from throughout the mid-Atlantic region (Delaware, Pennsylvania, Maryland, New Jersey, Virginia, and West Virginia). Forest floor carbon in this region is well predicted by three factors: ecological section (a broad landscape of similar geology and vegetation), latitude, and longitude; given the dominance of oak/hickory forests in the region, forest-type group is not a strong predictor. Generally the largest amounts of carbon in the forest floor are near the Atlantic Ocean; forest floor carbon generally increases moving from northwest to southeast (Fig. 66). Similarly, carbon in the forest mineral soil is strongly correlated with ecological province (a broad landscape larger than an ecological section) and longitude (Fig. 67). The carbon stocks in mineral soil have a stronger gradient from west to east.

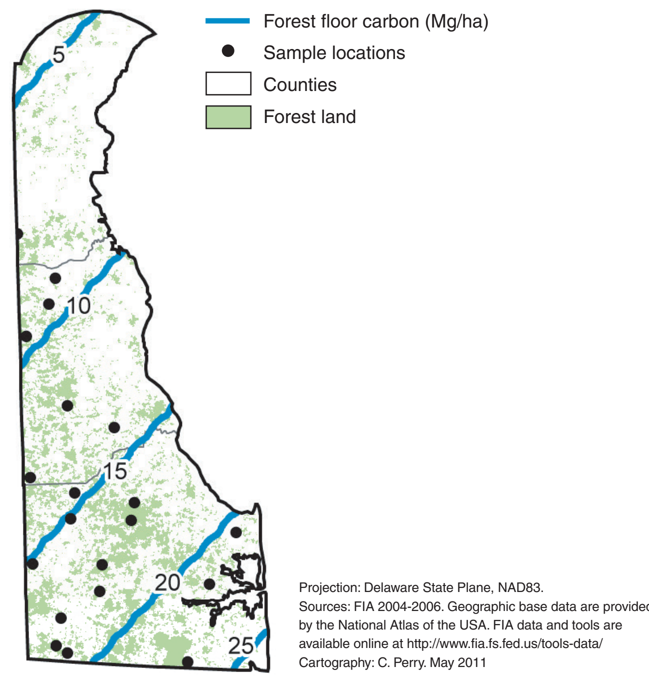


Figure 66.—Estimated forest floor carbon, Delaware. Plot locations are approximate.

By focusing on tree species found on many plots, it is possible to evaluate tree:soil interactions with some statistical rigor. To accomplish this, forest health plots were used from throughout the largest ecoprovince in Delaware: province 232, the Outer Coastal Plain Mixed Forest, which includes all of Sussex county, the majority of Kent County, and the southwest corner of New Castle County. The available plots extended from southern New Jersey through the Delmarva Peninsula and into coastal Virginia. Species of interest included red maple, yellow-poplar, blackgum, black cherry, and white oak.

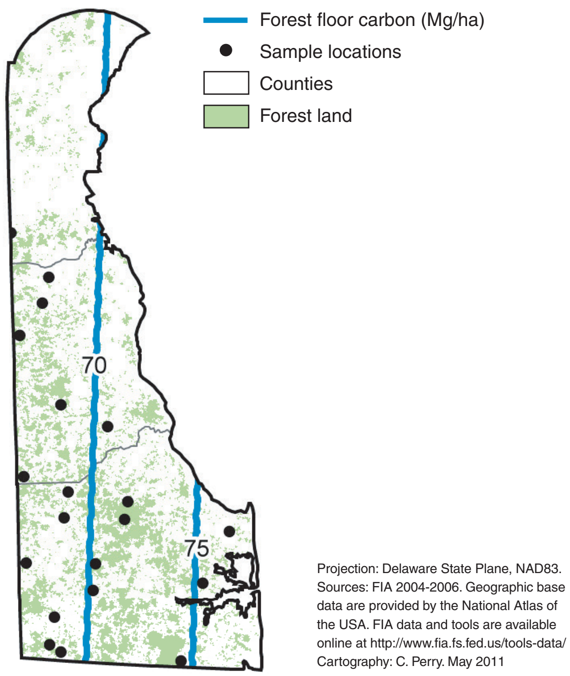


Figure 67.—Estimated carbon in the mineral soil (0-20 cm), Delaware. Plot locations are approximate.

The tree's crown is its energy source, so a healthy crown is often taken as the sign of a healthy tree. The structure of a tree's crown is influenced by many factors including competition, height, and overall nutrition. The plot data affirms that elemental ratios in the soil are useful predictors of tree vigor in coastal plain mixed forests, and the effect of these elements varies across tree species. The nuances of these relationships are difficult to explain in the space of this report, but some examples are illustrative.

The uncompacted live crown ratio is determined by dividing the live crown length by the actual tree length. Larger values are associated with healthier trees; low values of this ratio can be related to self-pruning and shading from other tree crowns, but other reasons include defoliation due to dieback, and loss of branches due to breakage or mortality. The uncompacted live crown ratios of blackgum increase with aluminum relative to calcium (Fig. 68) and magnesium relative to manganese (Fig. 69); white oaks crowns also get larger with increasing aluminum (Fig. 68). By contrast, the uncompacted live crown ratio of black cherry declines with increases in aluminum (Fig. 68) and magnesium content (Fig. 69). Yellow-poplar does not appear to be affected by changes in Al:Ca ratios, but they do respond to changes in magnesium:manganese (Mg:Mn) ratios.

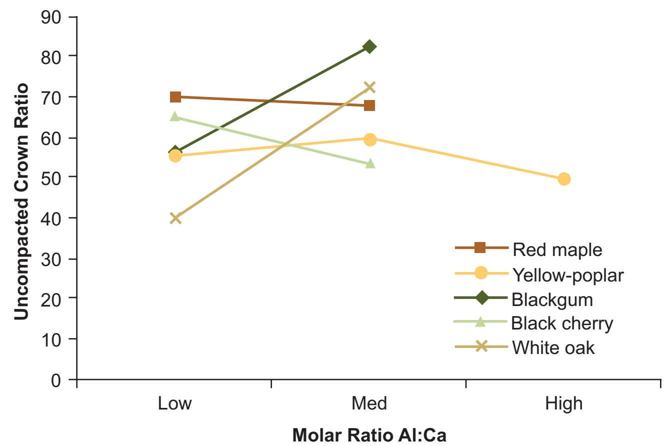


Figure 68.—The Al:Ca molar ratio by uncompacted crown ratio, Outer Coastal Plane Mixed Province.

