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Abstract

This report summarizes the third full annualized inventory of Indiana forests conducted from 2009 to 2013 by the Forest Inventory and Analysis program of the Northern Research Station in cooperation with the Indiana Department of Natural Resources, Division of Forestry. Indiana has nearly 4.9 million acres of forest land with an average of 454 trees per acre. Forest land is dominated by the white oak/red oak/hickory forest type, which occupies 72 percent of the total forest land area. Most stands are dominated by large trees. Seventy-eight percent of forest land consists of sawtimber, 15 percent contains poletimber, and 7 percent contains saplings/seedlings. Growing-stock volume on timberland has been rising since the 1980s and currently totals 9.1 billion cubic feet. Annual growth outpaced removals by a ratio of 3.3:1. Additional information on forest attributes, changing land use patterns, timber products, and forest health is included in this report. Detailed information on forest inventory methods and data quality, a glossary of terms, tabular estimates for a variety of forest characteristics, and additional resources are available online at http://dx.doi.org/10.2737/NRS-RB-107.

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Cover: Beautiful autumn view of Clark State Forest in Indiana from the fire tower. Photo by Indiana Department of Natural Resources, used with permission.

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Foreword

Welcome to Indiana Forests 2013, the latest results of our statewide forest inventory. This inventory is an ongoing joint venture between the Indiana Department of Natural Resources Division of Forestry and the Forest Inventory and Analysis program of the U.S. Forest Service. Results from this seventh inventory show Indiana forests continue to grow more wood than is being harvested, providing an important and essential element to Indiana's economy, the wood industry, and individual woodland owners. Indiana forests have expanded to nearly 4.9 million acres with an average volume of over 2,000 cubic feet per acre. These productive forests provide homes and food for wildlife; clean our water and air; protect soil that would otherwise disappear due to erosion; and provide fine quality hardwood products to Hoosiers, Americans, and the world.

Indiana is fortunate to have a productive and high quality stand of forest land, yet the industry is vulnerable to economic cycles. Eleven percent of all exported agricultural products are wood products, but that has not kept pace with other agriculture exports. Opportunities abound to further enhance the value of Indiana wood products to the economy through its export channels as well as by providing employment. Every 1,000 acres of forest land directly supports nearly eight manufacturing jobs in the primary, secondary, and ancillary wood-using industry.

While Indiana forests continue to be resilient and are actually expanding, there are concerns. Regeneration of some shade intolerant species such as oaks and hickories could be better. Average tract size continues to decrease with indications these holdings may also be changing ownership. Ash tree mortality resulted in a loss of 11 million cubic feet of volume per year, mostly attributed to the emerald ash borer, a nonnative insect accidentally introduced in Michigan that has spread to other states. There are a growing number of invasive plant species outcompeting native vegetation for sunlight and nutrients. In addition, white-nose syndrome is deadly to many of our beneficial forest- and cave-dwelling bats. All of these issues need to be monitored, and future management decisions may need to be altered to address such concerns.

I invite you to read and interpret the results of Indiana Forests 2013. Hopefully you enjoy perusing the information. As a result, perhaps you will become more interested in our State's forests and then participate in the discussions about the future of forests and forestry in Indiana.

John R. Seifert

John Seifert, State Forester

Contents

The one-mile loop trail at Tall Timbers Nature Preserve passes by a stand of old growth forest along Big Walnut Creek.
Photo by Indiana Department of Natural Resources, used with permission.

Highlights

On the Plus Side

- Eighty-four percent of Indiana's forest land is privately owned by corporations and family forest owners. The vast majority, an estimated 3.6 million acres (73 percent), are owned by family forest owners. An estimated 85,000 family forest ownerships across Indiana each own at least 10 acres of forest land.
- The statewide increase in timberland area between 1986 and 2013 may be attributed to farmland reversion; approximately 750,000 acres, nearly 20 percent, of privately owned forest land are enrolled in the Classified Forest and Wildlands Program (CFW). More than 13,000 landowners participate in the CFW program, and it appears conservation and stewardship measures are affecting the extent and quality of Indiana forests.
- Over the past six decades, the area of Indiana timberland increased slightly from 4 to 4.7 million acres. Over that same period, the volume of growing-stock timber nearly quadrupled from 2.6 to 9.5 billion cubic feet.
- Yellow-poplar continues to be the most voluminous species followed by sugar maple and white oak. Black cherry had the greatest percentage increase in volume—17 percent.
- The mortality rate in Indiana (1.1 percent) is similar to that in the neighboring states of Ohio (1.1 percent), Kentucky (1.0 percent), Illinois (1.6 percent), and Michigan (1.1 percent).
- During the recent recession, the number of employees working in the forest products industry hit its lowest level in 2010, while annual payroll (actual dollars) and the total value of shipments (actual dollars) bottomed out in 2009. After decreasing by 44 percent between 2004 and 2010, the number of employees working in the forest products industry increased by 13 percent between 2010 and 2013.

Issues to Watch

- Indiana forests are being affected by urbanization and fragmentation. Only 21 to 45 percent of the forest land in Indiana meets the definition of core forest statewide, and between 24 and 41 percent of the forest land is in unconnected fragments.

- Future changes in Indiana's forest land will depend on the pace of land development and, to a great extent, the economics of farming since idle farm land has been the source of much of the increase in forest land. Recently farm land prices have increased, suggesting that losses in farmland will likely slow or reverse. Increasing farmland values could also shift more development pressure to forest land.
- Invasive plant species were detected on more than 90 percent of the inventory plots. The data suggest that these plants are present throughout the State and have become widespread.
- Since 2008, mortality of live ash trees on forest land has increased by nearly two-thirds, averaging close to 1 million trees per year. By volume, this mortality represents an annual loss of 11 million cubic feet, an increase of more than 25 percent from 2008. This rate of mortality and volume loss is expected to continue through the next 5-year inventory cycle (through 2018) and then decrease and return to normal mortality levels as emerald ash borer completes its mortality wave through Indiana, which is expected to occur between 2018 and 2020.
- The current trajectory away from dominance by oaks represents a long, slow change that has implications for biodiversity, wildlife, recreation, and the forest products industry.
- Stands continue to shift to the sawtimber (large diameter) size class. In 2013, approximately 80 percent of the stands are in age classes greater than 40 years old and 78 percent are in sawtimber-size stands. Indiana forests are maturing. Currently, nearly half (48 percent) of the stands are over 61 years of age.
- The fungus, *Geosmithia morbida*, a component of thousand cankers disease (TCD), has been detected in Indiana. The fungus is deadly to black walnut trees but has not yet been detected in any black walnut trees. In Indiana there are an estimated 40.3 million walnut trees with a d.b.h. >1 inch. Approximately 17.7 million board feet of black walnut are harvested annually with a value of $21.4 million. If all forest walnut trees in Indiana died because of TCD, it would represent a $1.7 billion loss. Because walnut is a high value species, it is important for landowners to monitor black walnut stands for the presence of the fungus.

Background

Elk Creek trailhead of the Knobstone Trail in Jackson-Washington State Forest preserves the region's unique forested knobs. Photo by Indiana Department of Natural Resources, used with permission.

Forest Inventory Primer

Why inventory?

Inventories are the foundation for management planning (Schreuder et al. 1993). A viable business must have up-to-date inventories on all parts and related activities in order to make sound management decisions (Anderson et al. 1976). In the context of a national forest survey, a contemporary nation must have up-to-date forest inventories on all parts and related activities in order to frame forest policy and make sound forest management decisions that may include protection, utilization, and sustainability. Forest inventories have a long and illustrious history in the U.S. Forest Service. It is difficult to manage forest resources without a good inventory. If resource supplies run low or are feared to be low, or are affected by diseases, insects, drought, floods, or wind, monitoring of the forest resource becomes equally important (Schreuder et al. 2004).

The U.S. Forest Service, Forest Inventory and Analysis (FIA) program serves this capacity. FIA strategic, design-based, multi-resource inventories provide current information on the amount of and trends in forest resources. The measurement and remeasurement of permanent field plots provides information on forest composition; land-use changes including disturbance; forest growth, removals, and mortality; and other variables related to forest condition.

What is a tree?

Trees are perennial woody plants with central stems and distinct crowns. In general, the Forest Inventory and Analysis (FIA) program defines a tree as a woody plant usually having one or more erect perennial stems, a stem diameter at breast height of at least 3.0 inches, a more or less definitely formed crown of foliage, and a height of at least 15 feet at maturity (see glossary of terms in the Statistics, Methods, and Quality Assurance section located online at http://dx.doi.org/10.2737/NRS-RB-107). A complete list of the tree species measured in this inventory can be found in Appendix 1. Throughout this report, the size of a tree is expressed in diameter at breast height (d.b.h.), in inches. This is the measured diameter, outside bark, at a point 4.5 feet above ground.

What is a forest?

FIA defines forest land as land at least 10 percent stocked by trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands, that are at least 10 percent stocked with trees, and forest areas adjacent to urban and built-up lands. The minimum area for classification of forest land is 1 acre and 120 feet wide measured stem-to-stem from the outer-most edge. Unimproved roads, trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet wide. There are more specific area criteria for defining forest land near streams, rights-of-way, and shelterbelt strips (U.S. Forest Service 2012).

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

FIA defines three types of forest land:

- Timberland is forest land that is producing or is capable of producing crops of industrial wood and is not withdrawn from timber utilization by statute or administrative regulation. These areas are capable of producing in excess of 20 cubic feet per acre (equivalent to about ¼ cord) per year of industrial wood in natural stands. Inaccessible and inoperable areas are included.
- Reserved forest land is all forest land that is withdrawn from timber utilization through statute without regard to productive status, e.g., some natural areas in state parks, national parks, and Federal wilderness areas.
- Other forest land consists of forest land that is not capable of growing 20 cubic feet per acre per year and is not restricted from harvesting, e.g., some surface-mined areas with extremely degraded soil and some poorly drained areas where water inhibits tree growth. Sometimes such forest lands are referred to as being "less productive" or "unproductive" with respect to wood fiber production.

Timberland accounts for 96.7 percent of the forest land in Indiana. About 3.3 percent of the forest land is deemed reserved.

How many trees are in Indiana?

Indiana forests dominate the landscape of southern Indiana and are composed primarily of oak/hickory forest types. Indiana's forest land contains approximately 2.2 billion live trees with a d.b.h. of at least 1 inch. The exact number of trees is not known because only a sample of trees was measured (35,807 trees), roughly a sampling rate of 1 out of every 61,771 trees. These trees were measured on a total of 1,809 forest plots.

How do we estimate a tree's volume?

Forest inventories typically express volume in cubic feet, but the reader may be more familiar with cords (a stack of wood 8 feet long, 4 feet wide, and 4 feet high). A cord of wood contains approximately 79 cubic feet of solid wood and 49 cubic feet of bark and air.

Volume can be precisely determined by immersing a tree in a pool of water and measuring the amount of water displaced. Less precise, but much cheaper and easier to do with living trees, is a method adopted by the U.S. Forest Service's Northern Research Station. In this method, several hundred trees were cut and detailed diameter measurements were taken along their lengths to accurately determine their volumes (Hahn 1984). Statistical tools were used to model these data by species group. Using these models, we can produce individual tree volume estimates based on species, diameter, and tree site index.

This method was also used to calculate sawtimber volume estimates. FIA commonly reports sawtimber board-foot volume using the International ¼-inch rule. In Indiana, the Doyle log rule is commonly used. Although most of the sawtimber estimate findings in this report are presented using the International ¼-inch rule, due to State and local interest, a number of sawtimber volume, growth, and removal estimate discussions are presented using the Doyle log rule. To convert from International ¼-inch rule to Doyle or Scribner board-foot scales see Smith (1991). An important point to remember is that log rules are just estimates of the final board-foot and cubic foot volume. Cassens (2001) presents background and practical usage of the three log rules.

How much does a tree weigh?

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

How can I analyze FIA data?

In the past, FIA inventories were completed every 10 to 20 years. With these periodic inventories, it took decades to identify trends. With the new annual inventory, some trends will be easier to identify because a subset of observations (approximately 20 percent) are made every year. It is still necessary to look over long time periods because many trends, like succession, can be difficult to discern in short time spans. Technologies, definitions, methods, location, ownership, precision, scale dependencies, and temporal trends are important factors to consider when analyzing FIA data. Estimates are derived from sample plots throughout a state. Larger areas of interest will contain more plots and thus produce more reliable estimates. For example, there may not be a sufficient number of plots within a county or single forest type with which to provide reliable estimates. It also is important to consider the degree to which a variable can be measured precisely. For instance, a stand variable like age is not as precise as forest type, and a tree variable like crown dieback is not as precise as diameter. Definitions and procedures have also changed over time. Prior to the 1999-2003 inventory cycle in Indiana (Woodall et al. 2005), for most attributes FIA reports and databases only included data collected on timberland plots. As a result, trend analyses that use data prior to 1999 are limited to timberland for many attributes. Since 1999, the new annual inventory design allows us to report volumes on all forest land. Comparisons of current growing-stock volume to estimates prior to 1999 should be made with caution. Estimates of growth, removals, and mortality are based on remeasured plots across all forest land. In this report, most trend analyses focus on changes on forest land since 2008.

Comparing data from different inventories

The annual inventory measures a subset of observations (approximately 20 percent) every year. After 5 years of data collection, an analysis and report are created based on the full set, or "cycle" of plots. This creates a yearly moving window of 5-year cycles. The last year of each full cycle is used to identify the full set of plots. For example, the cycle of plots measured from 2009 through 2013 are collectively labeled the "2013 inventory" and were used to produce this 2013 report. Previous inventories of Indiana's forest resources were completed in 1950 (Winters 1953), 1967 (Spencer 1969), 1986 (Smith and Golitz 1988, Spencer et al. 1990), 1998 (Schmidt et al. 2000), 2003 (Woodall et al. 2005), and 2008 (Woodall et al. 2011).

To improve the consistency, efficiency, and reliability of the inventory, updates have been implemented over time. For the sake of consistency, a new, national plot design was implemented by all FIA units across the United States in 1999 (see the Statistics, Methods, and Quality Assurance section online). These major changes are reflected in the Indiana annual inventory that started in 1999. Prior to this new plot design, fixed and variable-radius subplots were used in the 1986 and 1998 inventories. The new design uses fixed-radius subplots exclusively. Both designs have strong points but they often produce different classifications for individual plot characteristics. Unpublished FIA research comparing these plot designs showed no noticeable difference in volume and tree-count estimates. Fewer and less precise forest types were assigned in the periodic inventories, but methods for determining stocking, forest type, and stand-size estimates have been improved twice since the annual inventory started. All annual data were updated with the improvements to facilitate easier temporal analyses. For additional information, see Arner et al. (2003).