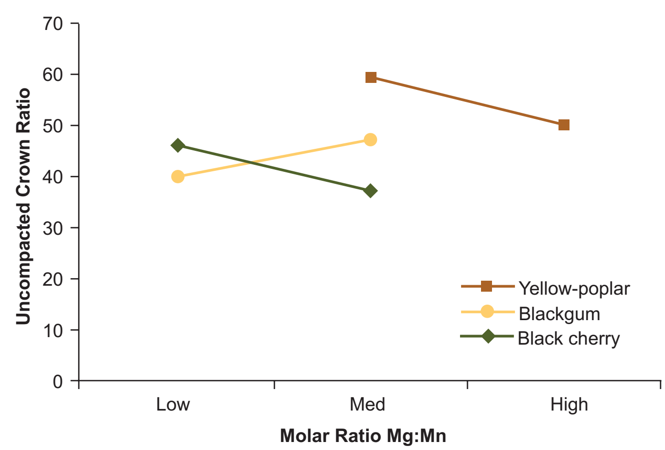


Figure 69.—The Mg:Mn molar ratio by uncompacted crown ratio, Outer Coastal Plane Mixed Province.

What this means

Tree species occupy different niches in the landscape. This provides a competitive advantage for colonization, growth, and reproduction. Atmospheric deposition of different compounds changes the soil substrate through additions and/or removals of nutrients and pollutants. These changes in the soil influence the ability of existing trees to thrive and reproduce in their current locations and affect the ability of other trees to colonize new landscapes. For example, our observations suggest that blackgum and white oaks have a competitive advantage in landscapes altered by acid deposition. It is important to document and understand natural and anthropogenic processes in the soil since they profoundly influence the current forest and success of future forest management plans. In turn, these changes in tree species composition across the landscape influence carbon sequestration rates by forests.

Understory Vegetation

Background

Forest understory vegetation enhances soil stability, provides nutrition and shelter for wildlife, regulates microclimate, and adds economic and aesthetic value to the forest. Assessments of the forest understory plant community provide information on forest structure, health, site quality, and other site characteristics. Botanical data can reveal the locations of rare and endangered species, as well as of invasive and nonnative species. In 2007 and 2008, detailed understory floristic data were collected on approximately 6 percent (41 plots) of the P3 plots in Delaware. In addition, invasive plant data were collected on approximately 20 percent (44 plots) of the P2 plots and these plots are referred to as "invasive plots". Both types of plots are used to assess the presence and cover of plant species on forest land. A complete assessment of understory vegetation, including native and nonnative species, is conducted on P3 plots, while the evaluation on the P2 invasive plots is limited to 43 target invasive plant species (Table 7).

What we found

There were 338 plant species observed on P3 plots in 2007 and 2008, and one-third of these species were classified as forbs or herbs based on the USDA's Natural Resources Conservation Service's PLANTS database definitions (NRCS 2011; Table 8). Forty-two species were classified as graminoids (grass or grass-like plants),

Table 7.—Forty-three invasive plant species target list for Northern Research Station Forest Inventory and Analysis P2 Invasive plots, 2007-2008.

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

65 as trees, 41 as shrubs, and 19 as vines. Seventy-one percent of the plant species were native to the United States with the remainder being introduced, cultivated, or of uncertain origin (Table 9). The most commonly observed species was red maple, which occurred on 38 plots (93 percent; Table 10), followed by sweetgum (34 plots; 83 percent). Of the 20 most commonly observed species, 18 (90 percent) were of woody growth form.

Table 8.—Number of species on Delaware P3 plots by growth habit (NRCS 2011), 2007-2008.

Growth Habit	Number of Species or Undifferentiated Genera
Forb/herb	112
Graminoid	42
Shrub	24
Shrub, subshrub, vine	4
Subshrub, shrub	9
Subshrub, shrub, forb/herb	4
Tree	39
Tree, shrub	24
Tree, shrub, subshrub	2
Vine	6
Vine, forb/herb	7
Vine, shrub	2
Vine, subshrub	2
Vine, subshrub, forb/herb	2
Unclassified	59
Total	338

Table 9.—Number of species on Delaware P3 plots by domestic or foreign origin (NRCS 2011), 2007-2008.

Origin	Number of Species	Percent
Cultivated or not in the U.S.	2	0.6
Introduced to the U.S.	34	10.1
Native and introduced to the U.S.	3	0.9
Native to the U.S.	241	71.3
Probably introduced to the U.S.	1	0.3
Unclassified	57	16.9

Table 10.—The top 20 plant species or undifferentiated genera or categories found on Delaware P3 plots, the number of plots found on (in brackets), and the mean number of tree seedlings and saplings per acre on the plots, 2007-2008.

Species	Tree Seedlings per acre	Tree Saplings per acre
Red maple (*Acer rubrum* [38])	1,215	551
Sweetgum (*Liquidambar styraciflua* [34])	1,360	601
Roundleaf greenbrier (*Smilax rotundifolia* [33])	1,343	614
American holly (*Ilex opaca* [32])	1,367	645
Sassafras (*Sassafras albidum* [31])	1,325	583
Blackgum (*Nyssa sylvatica* [30])	1,339	661
Black cherry (*Prunus serotina* [29])	1,191	378
Eastern poison ivy (*Toxicodendron radicans* [27])	1,346	493
Virginia creeper (*Parthenocissus quinquefolia* [26])	1,356	563
White oak (*Quercus alba* [25])	1,225	628
Cat greenbrier (*Smilax glauca* [23])	1,310	588
Japanese honeysuckle (*Lonicera japonica* [22])	938	303
American pokeweed (*Phytolacca americana* [21])	1,242	293
Coastal sweetpepperbush (*Clethra alnifolia* [21])	1,704	610
Loblolly pine (*Pinus taeda* [21])	1,650	800
Tuliptree (*Liriodendron tulipifera* [21])	1,221	543
Southern red oak (*Quercus falcata* [20])	1,424	747
Sedge (*Carex* spp. [19])	1,517	545
Highbush blueberry (*Vaccinium corymbosum* [18])	1,733	856
Southern arrowwood (*Viburnum denatatum* [18])	1,543	477

Table 11.—Nonnative plant species found on Delaware P3 plots, the number of plots where the species occurred (in brackets), and the mean number of tree seedlings and saplings per acre on the plots.

Species	Tree Seedlings per acre	Tree Saplings per acre
Japanese honeysuckle (*Lonicera japonica* [22])	938	303
Multiflora rose (*Rosa multiflora* [8])	913	246
Nepalese browntop (*Microstegium vimineum* [4])	1,149	394
Common sheep sorrel (*Rumex acetosella* [3])	577	221
Amur honeysuckle (*Lonicera maackii* [2])	244	0
European privet (*Ligustrum vulgare* [2])	50	0
Garlic mustard (*Alliaria petiolata* [2])	87	0
Ground ivy (*Glechoma hederacea* [2])	787	150
Indian strawberry (*Duchesnea indica* [2])	87	0
Norway maple (*Acer platanoides* [2])	87	0
Tree-of-heaven (*Ailanthus altissima* [2])	170	0
White mulberry (*Morus alba* [2])	722	450
Wine raspberry (*Rubus phoenicolasius* [2])	87	0
Asian bittersweet (*Celastrus orbiculata* [1])	100	0
Autumn olive (*Elaeagnus umbellata* [1])	1,395	698
Barnyardgrass (*Echinochloa crus-galli* [1])	900	525
Bigleaf periwinkle (*Vinca major* [1])	0	0
Black nightshade (*Solanum nigrum* [1])	265	0
Burningbush (*Euonymus alata* [1])	100	0
Chinese lespedeza (*Lespedeza cuneata* [1])	525	900
Common St. Johnswort (*Hypericum perforatum* [1])	662	662
Deptford pink (*Dianthus armeria* [1])	900	750
Japanese barberry (*Berberis thunbergii* [1])	100	0
Marshpepper knotweed (*Polygonum hydropiper* [1])	919	0
Oxeye daisy (*Leucanthemum vulgare* [1])	662	662
Princesstree (*Paulownia tomentosa* [1])	75	0
Rabbitfoot clover (*Trifolium arvense* [1])	400	200
Sweet autumn virginsbower (*Clematis terniflora* [1])	0	300
Sweet vernalgrass (*Anthoxanthum odoratum* [1])	1,124	525
Tatarian honeysuckle (*Lonicera tatarica* [1])	100	0
Tidalmarsh flatsedge (*Cyperus serotinus* [1])	1,124	375
Weeping lovegrass (*Eragrostis curvula* [1])	150	0
Yellow bristlegrass (*Setaria pumila* [1])	400	200

Table 12.—Invasive plant species found on Delaware P2 Invasive plots, the number of plots where the species occurred (in brackets), the mean number of tree seedlings and saplings per acre, and the average percent cover of invasive species on the plot, 2007-2008.

Species	Tree Seedlings per acre	Tree Saplings per acre	Coverage
Japanese honeysuckle (*Lonicera japonica* [24])	976	353	4.4
Multiflora rose (*Rosa multiflora* [9])	953	219	7.2
Nepalese browntop (*Microstegium vimineum* [4])	1,149	394	1.9
Amur honeysuckle (*Lonicera maackii* [2])	244	0	0.6
Autumn olive (*Elaeagnus umbellata* [2])	1,335	349	2.1
European privet (*Ligustrum vulgare* [2])	50	0	1.4
Garlic mustard (*Alliaria petiolata* [2])	87	0	6.1
Norway maple (*Acer platanoides* [2])	87	0	0.4
Tree-of-heaven (*Ailanthus altissima* [2])	170	0	5.0
Common reed (*Phragmites australis* [1])	1,727	785	0.3
Japanese barberry (*Berberis thunbergii* [1])	100	0	0.3
Oriental bittersweet (*Celastrus orbiculatus* [1])	75	0	2.8
Princesstree (*Paulownia tomentosa* [1])	75	0	8.5
Tatarian honeysuckle (*Lonicera tatarica* [1])	100	0	16.0

Eleven of the 43 target invasive plant species were found on the P3 plots and 14 were observed on the P2 plots. Japanese honeysuckle (*Lonicera japonica*) and mutliflora rose (*Rosa multiflora*) were the two most common invasive species on both types of plots (Tables 11 and 12). Figures 70 and 71 show the presence of these two species on the invasive plots.

What this means

Delaware's understory vegetation, the vast majority of which is native, represents a diverse mix of species of various growth forms. However, some of the nonnative species recorded in the understory are listed as invasive plants that have the potential to negatively affect the native plant community. Invasive plants can physically displace native plants by outcompeting them for space and other resources, and, like the common buckthorn (*Rhamnus cathartica*), can change soil chemistry and thus alter the suitability of a site for native species.

In Delaware, there is concern about the presence of invasive species. For example, the high number of plots with multiflora rose is concerning as these shrubs form dense mats that can survive across a broad range of light levels ranging from full sun to shade. Once established in the forest, multiflora rose can out-compete native vegetation, creating a homogeneous, species-poor understory. Another species of concern is Japanese honeysuckle, which is a trailing and climbing vine that can cover trees and compete for light and resources. Data on seedlings and sapling densities (Tables 10-12; Fig. 72) suggest that areas with more cover of invasives generally have lower numbers of tree seedlings and saplings than areas with less invasive cover, but one must be cautious in drawing conclusions from these data due to the small sample size.