Information published in this report and in related tables is based on the Forest Inventory and Analysis Database (FIADB), accessed from January-June 2015. Data were collected under field guides 4.0 to 6.02 and were compiled in National Information Management System (NIMS) version 6.0, installed on November 15, 2012. Due to occasional changes to NIMS and FIADB, trend analyses should be made using FIA's online estimation tools, not by comparing published reports or tables. FIA estimates, tabular data, and maps may be generated at http://www.fia.fs.fed.us/tools-data/. See Bechtold and Patterson (2005) and O'Connell et al. (2014) for definitions and technical details. A glossary of terms is also available in the Statistics, Methods, and Quality Assurance section located online at http://dx.doi.org/10.2737/NRS-RB-107.

A word of caution on suitability and availability

The FIA definition of reserved forest land does not account for all the forest land that is unsuitable or unavailable for timber harvesting. FIA does not identify timberland withheld from timber utilization or timberland that is not suitable or accessible for timber harvesting. It would be difficult to identify and maintain an up-to-date list of all lands withheld and not suitable or accessible for timber harvesting due to changing laws, owner objectives, markets, and site conditions.

Many factors make timberland unsuitable or unavailable for timber harvesting. For example, operability on some sites (e.g., wet or steep sites) is poor, and there are limitations related to wildlife. Threatened or endangered species habitat and old-growth areas may be subject to harvest restrictions. Some landlocked locations may be denied access, and the cost of entering some sites is prohibitive. There also are visually sensitive areas where aesthetics outweigh gains from harvests. FIA includes variables such as slope, physiographic class, and disturbance class that could help identify some lands with timber harvest constraints. It is also difficult to determine the availability of wood from private land. Many private land owners do not consider harvesting timber as an option for their timberland. The National Woodland Owner

Survey (NWOS) conducted by FIA quantifies private land owners' management objectives and attitudes toward timber harvesting. These data are useful in assessing how much timber is actually available for harvesting. Thus, forest inventory data alone are inadequate for determining the area of forest land available for timber production. Additional factors, like those provided above, need to be considered when estimating the timber base, and these factors may change with time.

Introduction

This report summarizes Indiana's third cycle of the annual forest inventory and covers the years 2009 through 2013. The completion of this cycle provided the Northern Research Station's Forest Inventory and Analysis program (NRS-FIA or FIA) with the opportunity to remeasure plots from the second annual inventory cycle (2004-2008) (Woodall et al. 2011). In addition, trend estimates of average annual change (growth, mortality, and removals) were generated by remeasuring plots from the first cycle (1999-2003) (Woodall et al. 2005).

FIA groups contiguous counties that have similar forest cover, soil, and economic conditions into geographic units. Estimates of area and volume are more accurate at the unit level than at the individual county level because of the larger number of plots used to make the estimates. In addition, plots at the unit level are stratified into estimation units, meaning that the area for each unit is set to a known value, usually taken from the U.S. Census Bureau, whereas the area for counties is determined by the distribution of plots. Because of this, most analysis in this report will be at the state or unit level. County level data are available but should be used with caution.

Indiana is divided into four FIA units. In the fertile corn belt (Northern Unit), lands are well-suited for agriculture. Terrain in this glaciated unit is mostly level to rolling with rich soils. The Knobs, Lower Wabash, and Upland Flats Units encompass Indiana's hill country where Indiana's topography generally becomes relatively rough and discourages farming in many of the areas. There is a close correlation between the amount of forest land and landscape relief. The relatively flat Northern Unit is sparsely forested. The three southern tier survey units cover about 40 percent of the land and water area but contain over 70 percent of the forest, with the Knobs survey unit containing about 40 percent of the forest (Fig. 1).

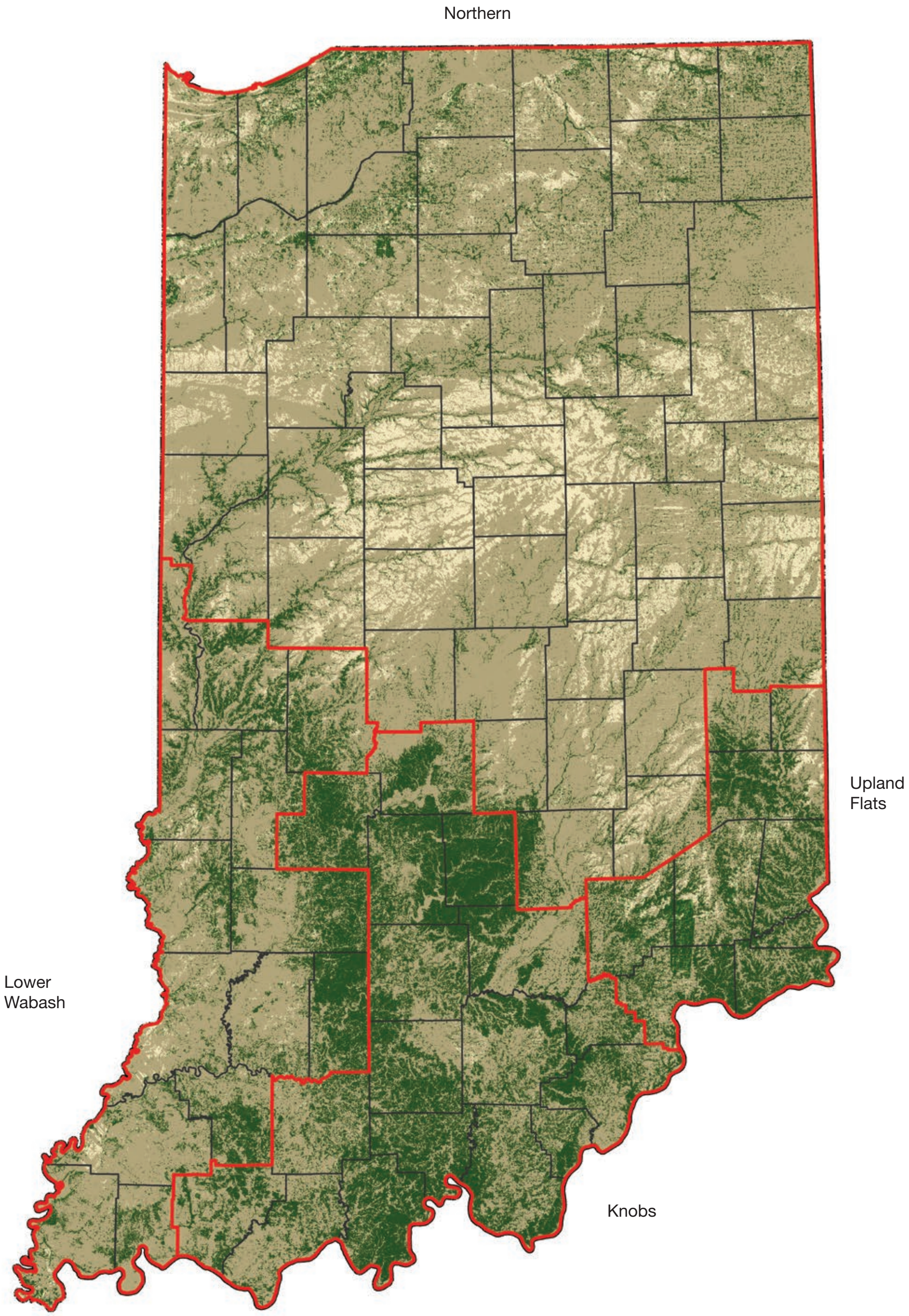

Figure 1.—Forest cover (dark green) by FIA unit, Indiana, 2013. Forest cover was derived by linking plot data to MODIS satellite pixels (250 m) which utilizes gradient nearest neighbor techniques (Wilson et al. 2012).

Log hauling team, Forest Township in Clinton County, Indiana, circa 1915. Photo by Sherman Wright, from Indiana Historical Society.

Historic Setting

Oaks (*Quercus*) and hickories (*Carya*) have been important species in Indiana and throughout the Central Hardwood region for the last several millennia (Fralish 2004, IN DNR 2008, Whitehead 1997). Following the retreat of the last glaciers from the Midwest, spruce (*Picea*) and fir (*Abies*) forests developed across prehistoric Indiana, which gave way to pine (*Pinus*), then hardwoods, approximately 9,500 years ago (Whitehead 1997). As the climate continued to warm and become drier, prairies expanded east through portions of present-day Indiana and Ohio, bringing with them an associated increase in wildfire (Fralish 2004). During this period it is likely oaks and hickories dominated the hardwood forests of the Midwest, eventually moving into uplands as precipitation levels rose after 5,000 years before present. The eventual invasion by mesophytic hardwoods (e.g., beech [*Fagus*], maple [*Acer*], ash [*Fraxinus*]) into bottoms and moist, rich slopes was associated with a period 5,000-6,000 years before present (Fralish 2004, IN DNR 2008, Parker and Ruffner 2004). It is likely that the advance of mesophytic hardwoods was slowed into uplands due to the use of fire and land clearing by early Native American cultures (Fralish 2004). Jenkins (2013) provides a more detailed account of prehistoric and presettlement forest conditions in Indiana.

Most of the forests in Indiana are in some stage of recovery from human impacts. No official inventories of Indiana's forested landscape exist prior to the mid-1900s. However, the forest primeval of Indiana as recorded in the original U.S. land surveys and an evaluation of previous interpretations of Indiana vegetation show that Indiana was more than 85 percent forest land (20 million acres) as recently as 200 years ago (Carman 2013, Potzger et al. 1956). The type of cutting that occurred in the late 1800s had a profound effect on the composition of Indiana's present forest. The high quality trees were cut off first: black walnut, yellow-poplar, black cherry, and white oak.[1] Later cuts removed every other marketable tree left on the land. The residual stands consisted of cull trees, small trees, and species not desirable for market use. The areas were often burned repeatedly to clear the brush (DenUyl 1954). The land was converted to agricultural uses and was settled. Indiana was left with a highly disturbed and relatively young forest resource that regenerated under the influence of frequent fire, widespread grazing, farming, and farm abandonment. These disturbances favored the accumulation of oak and hickory reproduction more so than American beech, maple, yellow-poplar and other associates (Abrams 2003). By the early 1900s, the majority of Indiana forests had been cleared for agriculture or cut to provide raw materials for a growing nation. Considering the marketability and utilization standards of this period, there must have been many oak trees over 24 inches in diameter (DenUyl 1954). The estimated total cut of hardwood sawtimber during the period from 1869 to 1903 was approximately 30 billion board feet, which equals an average yearly cut of about 800 million board feet. The records of amount of lumber cut are conservative because some operating sawmills did not report their cut. By that time, forests comprised approximately 1.5 million acres, or a mere shadow of about 7 percent of the original amount of forest land in the State. With reductions in large-scale clearcutting, wildfire, and woodland grazing in the mid-20th century, mesic species such as sugar maple, American beech, and yellow-poplar regenerated with notably greater success than oaks—even on sites that previously supported a vigorous oak overstory. Maple and beech were well adapted to the shaded understory of existing oak forests, and in the absence of periodic fires, the fast growing yellow-poplar was able to outcompete oaks and increase in dominance (Shifley and Woodall 2007). Carman (2013) provides a more detailed account of Indiana forest management history and practices.

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[1] Scientific names for all trees species are listed in Appendix 1.

What happened to the forests during the 20th century?

In 1950, Indiana forest land totaled 4.1 million acres (Winters 1953). By 2013, the amount of forest land increased by 800,000 acres to nearly 4.9 million acres (Fig. 2); however, the State total decreased from 1950 to 1967 (Schmidt et al. 2000), although the amount of timberland in southern Indiana increased. The loss, which was concentrated in the north-central part of the State, may be attributed to increased farming and the evolution from small family-run farms to larger agricultural operations. Between 1967 and 1986 timberland decreased in southern Indiana. The amount of forests being cleared for agricultural purposes leveled out or declined in the north; however, clearing forests for residential and commercial use continued, especially in southern Indiana.

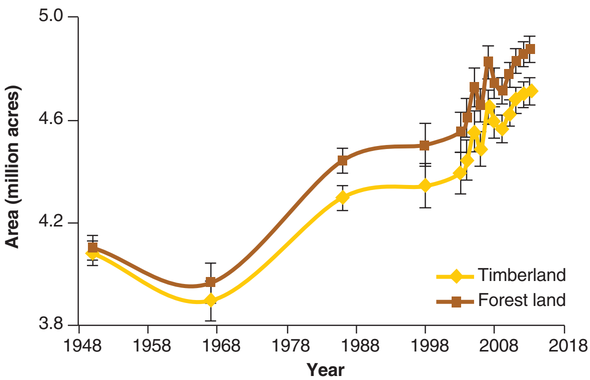

Figure 2.—Area of forest land and timberland by inventory year, Indiana. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

What does this mean

The forest composition and size structure in Indiana (and throughout the Central Hardwood region) are dynamic and are a product of past disturbances. Sixty years ago forests in Indiana were dominated by oaks (Winters 1953), but the original land surveys prior to widespread European emigration indicated a balanced mix of oak and beech-maple forest (Lindsey 1997, Potzger et al. 1956, Shifley and Woodall 2007).

The statewide increase in timberland area between 1986 and 2013 may be attributed to farmland reversion; however, it also indicates that conservation and stewardship programs and measures are affecting the extent and quality of Indiana forests. This trend has continued for three inventory periods. For example, since its inception in 1985, more than 21,000 Indiana farmers have participated in the Conservation Reserve Program (CRP). Lands enrolled in the CRP cumulatively top more than

280,000 acres and include over 41,000 acres planted in trees and over 122,000 wildlife habitat acre plantings. CRP is a voluntary program that allows eligible landowners to receive annual rental payments and cost-share assistance to establish long-term, resource-conserving covers on eligible farmland throughout the duration of their 10 to 15 year contracts. Under CRP, farmers plant grasses and trees in fields and along streams or rivers. The plantings prevent soil and nutrients from washing into waterways, reduce soil erosion that may otherwise contribute to poor air and water quality, and provide valuable habitat for wildlife. Indiana producers or landowners who are interested in more information regarding CRP should contact their local Farm Service Agency (FSA) County Office or visit FSA online at www.fsa.usda.gov. In addition, privately owned forest land enrolled in the Classified Forest and Wildlands Program (CFWP) approximates 750,000 acres, or nearly 20 percent of the privately owned forest land (Fig. 3). More than 13,000 landowners participate in the CFWP.