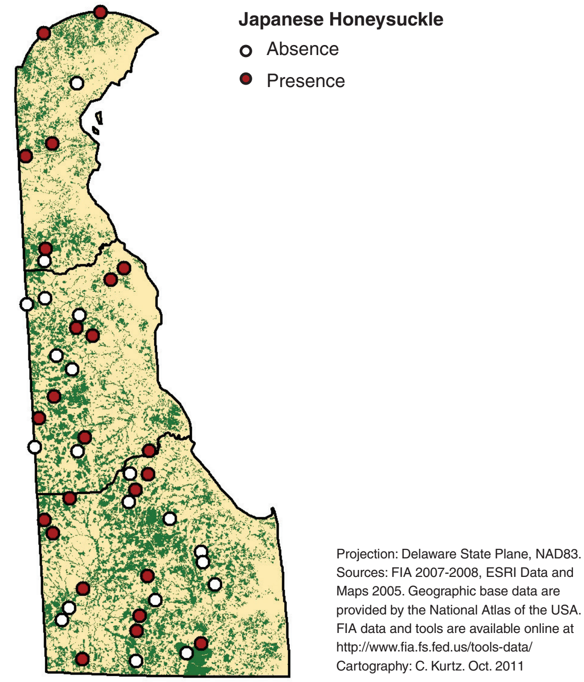


Figure 70.—Presence and absence of Japanese honeysuckle (*Lonicera japonica*) in Delaware observed on P2 invasive plots, 2007-2008. Plot locations are approximate.

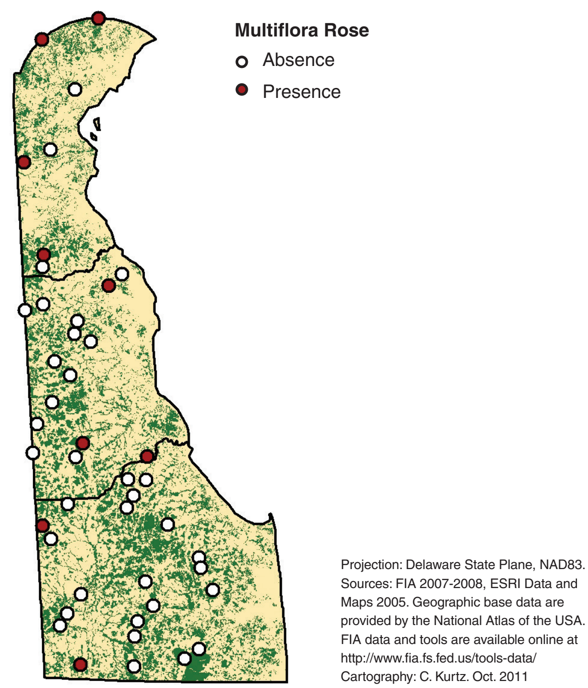


Figure 71.—Presence and absence of multiflora rose (*Rosa multiflora*) in Delaware observed on P2 invasive plots, 2007-2008. Plot locations are approximate.

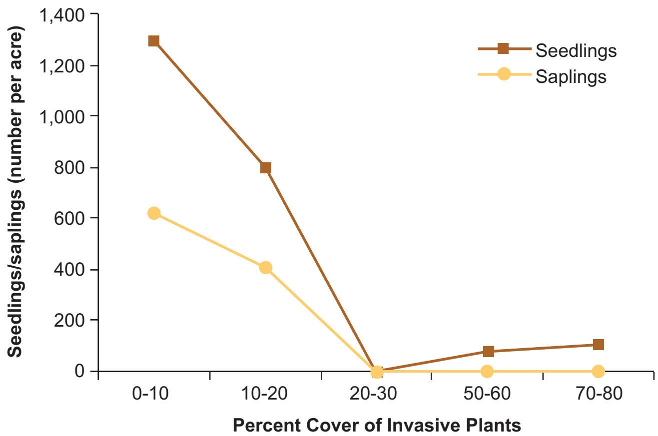


Figure 72.—Average number of seedlings and saplings per acre by invasive plant cover class for P2 invasive plots in Delaware, 2007-2008.

Emerald ash borer

Background

The emerald ash borer (*Agrilus planipennis*, EAB) is a wood-boring beetle native to Asia. In North America, EAB has been identified as an invasive pest that currently targets only ash (*Fraxinus* sp.) species (Poland and McCullough 2006). Trees and branches as small as 1-inch in diameter have been attacked. While stressed trees may be initially preferred, healthy trees are also susceptible (Cappaert et al. 2005). In areas with a high density of EAB, tree mortality generally occurs 1 to 2 years after infestation for small trees and after 3 to 4 years for large trees (Poland and McCullough 2006). Spread of EAB has been facilitated by human transportation of infested material. EAB was not found in Delaware during the 2004-2008 inventory period, however, the threat of EAB introduction increased with the 2003 introduction of this pest to neighboring Maryland.

What we found

Delaware's forest land contains an estimated 2.3 million ash trees (greater than 1-inch in diameter) that comprise 18.9 million cubic feet of volume. Ash makes up less than 1 percent of total species composition, however, it can be found across much of the State (Fig.73). Present on approximately 35,000 acres or 10 percent of forest land, ash is rarely the most abundant species in a stand.

When present, ash generally makes up less than 50 percent of total live-tree basal area (Fig. 74). Riparian forests contain more than 60 percent of ash trees.

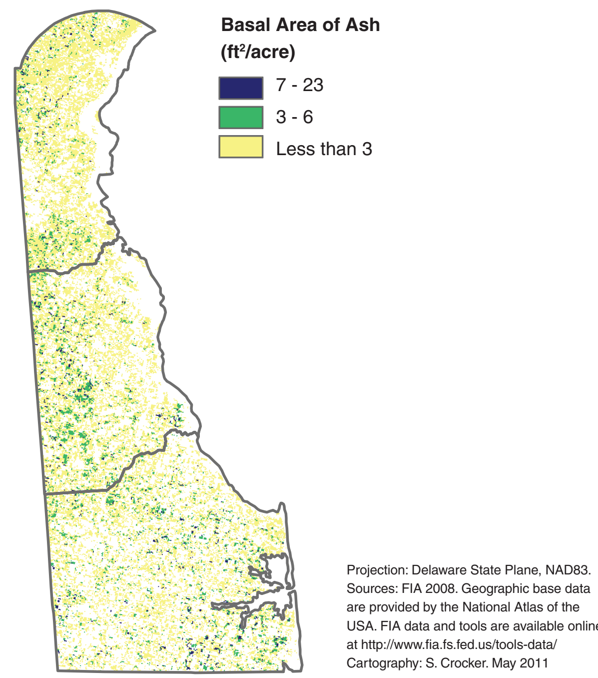


Figure 73.—Distribution of ash on forest land, Delaware, 2008.

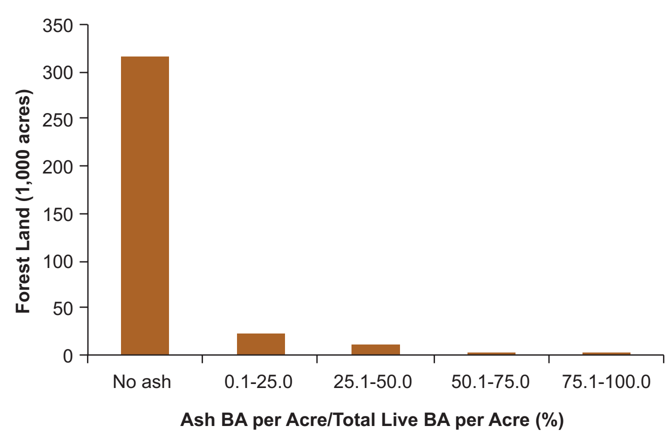


Figure 74.—Presence of ash on forest land, as a percentage of stand basal area (BA), Delaware, 2008.

What this means

Ash trees make up a small but important component of Delaware's forest resource. Abundant in riparian forests, ash is also widely distributed within many urban areas throughout the State. As such, the introduction of EAB to Delaware could have a significant impact on the composition and structure of statewide forest resources and related forest industries, such as timber, wood products, recreation and nurseries. Additionally, the loss of ash in riparian forests would have a major effect on species diversity, erosion, water quality, and food and habitat availability for macroinvertebrates. Continued monitoring will help identify the long-term impacts of EAB should this insect be introduced to Delaware.

Asian Longhorned Beetle

Background

The Asian longhorned beetle (*Anoplophora glabripennis*, ALB) is an exotic wood-boring beetle that attacks a variety of hardwood species found in Delaware. Larval activity girdles the trunk, resulting in tree mortality (USDA For. Serv. 2008). ALB was first identified in New York City in 1996 and has subsequently been found in Chicago, IL, Massachusetts, and northern New Jersey. Though not found during the 2004-2008 inventory period, the presence of ALB in New Jersey poses an increased risk of introduction to Delaware. ALB will attack a number of hardwood species, but maple (most favored), birch, willow, and elm are the preferred hosts. Occasional hosts include poplar and ash (USDA APHIS 2010).

What we found

A quarter of all trees in Delaware, or 61 million, are susceptible to ALB. Of this group, maples, specifically red maple, are the most dominant species across the State, followed by ash and birch (Fig. 75). Poplar, willow, and elm are present in small amounts. Susceptible host species account for 215.7 million cubic feet of total live-tree volume. While present throughout the State, these species are more abundant in Kent and Sussex Counties (Fig. 76).

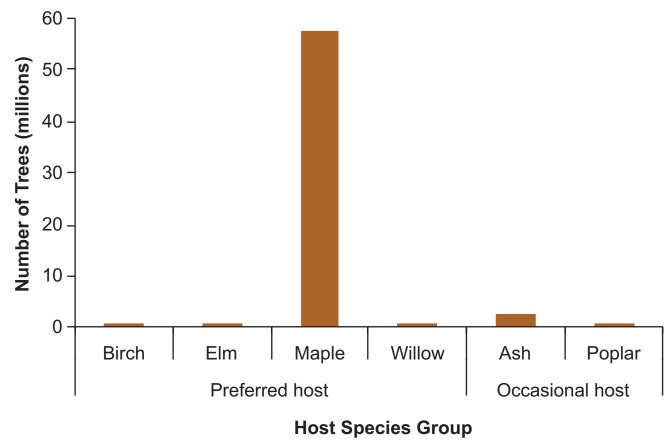


Figure 75.—Number of ALB-susceptible trees by host preference and species group, Delaware, 2008.

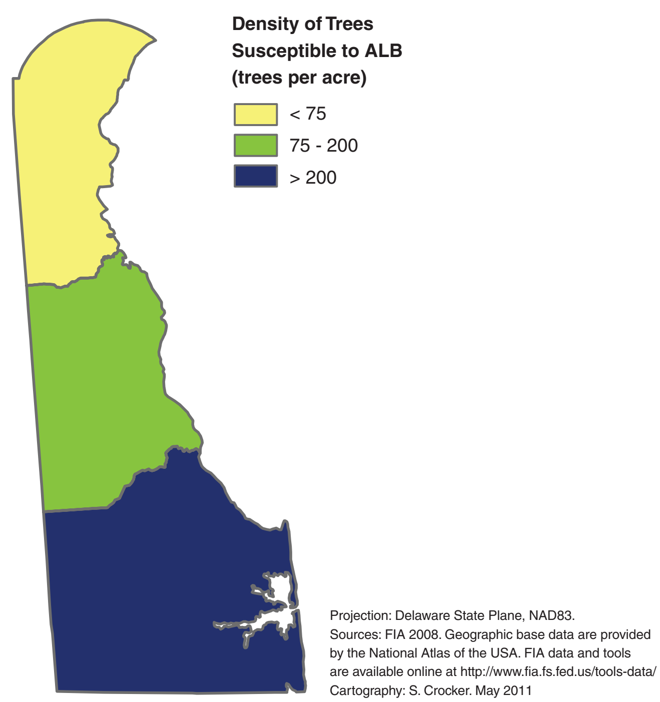


Figure 76.—Distribution of ALB-susceptible trees by county, Delaware, 2008.

What this means

ALB has caused major economic losses in China, where it is a pest of urban trees and trees in windbreaks and plantations (Haack et al. 2010, MacLeod et al. 2002). Since its introduction to the United States, ALB has been a significant source of urban tree mortality. However, with a wide range of susceptible host species, this insect could have a substantial impact on hardwood forests across Delaware. Quarantine establishment and management efforts have led to the successful eradication of ALB in Chicago and Jersey City, NJ.