It appears that forest land has rebounded and new forested habitat is being developed for wildlife. More streams and riversides are becoming forested in the north, helping to filter and clean the State's water. Through time, resources for forest products in northern Indiana may increase. Concurrent with this recovery, Indiana forests have continued to provide the raw materials needed by Indiana's forest products industry. Conversely, southern Indiana has the most continuous forests in the State. Wildlife habitats will be affected should these forests decline or be parceled into smaller sections. Smaller and separate pieces of forest land are less likely to support animals that require large, forested areas. Managing resources for forest products may also become more challenging. In addition, road construction could rise due to the increased demand and need to reach the more numerous, smaller, and separate forests.

Although the condition of Indiana forest land has progressively improved since 1967, there have been some setbacks and challenges. Starting with the chestnut blight (*Cryphonectria parasitica*) in the 1920s, the list of exotic insects and diseases found in Indiana continues to grow, with new additions becoming more frequent. By the mid-1970s, Dutch elm disease (*Ophiostoma ulmi*) had devastated elms in the State. More recent and recurring forest health problems include the emerald ash borer (*Agrilus planipennis*). In addition, the thousand cankers disease (*Geosmithia morbida*) that infects black walnut poses a real threat. These threats and other concerns are addressed in this report and make managing Indiana's future forests a continuing challenge.

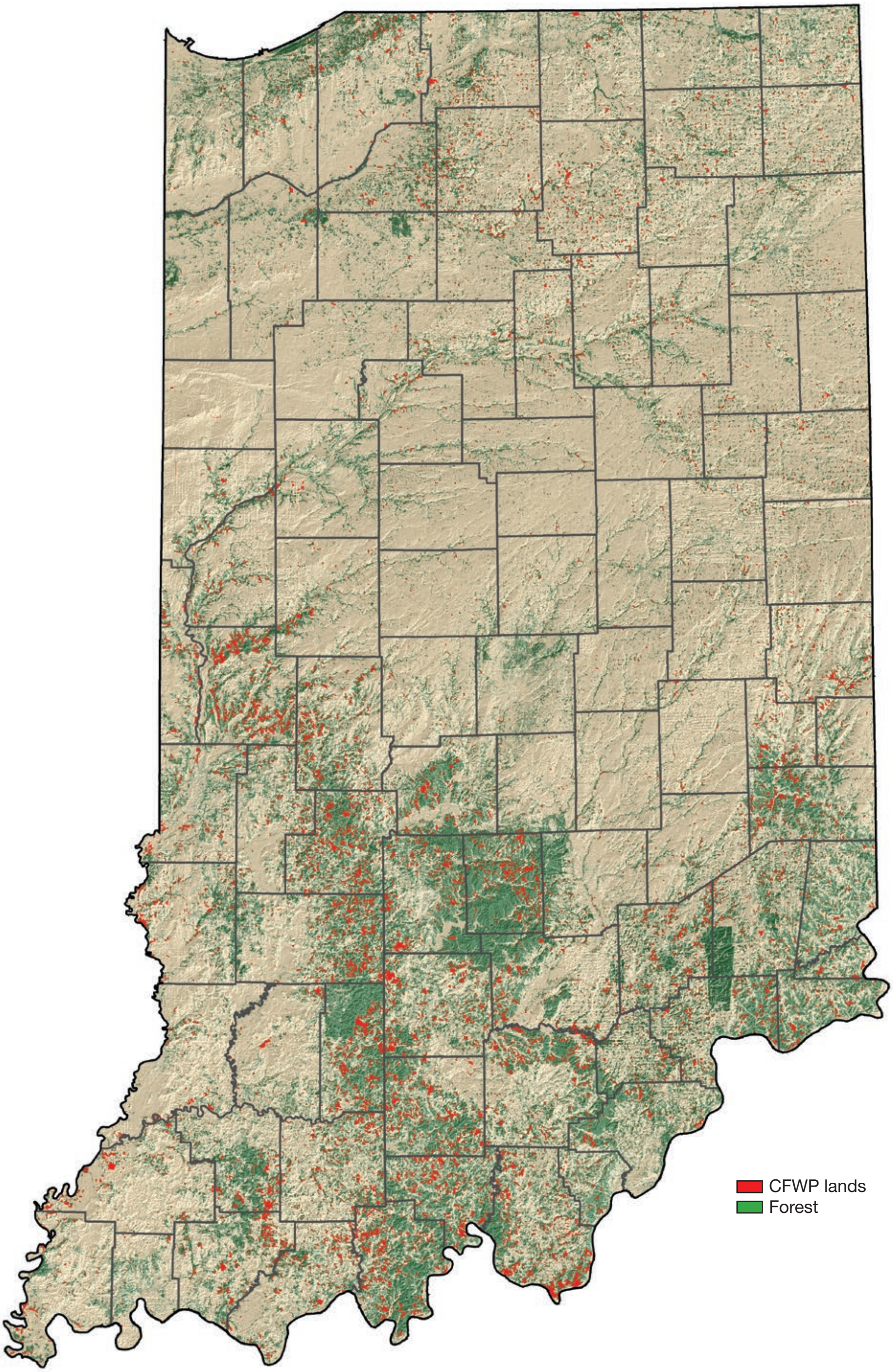

Figure 3.—Privately owned forest lands enrolled (red) in the Classified Forest and Wildlands Program (CFWP), Indiana, 2013.

Forest Features

Spring ephemerals emerge in the old growth forest at Calvert and Porter Nature Preserve. Photo by Indiana Department of Natural Resources, used with permission.

Forest Area

Background

The quantity, quality, structure, composition, age, and general health of our forest and timber lands are key measures for assessing forest resources and making informed decisions about their management and future. Trends in the forest land base serve as a barometer of forest sustainability, wetland and forest health, and land use stewardship practices. Gains and losses in forest area directly affect the benefits forests provide, including clean air and water (watershed protection), wildlife habitat, prevention of fertile soil erosion, materials for medicines, renewable energy development, wood products, and outdoor recreation opportunities like hiking, biking, camping, fishing, hunting, viewing wildlife, and enjoying nature.

FIA broadly classifies forest land into three components that describe the potential of the land to grow trees: reserved forest land, timberland, and other forest land. These categories help increase our understanding of the value and benefits of the forest resource and guide forest management and planning for future generations.

What we found

Indiana forests have increased in area by 800,000 acres since 1950 and now comprise nearly 4.9 million acres, with the percentage of land in forest cover increasing from north to south (Fig. 4). The State is divided into four survey units (Fig. 5), with forest land unevenly distributed among units: Northern (1.4 million acres), Lower Wabash (930,000 acres), Upland Flats (676,000 acres), and Knobs (1.9 million acres). The Knobs and Lower Wabash Units showed timberland losses between 1986 and 2003 but rebounded by 2013 (Fig. 6). The Upland Flats and Northern Units have experienced gains in forest land since 1986, and these gains combined with the units that have increased since 2003, account for the recent increase in forest land for the State.

Forest lands cover 21 percent of the land area in Indiana (Fig 7). Successive inventories have shown forest land area steadily increasing since 1986. The net increase of 131,229 acres (2.8 percent) since 2008 is just barely large enough to be statistically different from the 2008 estimate, although data from other sources showing decreases in farm land acreage support this increase in forest land. In terms of gross change, plot data show both gains and losses in forest. Since 2008 approximately 95,000 acres of forest land have been converted to nonforest land uses, and 177,000 acres of nonforest land have reverted to forest. Since 1950, the amount of land in farms (including farm woodlots) has decreased by 4.9 million acres (Fig. 8). Although a large amount of farm land has been developed to meet the needs of a growing population, some has been left untended and has reverted to forest through natural succession.

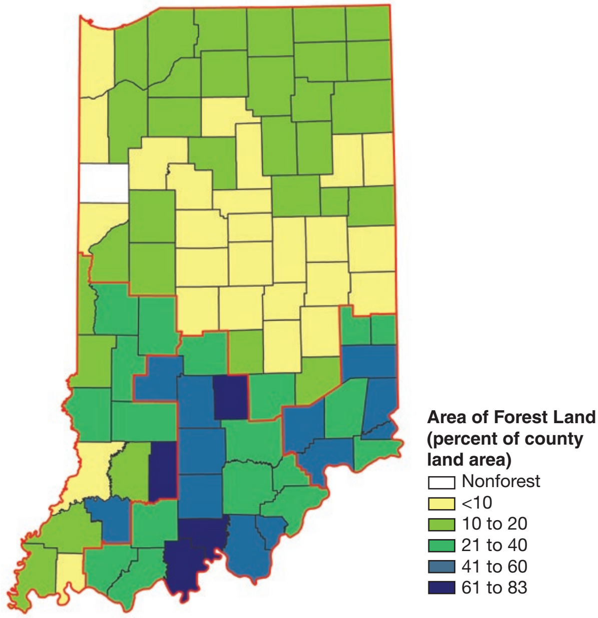

Figure 4.—Distribution of forest land area by county, Indiana, 2013.

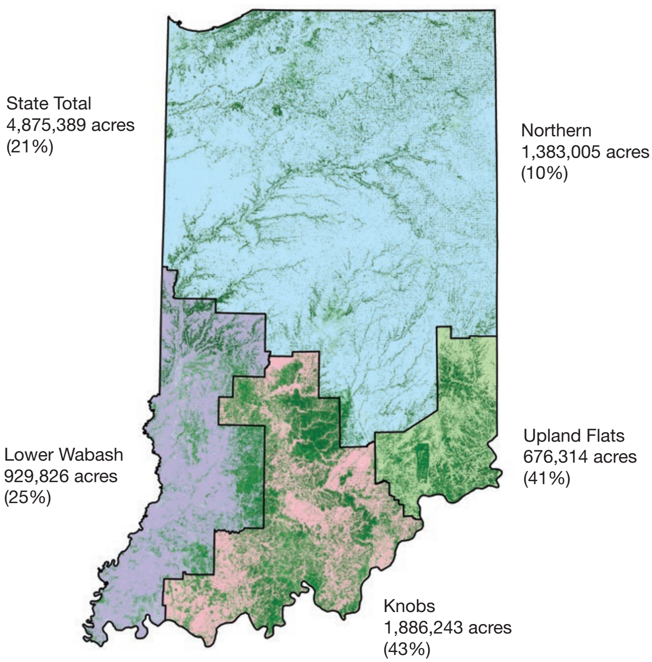

Figure 5.—Acreage of forest land and percentage of land in forest by FIA unit, Indiana, 2013.

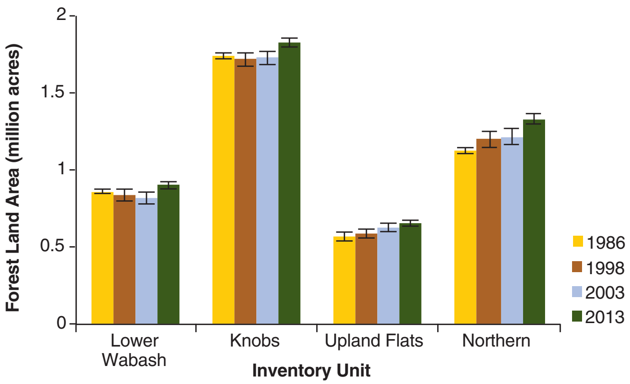

Figure 6.—Area of timberland by inventory unit and year. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

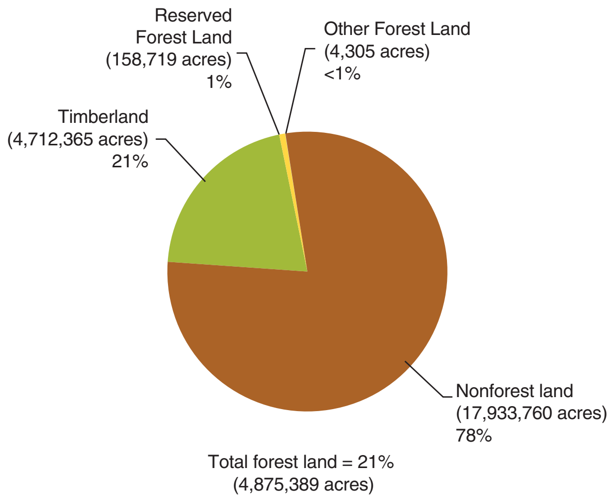

Figure 7.—Land area (acres) by major use, Indiana, 2013.

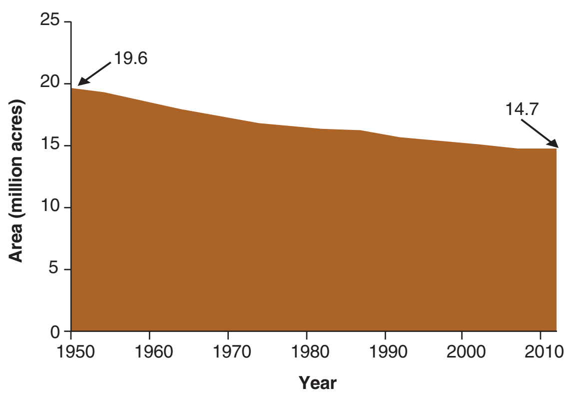

Figure 8.—Area of farm and agricultural acreage (including farm woodlots), Indiana, 1950-2012 (NASS 2014).

What this means

Increases in forest land have corresponded with decreases in farmland, but because of increased development in Indiana and a slowing in farm land losses, recent changes in total forest land have been small. These trends may indicate that the area of forest land in Indiana is nearing a peak. Future changes in Indiana forest land will depend on the pace of land development, and to a great extent on the economics of farming since idle farmland has been the source of much of the increase in forest land. Recent increases in farmland prices suggest losses in farmland will likely slow or reverse. Increasing farmland values could also shift more development pressure to forest land. Much of the forest land in Indiana is in close proximity to urban areas and derives value from its potential to be developed for residential housing and other nonforest purposes. A small percentage change in the area of nonforest land can significantly affect forest land area, especially in sparsely forested areas like Indiana's Northern Unit.