Literature Cited

Allen, O.; Barkus, B.; Bennett, K. 2006. **Delaware wildlife action plan, 2007-2017.** Dover, DE: Delaware Natural Heritage and Endangered Species Program, Delaware Division of Fish and Wildlife, Delaware Department of Natural Resources and Environmental Control.

Barlow, S.A.; Munn, I.A.; Cleaves, D.A.; Evans, D.L. 1998. **The effect of urban sprawl on timber.** Journal of Forestry. 96(12): 10-14.

Bechtold, W.A; Patterson, P.L., eds. 2005. **Forest Inventory and Analysis national sample design and estimation procedures.** Gen. Tech. Rep. SRS-GTR-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.

Brace, S.; Peterson, D.L.; Bowers, D. 1999. **A guide to ozone injury in vascular plants of Pacific Northwest.** Gen. Tech. Rep. PNW-GTR-446. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 63 p.

Brand, G.J.; Nelson, M.D.; Wendt, D.G.; Nimerfro, K.K. 2000. **The hexagon/panel system for selecting FIA plots under an annual inventory.** In: McRoberts, R.E.; Reams, G.A.; Van Deusen, P.C., eds. Proceedings of the first annual Forest Inventory and Analysis symposium. Gen. Tech. Rep. NC-213. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 8-13.

Brodo, I.M.; Sharnoff, S.D.; Sharnoff, S. 2001. **Lichens of North America.** New Haven, CT: Yale University Press. 795 p.

Butler, B.J. 2008. **Family forest owners of the United States, 2006.** Gen. Tech. Rep. NRS-27. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 73 p.

Butler, B.J.; Leatherberry, E.C.; Williams, M.S. 2005. **Design, implementation, and analysis methods for the National Woodland Owner Survey.** Gen. Tech. Rep. NE-336 Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 43 p.

Cappaert, D.; McCullough, D.G.; Poland, T.M.; Siegert, N.W. 2005. **Emerald ash borer in North America: a research and regulatory challenge.** American Entomologist. 51(3): 152-165.

Chappelka, A.H.; Samuelson, L.J. 1998. **Ambient ozone effects on forest trees of the eastern United States: a review.** New Phytologist. 139: 91-108.

Chen, J.Q.; Franklin, J.F.; Spies, T.A. 1992. **Vegetation responses to edge environments in old-growth douglas-fir forests.** Ecological Applications. 2(4): 387-396.

Claggett P.R.; Jantz C.A.; Goetz S.J.; Bisland, C. 2004. **Assessing development pressure in the Chesapeake Bay watershed: an evaluation of two land-use change models.** Environmental Monitoring and Assessment. 94: 129-146.

Coulston, J.W.; Smith, G.C.; Smith, W.D. 2003. **Regional assessment of ozone sensitive tree species using bioindicator plants.** Environmental Monitoring and Assessment. 83: 113-127.

Delaware Forest Service. 2010. **Delaware statewide forest strategy.** Dover, DE: Delaware Department of Agriculture, Forest Service. 38 p.

Donovan, T.M.; Lamberson, R.H. 2001. **Area-sensitive distributions counteract negative effects of habitat fragmentation on breeding birds.** Ecology. 82(4): 1170-1179.

Fan, Z.; Shifley, S.R.; Spetich, M.A.; Thompson, F.R., III; Larsen, D.R. 2003. **Distribution of cavity trees in midwestern old-growth and second-growth forests.** Canadian Journal of Forest Research. 33: 1481-1494.

Ferguson, R.H. 1959. **The timber resources of Delaware. A report on the forest survey made by the U.S. Forest Service.** Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 30 p.

Ferguson, R.H.; Mayer, C.E. 1974. **The timber resources of Delaware.** Resour. Bull. NE-32. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 42 p.

Flaspohler, D.J.; Temple, S.A.; Rosenfield, R.N. 2001. **Species-specific edge effects on nest success and breeding bird density in a forested landscape.** Ecological Applications. 11(1): 32-46.

Forman, R.T.T. 2000. **Estimate of the area affected ecologically by the road system of the United States.** Conservation Biology. 14: 31-35.

Forman, R.T.T.; Sperling, D.; Bissonette, J.A.; Clevenger, A.P.; Cutshall, C.D.; Dale, V.H.; Fahrig, L.; France, R.L.; Goldman, C.R.; Heanue, K.; Jones, J.; Swanson, F.; Turrentine, T.; Winter, T.C. 2003. **Road ecology: Science and solutions.** Washington, DC: Island Press. 504 p.

Frieswyk, T.S.; DiGiovanni, D.M. 1989. **Forest statistics for Delaware-1972 and 1986.** Resour. Bull. NE-109. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 86 p.

Griffith, D.M.; Widmann, R.H. 2001. **Forest statistics for Delaware: 1986 and 1999.** Resour. Bull. NE-151. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 58 p.

Haack, R.A.; Hérard, F.; Sun, J.; Turgeon, J.J. 2010. **Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: A worldwide perspective.** Annual Review of Entomology. 55: 521-546.

Hahn, J. T. 1984. **Tree volume and biomass equations for the Lake States.** Res. Pap. NC-250. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

Heath, L.S.; Hansen, M.; Smith, J.E.; Miles, P.D.; Smith, B.W. 2009. **Investigation into calculating tree biomass and carbon in the FIADB using a biomass expansion factor approach.** In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. Forest Inventory and Analysis (FIA) symposium 2008; 2008 October 21-23; Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 26 p.

Hoover, J.P.; Brittingham, M.C.; Goodrich. L.J. 1995. **Effects of forest patch size on nesting success of wood thrushes.** The Auk. 112(1): 146-155.

Huang, C.; Yang, L.; Wylie, B.; Homer, C. 2001. **A strategy for estimating tree canopy density using Landsat 7 ETM+ and high resolution images over large areas.** In: Third international conference on geospatial information in agriculture and forestry; 2001 November 5-7; Denver, CO. Ann Arbor, MI: ERIM International, Inc. [CD-ROM].