Land-use Change

Background

To better understand Indiana forest land dynamics, it is important to explore the underlying land-use changes occurring in the State. FIA characterizes land area using several land use categories which can be generalized to these classes: forest, rangeland, agriculture (including pasture and cropland), developed land, water, and other (including undeveloped beach, barren areas, and wetlands). The conversion of forest land to other uses is referred to as gross forest loss, and the conversion of nonforest land to forest is known as gross forest gain. The magnitude of the difference between gross loss and gain is defined as net forest change. By comparing the land uses on current inventory plots with the land uses recorded for the same plots during the previous inventory, forest land-use change dynamics can be characterized. Understanding land-use change dynamics is essential for monitoring the sustainability of Indiana's forest resources and helps land managers make informed policy decisions.

What we found

Indiana is dominated by agricultural land uses which cover 65 percent of the State's area (Fig 9). Other nonforest areas in the State include developed land (including rights-of-way, 13 percent), water (1 percent), other land (1 percent), and rangeland (<1 percent). Based on remeasured plots alone, approximately 20 percent of Indiana was forested in 2013. This nearly mirrors the actual 21 percent statewide estimate based on all plots which includes plots that were previously not forested but reverted to forest and were measured for the first time during the 2013 inventory cycle. Most of the FIA plots in Indiana either remained forested or stayed in a nonforest use (20 percent and 79 percent, respectively), and only the remaining 2 percent of plots experienced either a forest loss or gain from 2008 to 2013 (Fig. 10).

According to the FIA remeasurement data, Indiana lost nearly 95,000 acres (2 percent) of forest land from 2008 to 2013, which was more than offset by a gain of approximately 177,000 acres during the same time period (Fig. 11). Fifty-five percent of the forest gains come from agricultural uses including cropland (36 percent), pasture (11 percent), and other agriculture land (8 percent). The remaining forty-five percent of newly added forest land was formerly classified as developed land (41 percent), rights-of-way (8 percent), other (4 percent), and water (2 percent). More forest land was lost to developed and rights-of-way land uses (45 percent) than to the agricultural land use classes combined (31 percent). Some forest land was also diverted to other uses (16 percent) and water (10 percent) (Fig. 12).

FIA data can be used to characterize the forest land that has been lost and gained to see if it differs from the characteristics of forest land in all of Indiana. The forests of Indiana are dominated by stands in the large diameter size classes, with only 7 percent of forests in small diameter stands. The forest land that was gained, however, has a greater proportion of small diameter stands (39 percent) than in Indiana as a whole.

An examination of change in forest area by county indicates that 41 of the 92 counties in Indiana have experienced gains in forest area of more than 10 percent since 2003 (Fig. 13). A north-south gradient pattern is evident in the degree of forest cover change as would be expected given a similar gradient in population, travel corridors, topography, and agricultural activity. The distribution of remeasured plots across Indiana, highlighting plots on which 25 percent or more of the area has experienced a loss or gain in forest land (Fig. 14), also reflects the concentration of forest change in the northern and southern thirds of the State.

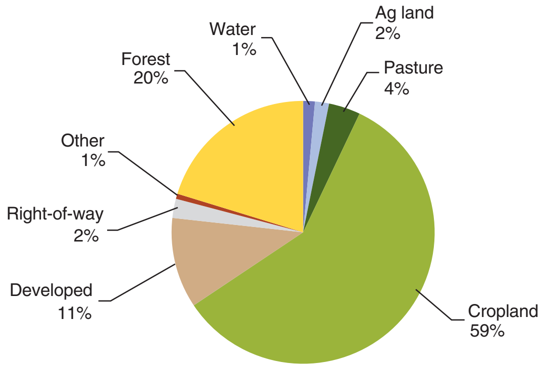

Figure 9.—Land use composition of remeasured plots, Indiana, 2013.

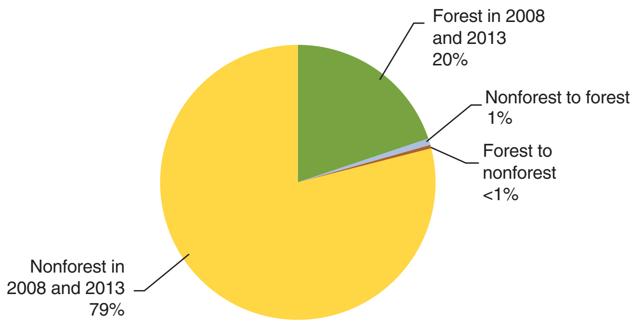

Figure 10.—Land use change, Indiana, 2008 to 2013.

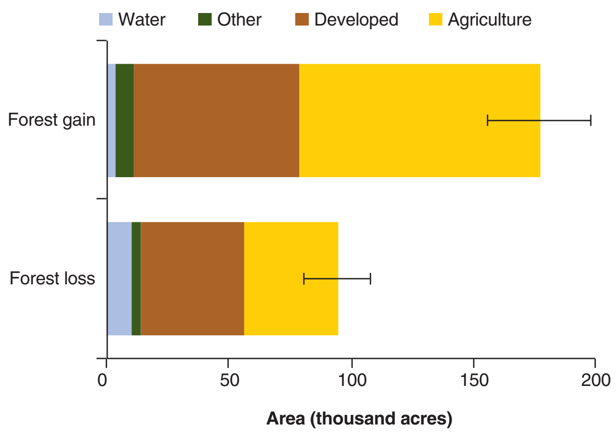

Figure 11.—Gross percent forest loss and forest gain by land use category, Indiana, 2008 to 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

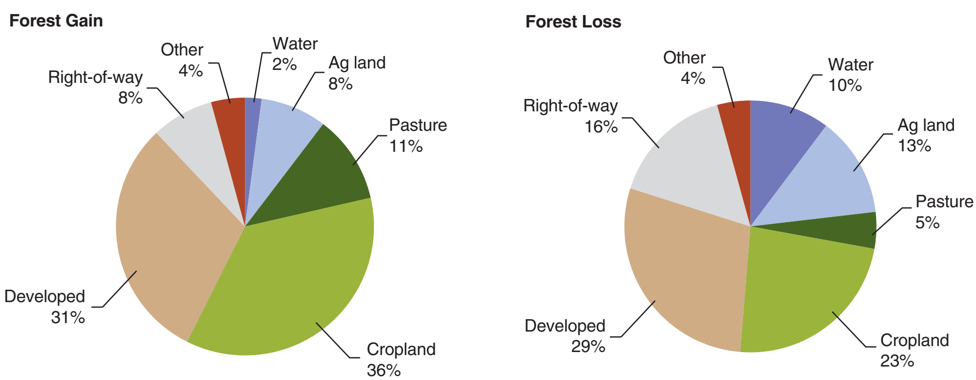

Figure 12.—Forest gain by previous land use and forest loss by current land use, Indiana, 2008 to 2013.

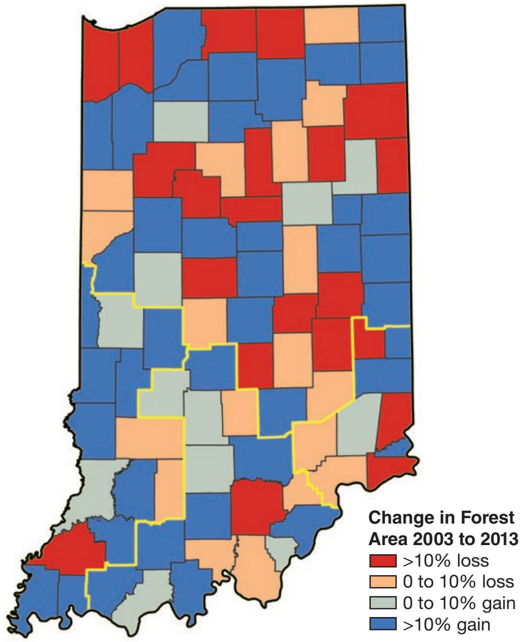

Figure 13.—Change in the area of forest land by county, Indiana, 2003-2013.

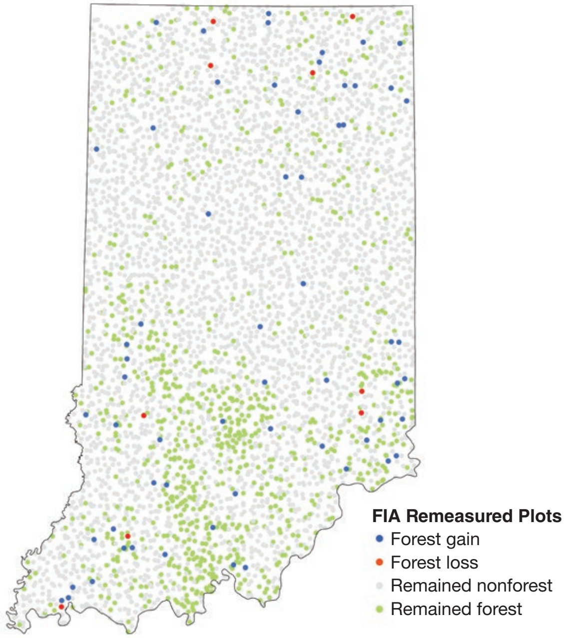

Figure 14.—Distribution of forest change inventory plots showing forest gains and losses of 25 percent or more, Indiana, 2008 to 2013. Plot locations are approximate.

What this means

Overall, there was a small net gain in forest land in Indiana from 2008 to 2013 which suggests a continued conservation and valuation of the State's forest resources. This trend of increasing forest land is consistent with what was reported in the last inventory cycle; however, the magnitude of the net gain was greater in the previous inventory. This difference in magnitude can be attributed primarily to a drop in the amount of nonforest land that reverted to forest; the amount of gross forest loss remained relatively stable between the two inventory cycles. Agriculture, particularly within the northern corn belt, is the dominant land use in Indiana, and gains and losses in pasture, cropland, and other agricultural land appear to drive much of the land-use change dynamics in the State. High net farm income, low interest rates, and high farmland demand with limited supply are the recent trends for Indiana farmlands. Forest losses to agricultural uses in Indiana may be a result of increased demand for agricultural-based biofuels. With increased interest in domestic fuel sources, there may be increased demand for suitable cropland.

Gains in forest land may come from agricultural land reverting to forests, especially land in close proximity to streams. There has been a concerted effort in the State's public and private sectors to prioritize the reforestation of these riparian areas. Agroforestry efforts promote the maintenance of tree cover in the form of windbreaks and forest buffers that help sustain a high agricultural output while conserving and protecting Indiana's soil and water resources. These forested areas are also important to Indiana's wildlife populations. Riparian forests often connect to form wildlife corridors which allow for greater species movement.

Some of the gains and losses of forest land in Indiana may be from marginal forest land moving into and out of the forest land base. This movement between forest and nonforest classifications may be a result of land meeting or not meeting FIA's definition of forest land due to small changes in understory disturbance, forest extent, or forest cover. These fluctuations likely contribute to the losses from and gains in developed land and rights-of-way. Permanent forest loss to development may also be occurring, especially near larger cities in the State, including Indianapolis where the population has increased by more than 3 percent in the last 4 years. For the State as a whole, however, the area of forest land lost to development is relatively small. Rather, the primary land source for new development in Indiana is agriculture. Of the gains in developed land, 92 percent come from converted agricultural land versus 5 percent from forest land.

Forest Ownership

Background

How land is managed is primarily the owner's decision. Therefore, to a large extent, the availability and quality of forest resources, including recreational opportunities, timber, and wildlife habitat, are determined by landowners. By understanding the priorities of forest land owners, leaders of the forest conservation community can better help to meet their needs, and in so doing, help conserve Indiana forests for future generations. The National Woodland Owner Survey (NWOS), conducted by the U.S. Forest Service Forest Inventory and Analysis program, studies private forest landowners' attitudes, management objectives, and concerns. It focuses on the diverse and dynamic group of owners that is the least understood—families, individuals, and other unincorporated groups, collectively referred to as "family forest owners." The NWOS data reported here are based on the responses from 232 family forest ownerships from Indiana that participated between 2011 and 2013.

What we found

Public owners control approximately 800,000 acres of Indiana forest land, or roughly16 percent of the total forest land in the State (Figs. 15 and 16). This includes the Federal government who manages an estimated 400,000 acres of forest land (8 percent), of which half is in the Hoosier National Forest. State forest, park, and wildlife agencies are stewards of another 400,000 or so acres (7.5 percent), and local government agencies control an estimated 50,000 acres (about 1 percent) of forest land in the State. The remaining 84 percent of the forest land of Indiana is privately owned by corporations and family forest owners. The vast majority of these private acres, an estimated 3.6 million acres (73 percent), are owned by family forest owners (Fig. 17). Corporations own an estimated 400,000 acres (8 percent) and other private owners, including conservation organizations, unincorporated clubs and partnerships, and Native American tribes, own an additional estimated 100,000 acres (2 percent).

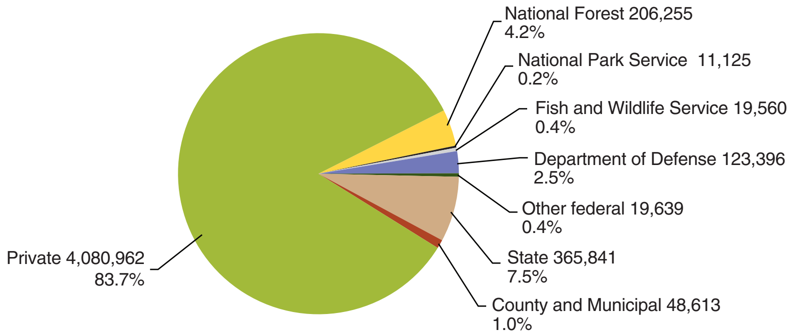

Figure 15.—Forest land ownership (acres) and percentage of forest land owned, Indiana, 2013.

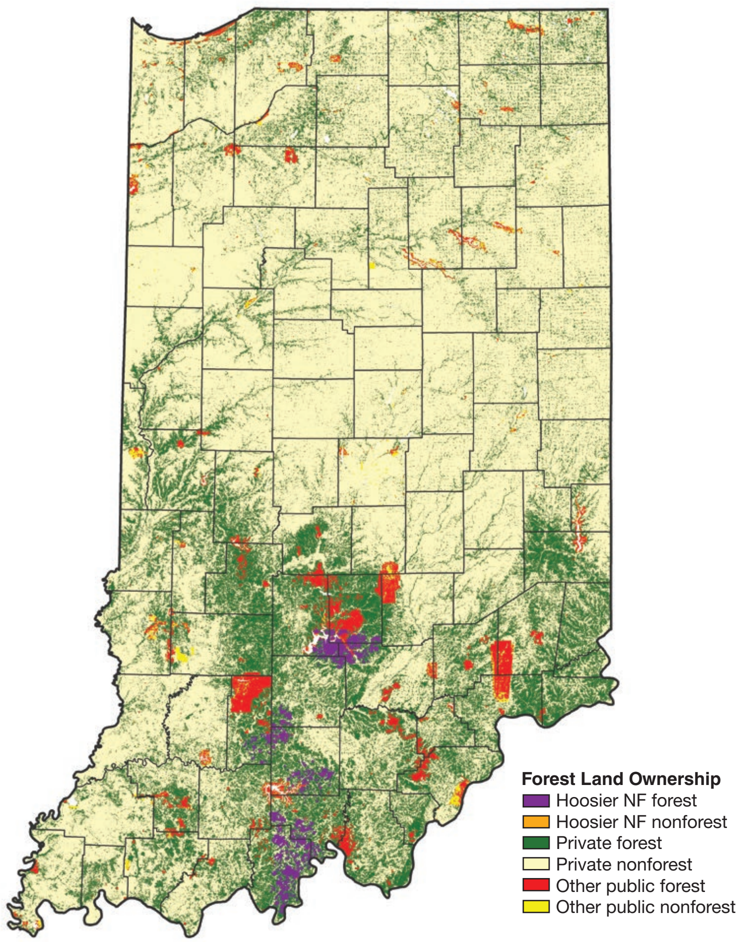

Figure 16.—Distribution of forest land by ownership category, Indiana, 2013.

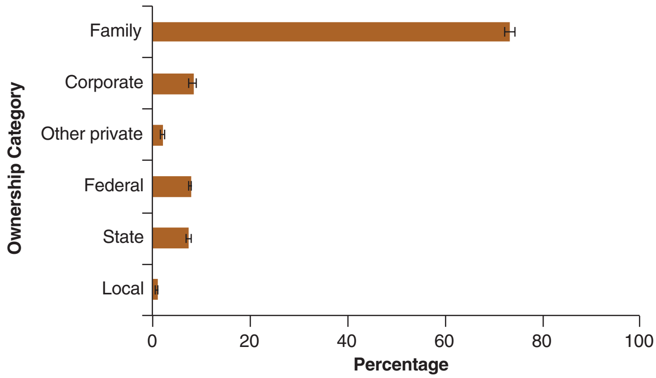

Figure 17.—Indiana forest land ownership, Indiana, 2013.

According to the NWOS, an estimated 85,000 family forest ownerships across Indiana own at least 10 acres of forest land, for a total of 3.2 million acres. The average forest holding size of this group is 37 acres. Of these family forest ownerships, 79 percent own less than 50 acres of forest land, but 56 percent of the family forest land is in holdings of at least 50 acres (Fig. 18). The primary reasons for owning forest land are related to aesthetics, wildlife, nature protection, and family legacy (Fig. 19). The most common activities on their land are personal recreation, such as hunting and hiking, and cutting trees for personal use, such as firewood (Fig. 20). Most family forest ownerships have not participated in traditional forestry management and assistance programs in the past 5 years; the most common is having received management advice, but this is less than 25 percent of the ownerships (Fig. 21). The average age of family forest owners in Indiana is 62 years, and 39 percent of the family forest land is owned by people who are at least 65 years of age (Fig. 22).

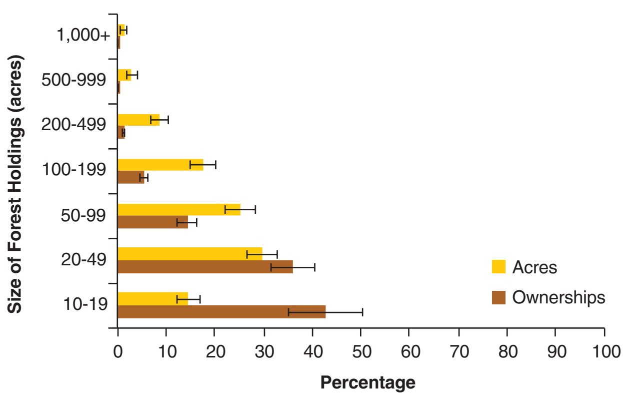

Figure 18.—Percentage of owners and area owned for family forest ownerships of 10+ acres, by size of forest holdings, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

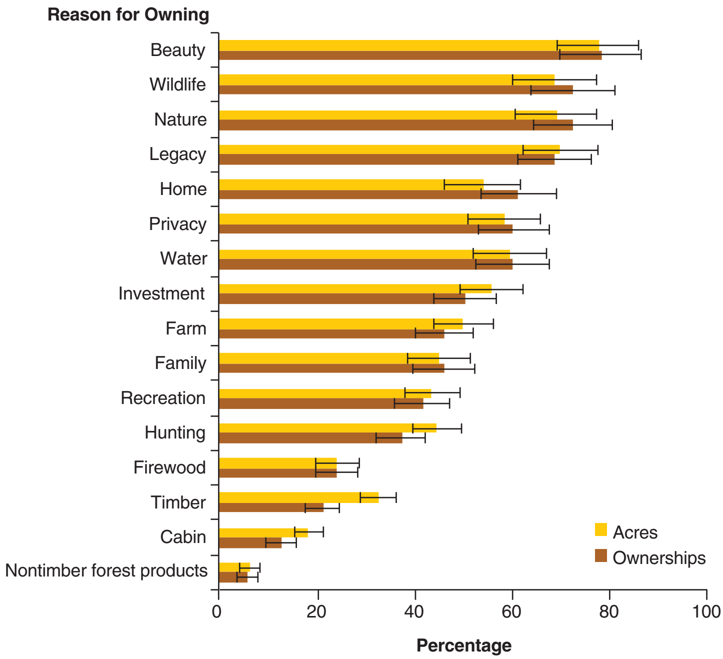

Figure 19.—Reasons for owning forest land by percentage of owners and area owned, for family forest ownerships of 10+ acres, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

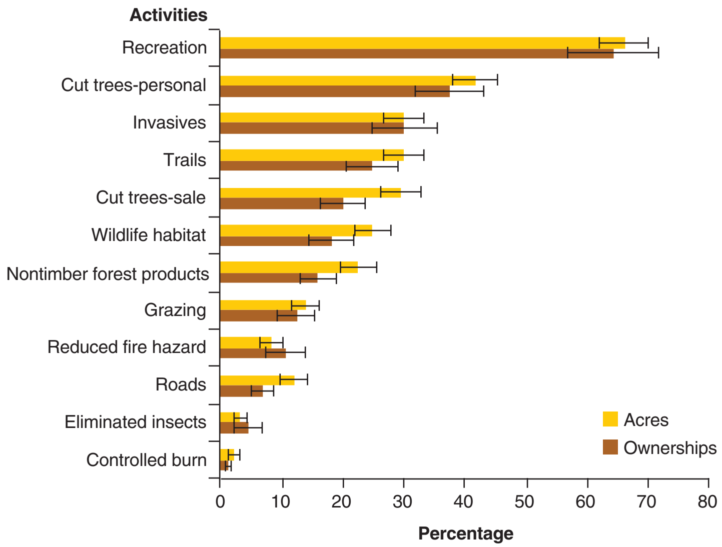

Figure 20.—Most common activities of family forest ownerships with 10+ acres, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

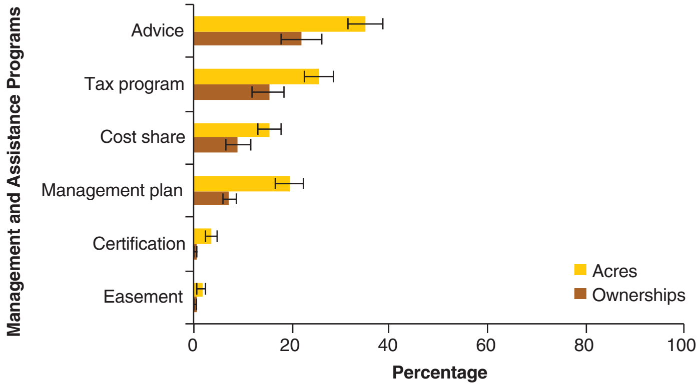

Figure 21.—Participation of family forest ownerships of 10+ acres in traditional forestry management and assistance programs in the past 5 years, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

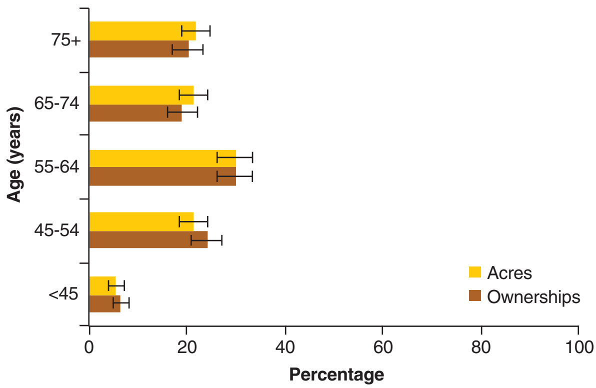

Figure 22.—Average age of family forest owners with 10+ acres, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

What this means

The fate of the forest lies primarily in the hands of those who own and control the land. It is therefore critical to understand forest owners and what policies and programs can help them conserve the forests for current and future generations. Family forest ownerships own their land primarily for amenity reasons, but many are actively doing things with their land. Timber production is not a priority in landowners' minds, but they are not adverse to harvesting and other activities in their woods. More than 90 percent of them do not have a management plan nor have they participated in most other traditional forest management planning or assistance programs. Natural resource professionals need to better communicate with family forest owners and help them better manage their woods. Programs such as Tools for Engaging Landowners Effectively (http://www.engaginglandowners.org) can help the conservation community develop and implement programs more effectively and efficiently. In addition, a viable private forest and wildland management option is the Indiana Classified Forest and Wildlands Program (http://www.in.gov/dnr/forestry/4801.htm). The program encourages timber production, watershed protection, and wildlife habitat management on private lands in Indiana by providing a property tax reduction for owners who follow a professionally written management plan. The minimum requirement for program enrollment is 10 acres of forest, wetland, shrubland, and/or grassland.

In addition to the State CFWP there are federal programs such as the Forest Stewardship Program, Conservation Reserve Program, Environmental Quality Incentives Program, Forest Land Enhancement Program, Forest Legacy Program, Forestry Incentives Program, Wetlands Reserve Program, Wildlife Habitat Incentives Program, and State programs like the Indiana Lake and River Enhancement Program. There are also private industry assistance programs for forest management and timber marketing like the National Wild Turkey Federation Wild Turkey Woodlands Program and the Nature Conservancy Forest Bank Program. For more information on forest, water, and wildlife programs on privately owned lands consult "A Landowner's Guide to Sustainable Forestry in Indiana" (https://www.extension.purdue.edu/extmedia/FNR/FNR-187.pdf) or visit the Indiana DNR's forestry web site (http://www.in.gov/dnr/forestry/).

Another important trend to watch is the aging of the family forest owners. The family legacy of passing land on is a major ownership objective, but it is also a major concern for both landowners and natural resource managers. Landowner turnover is something that is perpetually happening, but it is also a critical juncture for landowners and the land. Forest land is at increased risk of parcelization and poor harvesting practices shortly before and after transfer of ownership. With many owners being relatively advanced in age, this portends many acres of land passing on to the next generation in the not too distant future. There are programs such as Your Land Your Legacy (http://masswoods.net/monthly-update/your-land-your-legacy-deciding-future-your-land) and Ties to the Land (http://tiestotheland.org) that have been implemented to help owners meet their bequest goals, but it is uncertain who the future forest owners will be and what they will do with their land.

Tree Density, Size, and Stocking

Background

How well forests are populated with trees is determined by two measurements: the trunk diameter taken at 4.5 feet above the ground, referred to as diameter at breast height, and by the number of trees. Generally, as stands mature and trees become larger, the number of trees per acre decreases and stand volume increases. The number of trees per acre and their diameters are used to determine levels of stocking, which is a measure of how well a site is being utilized to grow trees. In Indiana, stocking levels are reported for all live trees exclusive of merchantability or for growing-stock trees only. Growing-stock trees are economically important and do not include noncommercial species (e.g., pawpaw, hawthorn spp., red mulberry, flowering dogwood, and Osage-orange) or trees with large amounts of cull (rough and rotten trees). In fully-stocked stands, trees use all of the potential of the site to grow. As stands become overstocked, trees become overcrowded, growth begins to slow, and mortality increases. In poorly stocked stands trees are widely spaced, or if only growing-stock trees are included in the stocking calculations, the stands may contain many rough and rotten trees with little or no commercial value. Poorly stocked stands can develop on abandoned agricultural land or result from major disturbances such as windstorms, disease outbreaks, wildfires, or poor harvesting practices. Poorly stocked stands are not expected to grow into a fully stocked condition in a reasonable amount of time, whereas moderately stocked stands will. Comparing stocking levels of all live trees with that of growing-stock trees shows how much of the growing space is being used to grow trees of commercial importance and how much is occupied by trees of little or no commercial value. If stands are not disturbed, stocking levels increase over time as trees naturally reproduce and grow. As disturbances such as harvesting or wind events lower stocking levels, changes in species composition, diameter distribution, residual tree quality, and regeneration become of increasing concern to forest managers.

Tree diameter measurements are used by FIA to assign a stand-size class to sampled stands. The categories are determined by the class that accounts for the most stocking of live trees per acre. Sapling or small diameter stands are dominated by trees less than 5 inches d.b.h. Poletimber or medium diameter stands have a majority of trees with a d.b.h. of 5 inches and larger, but less than the large diameter stands. Sawtimber or large diameter stands consist of a preponderance of trees at least 9 inches in d.b.h. for softwood species and 11 inches d.b.h. for hardwood species.

What we found

The number of trees greater than or equal to 1 inch in diameter increased by 0.8 percent from 2008 to 2013 (Fig. 23), reaching roughly 2.2 billion trees. This increase is not distributed evenly across diameter classes, but has shifted toward larger diameter trees (Fig. 24). Saplings (trees 1 to 4.9 inches d.b.h.) showed a 1.7 percent decrease. The number of trees in diameter classes less than 16 inches increased by 0.5 percent while tree numbers in classes 16 inches and larger increased by 8.3 percent. This is also reflected in the continued increase in the average diameter for all trees 5 inches d.b.h. and larger on timberland which increased from 9.7 inches in 1986, to 10.2 inches in 1998, and 10.5 inches in 2013.