Hunsaker, C.T.; Levine, D.A.; Timmins, S.P.; Jackson, B.L.; O'Neill, R.V. 1992. **Landscape characterization for assessing regional water quality.** In: McKenzie, D.H.; Hyatt, D.E.; McDonald, V.J., eds. Ecological indicators. New York, NY: Elsevier Applied Science: 997-1006.

Hunter, W.C.; Buehler, D.A.; Canterbury, R.A.; Confer, J.L.; Hamel, P.B. 2001. **Conservation of disturbance-dependent birds in eastern North America.** Wildlife Society Bulletin. 29(2): 440-455.

Iverson, L.R.; Prasad, A.M. 1998. **Predicting abundance of 80 tree species following climate change in the eastern United States.** Ecological Monographs. 68(4): 465-485.

Jenkins, J.C.; Chojnacky, D.C.; Heath, L.S.; Birdsey, R.A. 2004. **Comprehensive database of diameter-based biomass regressions for North American tree species.** Gen. Tech. Rep. NE-319. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 45 p. [CD-ROM].

Kline, J.D.; Azuma, D.L.; Alig, R.J. 2004. **Population growth, urban expansion, and private forestry in Western Oregon.** Forest Science. 50(1): 33-43.

Liebhold, A.M.; Mcdonald, W.M.; Bergdahl, D.; Mastro, V.C. 1995. **Invasion by exotic forest pests: a threat to forest ecosystems.** Forest Science Monographs. 30: 1-49.

MacLeod, A.; Evans, H.F.; Baker, R.H.A. 2002. **An analysis of pest risk from an Asian longhorn beetle (*Anoplophora glabripennis*) to hardwood trees in the European community.** Crop Protection. 21: 635-645.

McCune, B. 2000. **Lichen communities as indicators of forest health.** The Bryologist. 103(2): 353-356.

McRoberts, R.E. 1999. **Joint annual forest inventory and monitoring system, the North Central perspective.** Journal of Forestry. 97(12): 27-31.

McRoberts, R.E. 2005. **Overview of the enhanced Forest Inventory and Analysis program.** In: Bechtold, W.A.; Patterson, P.L., eds. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 1-10.

Montreal Process. 1999. **Criteria and indicators for the conservation and sustainable management of temperate and boreal forests: the Montreal process.** 2nd ed. Ottawa, Canada: Natural Resources Canada, Canadian Forest Service. 19 p.

Munn, I.A.; Barlow, S.A.; Evans, D.L.; Cleaves, D. 2002. **Urbanization's impact on timber harvesting in the south central United States.** Journal of Environmental Management. 64: 65-76.

National Climatic Data Center. 2010. **Plot time series data.** Washington, DC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Available at: http://lwf.ncdc.noaa.gov/temp-and-precip/time-series/index.php. (Accessed February 18, 2011).

National Oceanic and Atmospheric Administration. 2007. **C-CAP zone 65 2001-2006-Era land cover metadata.** Charleston, SC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Coastal Services Center. Available at http://www.csc.noaa.gov/digitalcoast/data/ccapregional/ (Accessed June 28, 2010).

Natural Resources Conservation Service. 2011. **The PLANTS database.** Greensboro, NC: U.S. Department of Agriculture, Natural Resources Conservation Service, National Plant Data Team. Available at http://plants.usda.gov (Accessed October 25, 2011).

Nowak, D.J.; Walton, J. 2005. **Projected urban growth (2000–2050) and its estimated impact on the US forest resource.** Journal of Forestry. 103(8): 383-389.

Pimentel, D.; Lach, L.; Zuniga, R.; Morrison, D. 2000. **Environmental and economic costs of nonindigenous species in the United States.** BioScience. 50(1): 53-65.

Poland, T.M.; McCullough, D.G. 2006. **Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource.** Journal of Forestry. 104(3): 118-124.

Powell, D.S. 1985. **Forest composition of Maine: an analysis using numbers of trees.** Resour. Bull. NE-85. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experimental Station. 40 p.

Radeloff, V.C.; Hammer, R.B.; Stewart, S.I.; Fried, J.S.; Holcomb, S.S.; McKeefry, J.F. 2005. **The wildland urban interface in the United States.** Ecological Applications. 15: 799-805.

Raile, G.K. 1982. **Estimating stump volume.** Res. Pap. NC-224. St Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 4 p.

Riemann, R.; Lister, T.; Lister, A.; Meneguzzo, D.; Parks, S. 2008. **Development of issue-relevant state level analyses of fragmentation and urbanization.** In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. Proceedings, Forest Inventory and Analysis (FIA) Symposium, 2008. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. [CD-ROM].

Riitters, K.H.; Wickham, J.D. 2003. **How far to the nearest road?** Frontiers in Ecology and the Environment. 1(3): 125-129.

Riva-Murray, K.; Riemann, R.; Murdoch, P.; Fischer, J.M.; Brightbill, R.A. 2010. **Landscape characteristics affecting streams in urbanizing regions of the Delaware River Basin (New Jersey, New York, and Pennsylvania, U.S.).** Landscape Ecology. 25(10): 1489-1503.

Rosenberg, K.V.; Rohrbaugh, R.W., Jr; Barker, S.E.; Lowe, J.D.; Hames, R.S.; Dhondt, A.A. 1999. **A land managers guide to improving habitat for scarlet tanagers and other forest-interior birds.** Ithaca, NY: Cornell University Lab of Ornithology. 23 p.

Scott, C.T. 1979. **Northeastern forest survey board-foot volume equations.** Res. Note NE-271. Broomall, PA: U.S. Forest Service, Northeastern Forest Experiment Station. 3 p.

Scott, C.T. 1981. **Northeastern forest survey revised cubic-foot volume equations.** Res. Note NE-304. Broomall, PA: U.S. Forest Service, Northeastern Forest Experiment Station. 3 p.

Showman, R.E.; Long, R.P. 1992. **Lichen studies along a wet sulfate deposition gradient in Pennsylvania.** The Bryologist. 95(2): 166-170.

Smith, G.; Coulston, J.; Jepsen, E.; Pritchard, T. 2003. **A national ozone biomonitoring program – results from field surveys of ozone sensitive plants in northeastern forests (1994-2000).** Environmental Monitoring and Assessment. 87: 271-291.