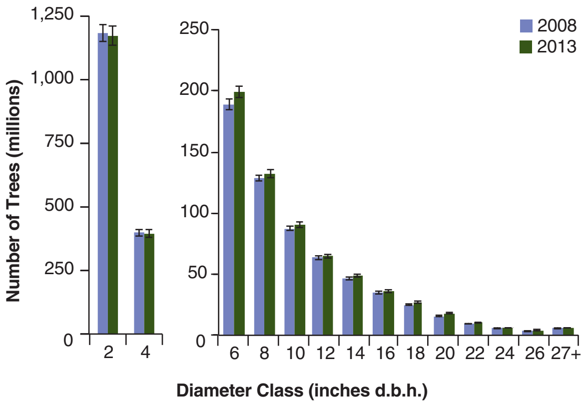

Figure 23.—Number of live trees on forest land by diameter class and inventory year, Indiana, 2008 and 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

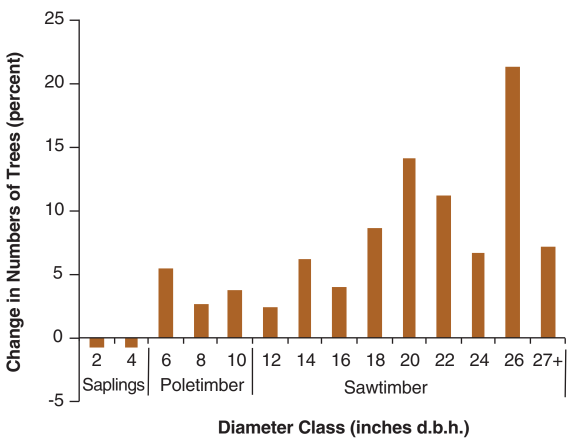

Figure 24.—Change in the number of live trees on forest land by diameter class, Indiana, 2008 to 2013.

The shift in tree size has brought about an increase in stands dominated by sawtimber-size trees (Fig. 25). Trends show sawtimber-size stands continuing to increase at the expense of poletimber and seedling-sapling-size stands. In 2013, more than three quarters (3.7 million acres) of timberland in the State was in sawtimber-size stands. Poletimber stands have experienced little change since 1986 and total 684,000 acres in 2013. Seedling-sapling-size stands and nonstocked timberland continued to decrease and currently represent 7.0 percent of timberland (332,000 acres).

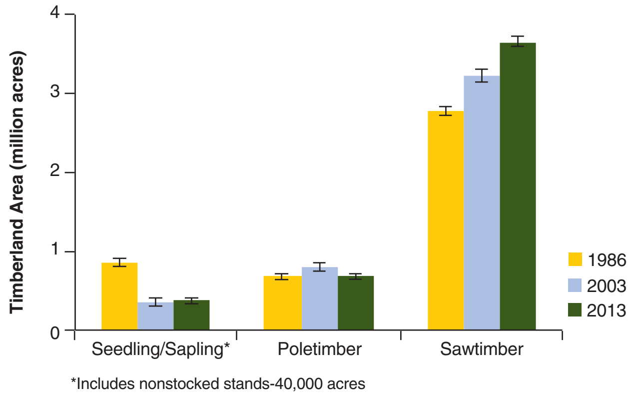

Figure 25.—Timberland area by stand-size class and inventory year, Indiana. Error bars represent 68 percent confidence interval around the mean.

Indiana has the lowest percentage of forest land in seedling-sapling size stands (7.1 percent) compared to the surrounding states of Michigan (18.6 percent), Ohio (11.6 percent), Kentucky (9.7 percent), and Illinois (7.9 percent). Indiana also has the lowest forest land percentage of poletimber size stands (14.7 percent) of the surrounding states of Michigan (32.8 percent), Ohio (21.0 percent), Kentucky (19.4 percent), and Illinois (15.2 percent). Consequently, Indiana has the highest percentage of forest land in sawtimber-size stands (77.4 percent) when compared to the surrounding states of Illinois (75.6 percent), Kentucky (70.6 percent), Ohio (66.6 percent), and Michigan (47.9 percent).

In Indiana, 2 million acres (43 percent) of timberland are fully stocked or overstocked with live trees, nearly 2 million acres (42 percent) have medium stocking, and 688,000 acres (15 percent) are either poorly stocked or nonstocked (Fig. 26). Since 1986, stocking has shifted from overstocked toward fully stocked and medium stocked levels. Acreage in fully stocked and overstocked stands has decreased by 1.2 million acres since 1986 when nearly 75 percent (3.2 million acres) was either overstocked (765,000 acres) or fully stocked (2.4 million acres). Now, more than half of all stands are less than fully stocked with live trees. When considering only the commercially important growing-stock trees, the area with poor stocking is 986,000 acres, or twice the area when including all trees (Fig. 27). Most of the acreage in these stands is in older age classes or in stands dominated by large trees (Fig. 28). Nearly 80 percent of the acreage is in age classes more than 40 years old, and 78 percent is in large diameter stands (Fig. 29). Indiana forests are maturing. Currently, nearly half (48 percent) of the stands are over 61 years of age.

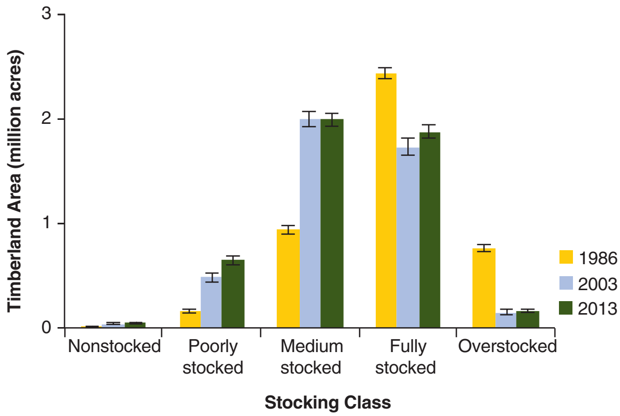

Figure 26.—Area of timberland by stocking class and inventory year, for all live trees, Indiana. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

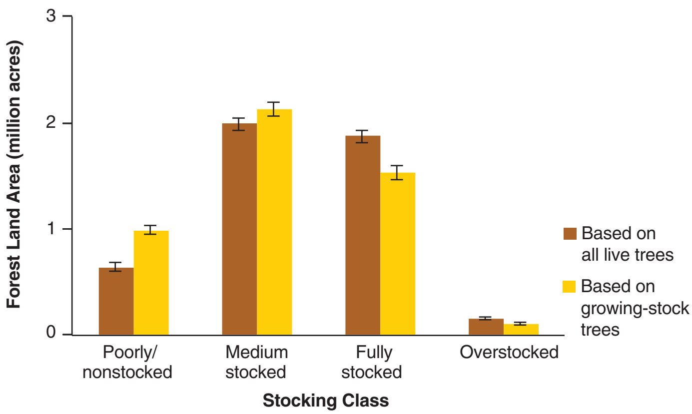

Figure 27.—Area of forest land by stocking class based on all live trees, and on growing-stock trees, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

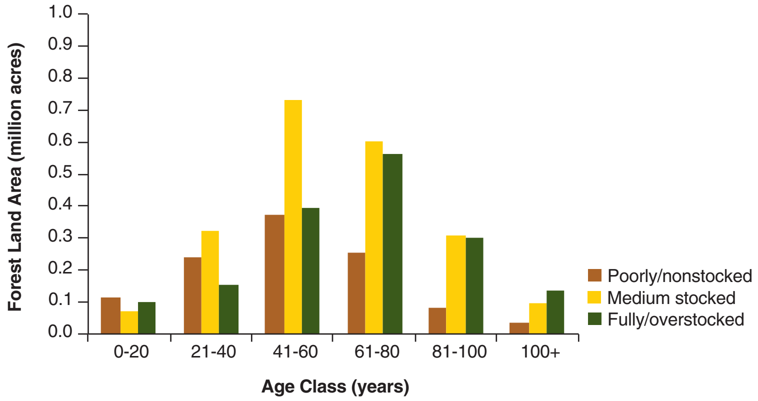

Figure 28.—Area of forest land by stand-age class and stocking level for growing-stock trees only, Indiana, 2013.

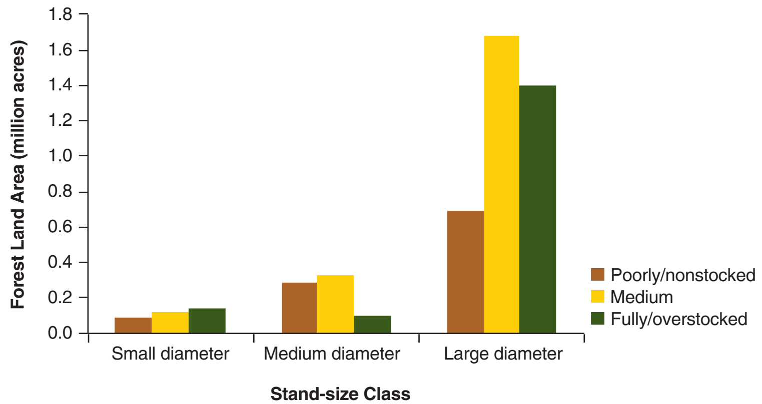

Figure 29.—Area of forest land by stand-size class and stocking level for growing-stock trees only, Indiana, 2013.

What this means

The continued shift to larger size trees and the increase in area of sawtimber-size stands indicates that Indiana forests are maturing. Increases in tree size have also brought about an overall improvement in stocking levels and contribute to Indiana's economy by supporting the timber products industry. The 2 million acres in fully-stocked and overstocked stands present opportunities for forest management. Managing these stands can keep them growing optimally.

Fifty-six percent of forest land is less than fully stocked with trees, but when only growing-stock trees are considered, this level increases to 65 percent. The broad extent of these less than fully-stocked stands indicates that a large amount of disturbance, both natural and human-caused, has occurred in Indiana forests. The nearly one million acres of forest land that are poorly stocked or nonstocked represents a loss of potential growth. Trees in these stands are either widely spaced or are low value trees that occupy growing space that could otherwise be used to grow quality timber. These stands may have originated from farmland that reverted to forest or from poor harvesting practices. Poorly stocked stands include an estimated 700,000 acres that are more than 40 years old and dominated by medium and large size trees. These stands are likely the result of poor harvesting practices (e.g., high grading), although they could occur from using acceptable forestry practices such as shelterwood or seed tree harvesting methods to regenerate the stands. Poorly stocked stands represent a challenge to forest managers because they contain little value to pay for improvement, and although they are considered a sign of past poor management, they still provide wildlife habitat. The difference in stocking levels when using only growing-stock trees versus all live trees implies that many low-quality trees have been left behind after harvesting. These cull and noncommercial species occupy space and inhibit effective new growth of more valuable trees. Retaining large amounts of residual trees during harvesting also impedes the start of new age classes that are important to maintaining forest health and future timber supplies.

The 7 percent of forest land in seedling-sapling stands is likely the result of farmland reverting to forest or timber harvesting using even-age management. Currently, agricultural lands reverting to forest and the participation of farmers and private forest landowners in conservation programs are two major sources of seedling-sapling stands. Slowing these processes would likely continue the decline in this stand-size class. Young stands offer opportunities for further increases in Indiana's timber resource but also provide unique early successional wildlife habitat features that are not provided by sawtimber-size stands. Across the northeastern states, the number of animal species that require early-successional habitats are declining because of changing habitats. Besides offering diverse habitats and providing a steady flow of wood products, forests that contain stands of various sizes may be more resistant to devastating outbreaks of insects and diseases. The shift to denser levels of stocking indicates that growing conditions in Indiana are becoming crowded, and therefore more shaded.

Forest Composition

Background

Long-term changes in forest composition can alter wildlife habitats and affect the value of the forest for timber products. The species composition of a forest is the result of the interaction of climate, soils, disturbance, competition among tree species, and other factors over time. In the last 60 years, low levels of selective timber harvest on public lands, partial-cutting and high grading on private lands, and a lack of fire as a periodic disturbance regime have reduced oak recruitment in Central Hardwood forests, particularly on high quality (mesic) sites (Hicks 1998, IN DNR 2008, Schmidt et al. 2000, Van Lear and Watt 1993, Woodall et al. 2005). Other factors that contribute to poor oak and hickory regeneration include understory growing conditions that favor more shade tolerant hardwoods, preferential browsing of oak seedlings by white-tailed deer (*Odocoileus virginianus*), and the low intensity harvesting practices that leave only small gaps in the canopy (Johnson et al. 2002).

Without periodic understory disturbances to reduce competition from more shade tolerant and less fire-tolerant species such as sugar maple, oaks and hickories are eventually out-competed when openings or large gaps are created in the canopy (Hicks 1998, IN DNR 2008, Lorimer 1993). Unless sufficient advance regeneration is in place when openings are made in the canopy, rapidly establishing and faster growing species such as yellow-poplar quickly overtop oak seedlings and dominate the site (Johnson et al. 2002).

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

What we found

The 2013 inventory identified 95 tree species (see Appendix 1), 50 forest types, and 12 forest-type groups across Indiana. Hardwoods are the dominant tree species group and oak/hickory is the most common forest-type group, occupying 72 percent of forest land, the bulk of which resides in the white oak/red oak/hickory forest type

(1.5 million acres). The oak/hickory forest-type group consists of white oak, northern red oak, hickory species, white ash, walnut, yellow-poplar, and red maple. Softwoods alone occupy 103,000 acres. The oak/pine forest-type group occupies almost 160,000 acres, which represents 3 percent of the forest land. These broad species groups have undergone little change in extent since 2008. Indicative of a maturing (aging) forest, the white oak/red oak/hickory forest type is found primarily in the large stand-size class (Fig. 30). The cherry/white ash/yellow-poplar forest type is less common (470,000 acres) as is the mixed upland hardwoods forest type (380,000 acres). Both show similar distributions across stand-size classes with a large proportion in the medium and large diameter classes. The sugar maple/beech/yellow birch forest-type group is relatively abundant (211,000 acres) and occurs mostly in large stand-size classes.

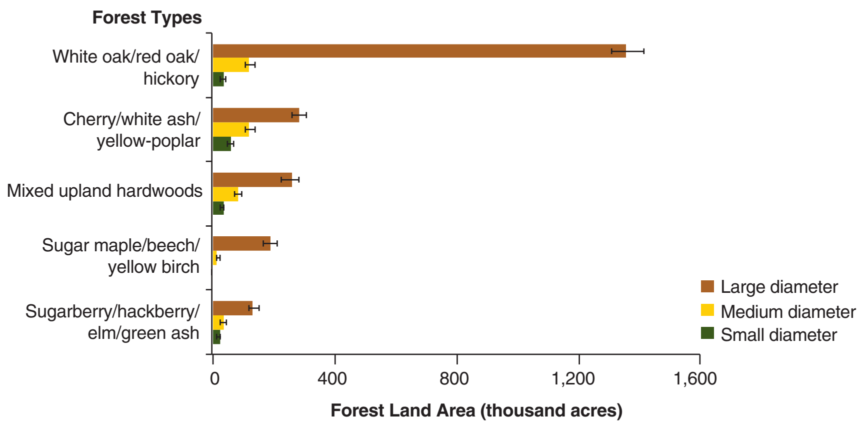

Figure 30.—Area of forest land by five most common forest types and stand-size class, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

Timberland area in Indiana is approximately 4.7 million acres or 19 percent of Indiana's land area and has increased by 16 percent from 1950 to 2013. Over the same period the volume of growing stock on timberland increased by more than 3.5 times, from 2.6 to 9.1 billion cubic feet; the proportional volume increase was slightly less if expressed in sawtimber board-foot volume (Fig. 31). Between 1950 and 2013 the proportion of all timberland in the sawtimber-size class (i.e., stands where the overstory trees are predominantly >11 inches d.b.h.) increased from 52 to 78 percent (Fig. 32). This increase in size class and volume is mostly due to the maturing of the forest resource and indicates disturbances to the main canopy are either infrequent or of low intensity (e.g., harvest by individual tree selection).

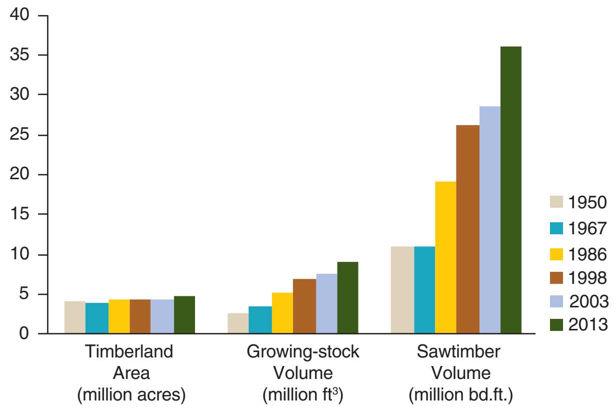

Figure 31.—Timberland area, growing-stock volume, and sawtimber volume (International ¼-inch rule) by inventory year, Indiana.

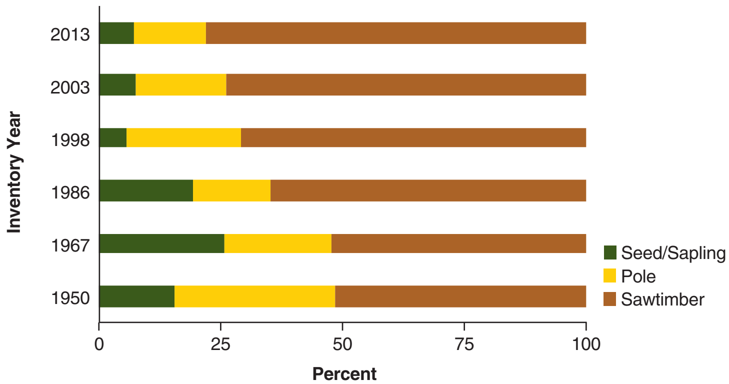

Figure 32.—Area of timberland by stand-size class and inventory year, Indiana.

White ash, the species with the most trees in the seedling-size class (trees less than 1 inch d.b.h. and at least 1 foot in height), represents about 20 percent of all seedlings, followed by sugar maple, pawpaw, sassafras, and eastern hophornbeam (Fig. 33). Northern red and white oaks occur at low densities in the seedling-size class, ranking 25th and 11th, respectively. Bitternut and shagbark hickories also rank low at 19th and 20th, respectively.

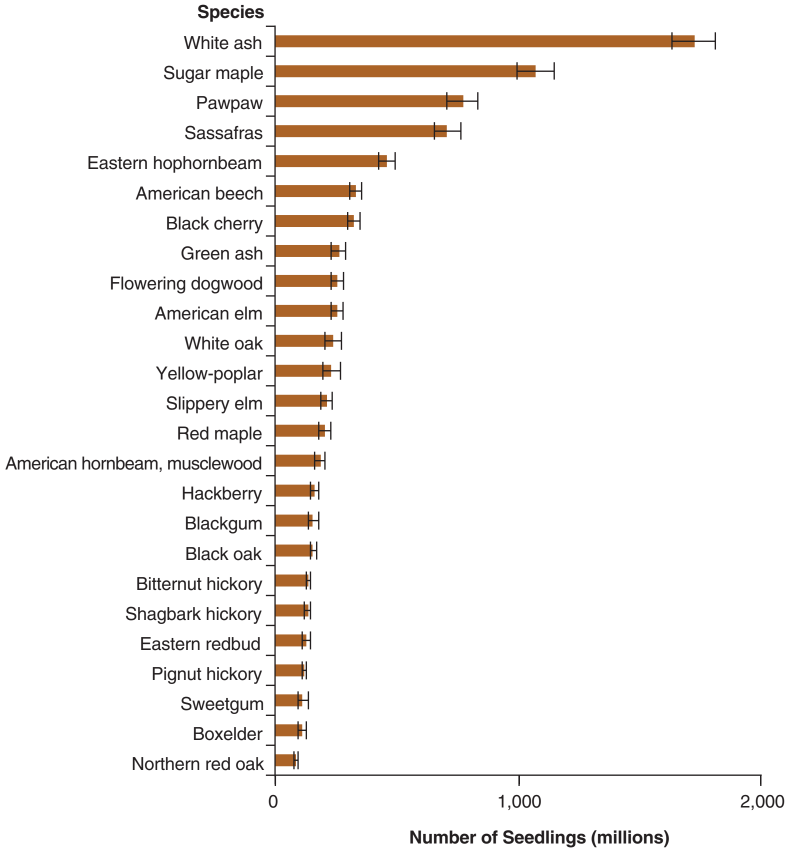

Figure 33.—Most numerous species ranked by number of seedlings (trees less than 1 inch d.b.h. and at least 1 foot tall), Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

The ranking of saplings is somewhat different than that of seedlings (Table 1). Sugar maple is the most numerous sapling followed by American elm and American beech. Oak and hickory species rank poorly in this size class. White oak declined 18.2 percent and northern red oak saplings declined by nearly a third since 2008. Saplings that had the largest percentage gains since 2008 are black walnut (33 percent), red mulberry (32 percent), silver maple (25 percent), and pawpaw (24 percent). Species with the largest decreases in sapling numbers since the previous inventory are sweetgum (48 percent), American basswood (46 percent), black oak (36 percent), and northern red oak (32 percent). Shagbark hickory and black cherry also showed modest declines of 10 and 16 percent, respectively. The proportion of oaks in the seedling and sapling-size classes lagged well behind that of maple and beech. Even yellow-poplar, a shade intolerant species, is approximately as common in the small tree-size classes as the entire white oak or red oak groups.

Table 1.—Ranking of number of saplings (trees 1 to 4.9 inches d.b.h.) by species for the 2013 and 2008 inventories, the total number of stems in the 2013 inventory, and the percent change from 2008 to 2013, Indiana

Rank 2013	Rank 2008	Species	Number of saplings 2013 (millions)	Percent change 2008-2013
1	1	Sugar maple	279	0
2	2	American elm	106	-0.5
3	4	American beech	98	14.2
4	5	Sassafras	88	7.2
5	3	Flowering dogwood	77	-15.9
6	7	Red maple	77	1.8
7	6	Black cherry	69	-16.2
8	8	White ash	69	-3.3
9	9	Eastern redcedar	47	-15.3
10	13	Hackberry	46	18.9
11	15	American hornbeam, musclewood	40	10.8
12	14	Eastern hophornbeam	38	3.4
13	12	Yellow-poplar	37	-7
14	18	Pawpaw	36	24
15	11	Eastern redbud	33	-22.7
16	17	Ohio buckeye	31	8.7
17	10	Sweetgum	29	-48.1
18	21	Green ash	27	16.9
19	16	Slippery elm	25	-22
20	22	Boxelder	24	10.3
21	20	Blackgum	23	-6.5
22	19	Shagbark hickory	23	-10
23	24	Hawthorn spp.	22	13.4
24	29	Black walnut	16	33.1
25	23	Black oak	15	-36
26	27	Bitternut hickory	14	1.9
27	30	Red mulberry	14	31.6
28	25	American basswood	12	-46.2
29	28	White oak	12	-18.2

Note: An additional 51 species make up less than 10 percent of the total number of saplings.

For trees of poletimber size and larger (5 inches d.b.h. and larger), sugar maple still dominates, followed by yellow-poplar and red maple (Fig. 34). If only trees in the 18-inch and larger diameter classes are considered, yellow-poplar is the most numerous species followed by white oak, red maple, sugar maple, and black oak. Oaks and hickories are better represented in diameters larger than 11 inches (Fig. 35) and make up 23 and 10 percent of the total number of trees in that class, respectively.

In the current inventory, oaks represent more than 34 percent of trees 20 inches and larger in diameter, but less than 4 percent of trees in the 2- and 4-inch diameter classes (Fig. 36). Hickories make up less than 3 percent of trees in the 2- and 4- inch diameter classes. Conversely, maple species have a disproportionate share of trees in the 2- and 4-inch diameter classes amounting to 23 percent, compared to their presence in the larger diameter classes at 11 percent for trees 20 inches d.b.h. and larger.

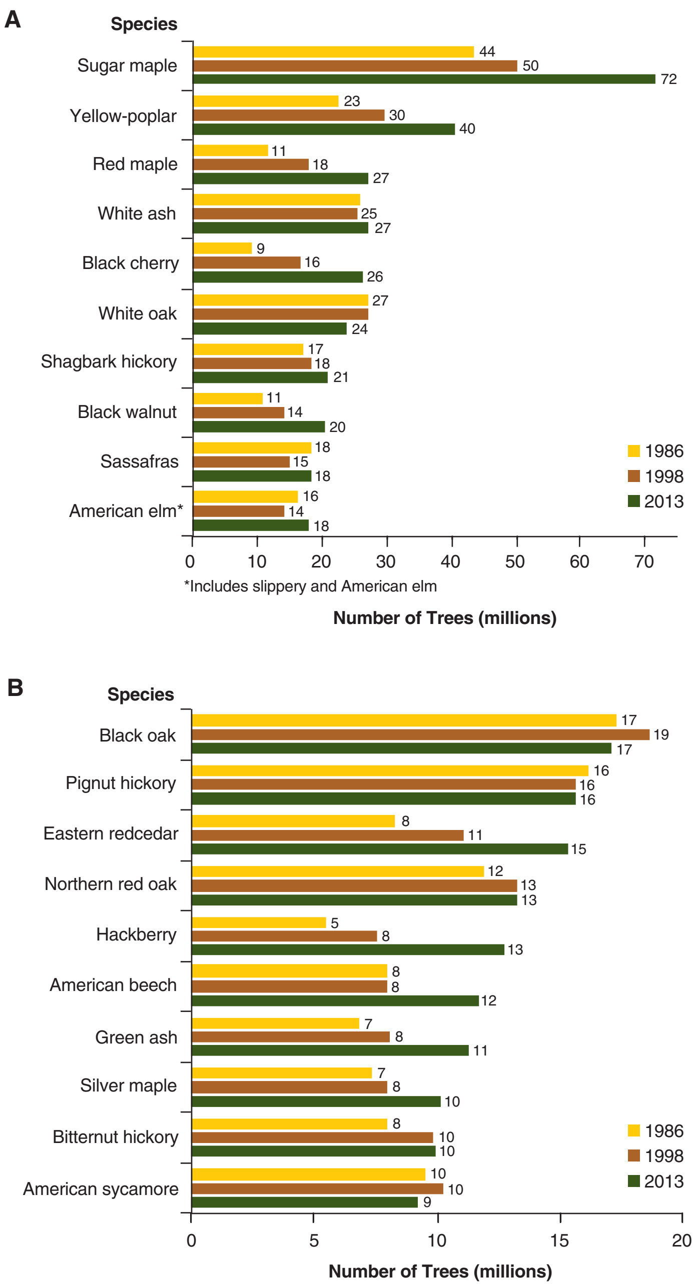

Figure 34.—Most abundant species ranked by the numbers of trees 5.0 inches d.b.h. and larger in 2011, with estimates for number of trees in 1986 and 1998 on timberland, Indiana. Ten most abundant species are depicted in A, with the second group of 10 in B. (Note the difference in the x-axis scale for A and B.)

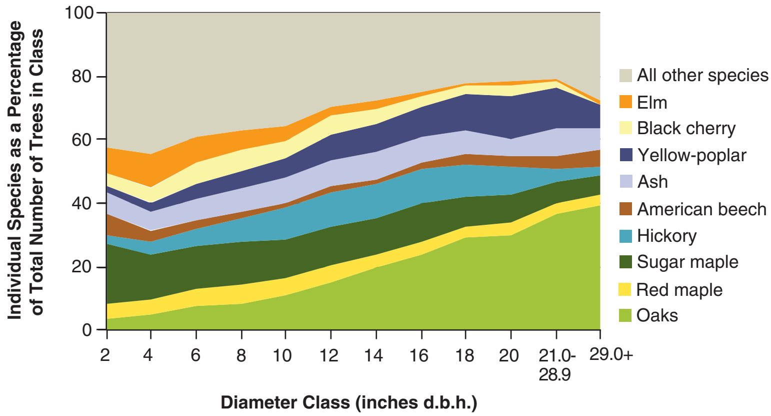

Figure 35.—Species composition by diameter class on forest land, Indiana, 2013.