Smith, G.C.; Smith, W.D.; Coulston, J.W. 2007. **Ozone bioindicator sampling and estimation.** Gen. Tech. Rep. NRS-20. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 34 p.

Smith, J.E.; Heath, L.S.; Skog, K.E.; Birdsey R.A. 2006. **Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States.** Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p.

Sprague, E.; Burke, D.; Claggett, S.; Todd, A. 2006. **The state of Chesapeake forests.** Annapolis, MD: The Conservation Fund; and Washington, DC: U.S. Department of Agriculture, Forest Service. 114 p.

Steinman, J. 2000. **Tracking the health of trees over time on forest health monitoring plots.** In: Hansen, M.; Burk, T., eds. Integrated tools for natural resources inventories in the 21st century. Gen. Tech. Rep. NC-212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 334-339.

U. S. Census Bureau. 2007. **2007 economic census.** Washington, DC: U.S. Department of Commerce, Census Bureau. Available at: http://www.census.gov/econ/census07. (Accessed November 3, 2010).

U. S. Census Bureau. 2009. **2009 population estimates.** Washington, DC: U.S. Department of Commerce, Census Bureau. Available at: http://factfinder.census.gov/servlet/SAFFPopulation. (Accessed June 10, 2011).

U.S. Department of Agriculture, Animal and Plant Health Inspection Service [USDA APHIS]. 2010. **Asian longhorned beetle.** Washington, DC: U.S. Department of Agriculture, Animal Plant Health Inspection Service. Available at: http://www.aphis.usda.gov/plant_health/plant_pest_info/asian_lhb/background.shtml. (Accessed April 1, 2011).

U.S. Department of Agriculture, Forest Service. 2008. **Asian longhorned beetle, pest alert.** NA-PR-01-99GEN. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 2 p. Available at: http://www.na.fs.fed.us/pubs/palerts/alb/alb_pa.pdf. (Accessed April 1, 2011).

U.S. Department of Agriculture, Forest Service. 2009. **Forest Inventory and Analysis national core field guide (phase 2 and 3).** Version 4.0. Washington, DC: U.S. Department of Agriculture, Forest Service. Available at: http://www.fia.fs.fed.us/library/field-guides-methods-proc/ (Accessed December 2009).

Vitousek, P.M.; D'Antonio, C.M.; Loope, L.L.; Westbrooks, R. 1996. **Biological invasions as global environmental change.** American Scientist. 84: 468-478.

Wear, D.N.; Liu, R.; Foreman, M.J.; Sheffield, R.M. 1999. **The effects of population growth on timber management and inventories in Virginia.** Forest Ecology and Management. 118(1-3): 107-115.

Westfall, J.A.; Frieswyk, T.; Griffith, D.M. 2009. **Implementing the measurement interval midpoint method for change estimation.** In: McRoberts, R.E.; Reams, G.A.; Van Deusen, P.C.; McWilliams, W.C., comps. Proceedings, Forest Inventory and Analysis (FIA) symposium, 2006. Gen. Tech. Rep. WO-79. Washington, DC: U.S. Department of Agriculture, Forest Service: 231-236.

Wilcox, B.A.; Murphy, D.D. 1985. **Conservation strategy: the effects of fragmentation on extinction.** American Naturalist. 125(6): 879-887.

Woodall, C.W.; Amacher, M.C.; Bechtold, W.A.; Coulston, J.W.; Jovan, S.; Perry, C.H.; Randolph, K.C.; Schulz, B.K.; Smith, G.C.; Tkacz, B.; Will-Wolf, S. 2010. **Status and future of the forest health indicator inventory of the United States.** Environmental Monitoring and Assessment. 177: 419-436.

Woodall, C.W.; Monleon, V.J. 2008. **Sampling protocols, estimation procedures, and analytical guidelines for down woody materials indicator of the Forest Inventory and Analysis Program.** Gen. Tech. Rep. NRS-22. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 68 p.

Lister, Tonya W.; Gladders, Glenn; Barnett, Charles J.; Brand, Gary J.; Butler, Brett J.; Crocker, Susan J.; Domke, Grant M.; Griffith, Douglas M.; Hatfield, Mark A.; Kurtz, Cassandra M.; Lister, Andrew J.; Morin, Randall S.; Moser, W. Keith; Nelson, Mark D.; Perry, Charles H.; Piva, Ronald J.; Riemann, Rachel; Woodall, Christopher W. 2012. **Delaware's Forests 2008.** Resour. Bull. NRS-62. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 56 p. [DVD included].

The fifth full inventory of Delaware's forests reports an 8 percent decrease in the area of forest land to 352,000 acres, which cover 28 percent of the State's land area and has a volume of approximately 2,352 cubic feet per acre. Twenty-one percent of the growing-stock volume is red maple, followed by sweetgum (13 percent), and loblolly pine (12 percent). All species of oaks combined account for 24 percent of the volume. Red maple is the most abundant species in terms of number of trees and the population had been rising through the 1980s and 1990s, but current data show little change since 1999. Oak species and loblolly pine decreased in numbers of trees and volumes. Seventy-three percent of forest land consists of large-diameter trees and 10 percent is in the small-diameter stand-size classes. Average annual growth as a percentage of total growing-stock volume increased from 2.3 to 3.9 percent between 1999 and 2008, while removals and mortality changed little. Additional information on forest attributes, land-use change, carbon, timber products, and forest health is presented in this report. A DVD included in the report provides information on sampling techniques, estimation procedures, a glossary, tables of population estimates, raw data, and a data summarization and reporting tool.

KEY WORDS: inventory, forest statistics, forest land, volume, biomass, carbon, growth, removals, mortality, forest health, Delaware

DVD Contents

Delaware's Forests 2008 (PDF)

Delaware's Forests: Statistics, Methods, and Quality Assurance (PDF)

Delaware Inventory Database (CSV file folder)

Delaware Inventory Database (Access file)

Field guides that describe inventory procedures (PDF)

Database User Guides (PDF)

Delaware's Forests 2008
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NRS-62

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