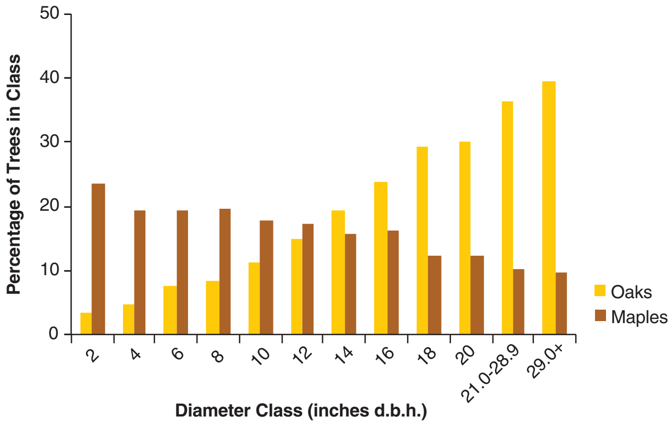

Figure 36.—Oaks and maples on forest land as a percentage of all trees by diameter class, Indiana, 2013.

In 1967, the proportion (or the total number) of red oaks and proportion of white oaks each exceeded that of maple and beech for diameter classes larger than about 8 inches d.b.h. (Fig. 37A). By 2013, the proportion of maples and beech increased in smaller diameter classes, and the point of intersection increased to approximately 18 inches d.b.h. (Fig. 37B).

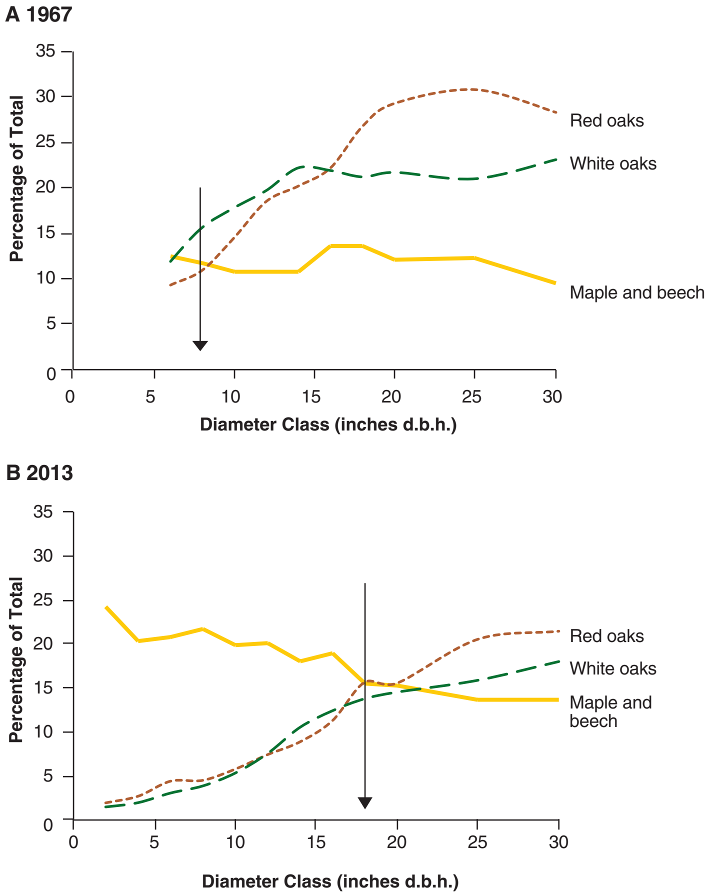

Figure 37.—Changes in the size distribution of trees in the red oak, white oak, and maple-beech species groups, Indiana, 1967 (A) and 2013 (B). Arrow indicates diameter class at which three species groups intersect.

What this means

The area of the oak/hickory forest-type group and other major forest-type groups has remained stable since 1986, but this does not fully depict the underlying shifts in individual species. The species composition of the seedling and sapling-size classes has future forest composition implications. Sixteen percent of all trees on timberland are now sugar maple, and no single oak or hickory species ranks in the top 15 species in terms of total number of trees. Yet oak species as a group have more volume than any other species group, and oaks dominate in the largest diameter classes. The current trajectory away from dominance by oaks and hickories has implications for biodiversity, wildlife, recreation, and the forest products industry. Widespread losses of oak and hickory would directly and indirectly affect multitudes of species, reduce native biodiversity, and drive community-level shifts and alterations (Fralish 2004, IN DNR

2008, McShea et al. 2007, Ostfeld et al. 1996, Rodewald 2003). Throughout Indiana and the entire Central Hardwood region, oak/hickory forests are maturing and in many places shifting to different forest types (Abrams 2003, Aldrich et al. 2005, McCune and Cottam 1985, Schmidt et al. 2000, Woodall et al. 2005). As maturing oaks and hickories die, they often are replaced by other competing species, such as sugar maple and yellow-poplar, rather than young oaks or hickories. Driving these shifts are significant reductions or even failures in oak/hickory regeneration (Aldrich et al. 2005, IN DNR 2008, Lorimer 1993, Woodall et al. 2005).

Maples will play an increasing role in the future forests of Indiana. Though oak and hickory seedlings can still be found in Indiana forests, statewide there typically are substantially more competitors, such as sugar maple, that outnumber any single oak or hickory seedling species by a factor of 4 to 1. In terms of number, sugar maples dominate, with three times as many trees as any other species. This will likely cause the area occupied by the oak/hickory forest-type group to undergo a long-term decline and be replaced by the beech/maple/birch group.

Large increases in the numbers of sapling-size American hornbeam and eastern hophornbeam may be due to these species responding to gaps created by partial harvests and other disturbances. Both of these species are tolerant of shade and grow well in the understory. They may also be filling niches vacated by flowering dogwoods that are dying from dogwood anthracnose (*Discula destructiva* Redlin), a fungal disease.

If the perpetuation of the oak/hickory forest type is a primary goal for the forests of Indiana, forest land owners and natural resource managers will need new management strategies and practices to change the current trends, which could take decades to alter. To assure this composition and structure is maintained, periodic inventories at the stand and system level must be taken, with management treatments applied as necessary. Adequate timber harvest levels with emphasis on methods, timing, and follow-up silvicultural treatment would assist problematic oak and hickory regeneration and, ultimately, recruitment. Placement and size of harvest openings is critical to supporting oak and hickory seedlings in concert with sufficient understory treatment to reduce competition from other species. Due to the immediacy and severity of the problem, relying on a "hands-off" approach to oak and hickory regeneration is not likely to be successful in the long-term; some form of active management is necessary to emulate natural regeneration (IN DNR 2008). One guide, the Indiana Department of Natural Resources, Division of Forestry offers a treatise on the problems and challenges facing forest ecologists and land managers as they design harvest and vegetation management regimes to successfully regenerate oak and hickory in the Central Hardwood region (IN DNR 2008). It features an extensive array of research studies and programs currently underway on state forest properties that investigate the site-specific challenges to oak and hickory regeneration. The results of the long-term studies are expected to guide future forest management activities on Indiana's State forests and provide a model for successful oak/hickory management throughout the State and region. More information on Indiana forest regeneration can be found in the regeneration section later in this report.

Tree Volume

Background

The assessment of the volume of live trees provides information on trends in the resource, the potential uses of that wood, and its economic value. Current volumes and changes in volume over time can characterize forests and reveal important resource trends. FIA reports tree volume in several ways: sound and net volume of live trees, growing stock and sawtimber volume of live trees of commercial species, and biomass in dry tons. Each of these measures characterizes the wood resource in a different way and provides insights into its use and management. And, as discussed in the next section, biomass estimates are a means for quantifying carbon storage. Because of changes in procedures, comparisons to past inventories are less consistent for some measures than others.

What we found

Eighty-five percent (9.1 billion cubic feet) of the live sound wood volume is categorized as growing-stock volume (Fig. 38). Also contained within these growing-stock trees is an additional 144.5 million cubic feet categorized as sound cull. On timberland, rough and rotten trees account for a combined 1.1 billion cubic feet and represent 9 percent and 1 percent of total sound volume, respectively.

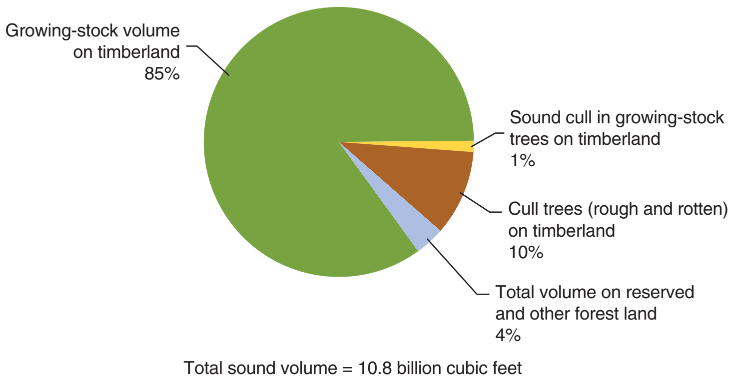

Figure 38.—Components of live sound wood volume on forest land, Indiana, 2013.

Since 1986, the net volume of live trees on Indiana timberland has steadily increased and now totals over 10 billion cubic feet, a 6 percent increase from 2008 (Fig. 39). On a per-acre basis, this volume averages 2,137 cubic feet per acre, a 51 percent increase since 1986. Volume has been shifting toward the sawtimber-size classes (Fig. 40). The most recent inventory shows that since 2008, volume has increased in all diameter classes (Fig. 41). Trees less than 11 inches now make up about a third of the total volume, 1 percent less than in 2008. All of the gains in volume were in trees large enough to produce saw logs (≥11 inches d.b.h. for hardwood species), which reflects the changes in the number of trees discussed previously. Recent gains are a continuation of the increases that have been occurring over the last 60 years.

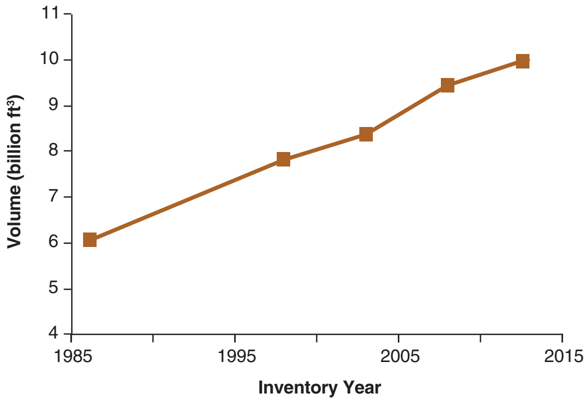

Figure 39.—Net volume of live trees on timberland by inventory year, Indiana.

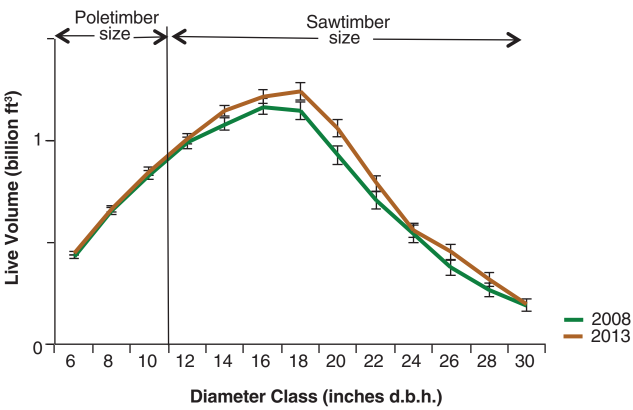

Figure 40.—Net volume of live trees on forest land by diameter class, Indiana, 2008 and 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

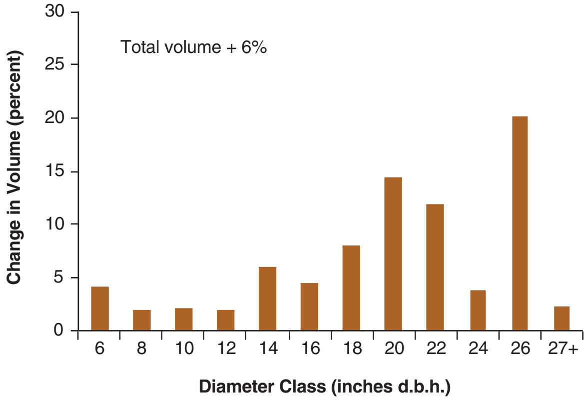

Figure 41.—Percent change in net volume of live trees on forest land by diameter class, Indiana, 2008 to 2013.

In the current inventory, net volume of sawtimber trees on timberland was highest in the Knobs Unit (10.2 million board feet), followed by the Northern Unit (6.4 million board feet), Lower Wabash Unit (5.1 million board feet), and Upland Flats Unit (2.9 million board feet) (Fig 42). Yellow-poplar continues to be the most voluminous species followed by sugar maple and white oak (Fig. 43). Volume increased in all three species. Black cherry had the greatest percentage increase in volume at 17 percent. Although volume increased in most major species, eastern cottonwood and pignut hickory showed decreases in volume. Sixteen species compose 76 percent (7.9 billion cubic feet) of the live volume found throughout Indiana (Fig. 43). The ten most common species by volume differ somewhat by unit and represent the following percentage of the live volume: Lower Wabash (62 percent), Knob (73 percent), Upland Flats (79 percent), and Northern Units (51 percent) (Fig. 44). In the Lower Wabash Unit, the decrease in black oak volume is caused by oak decline and associated drought periods, and the decrease in white ash volume is attributed to emerald ash borer.

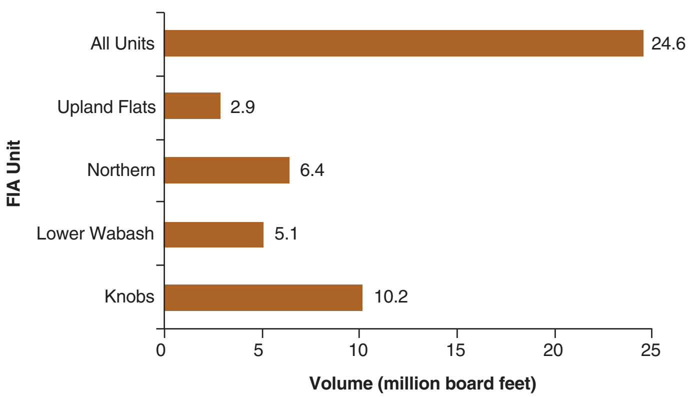

Figure 42.—Net volume of growing stock sawtimber trees on timberland, in million board feet (Doyle log rule), by FIA unit, Indiana, 2013.

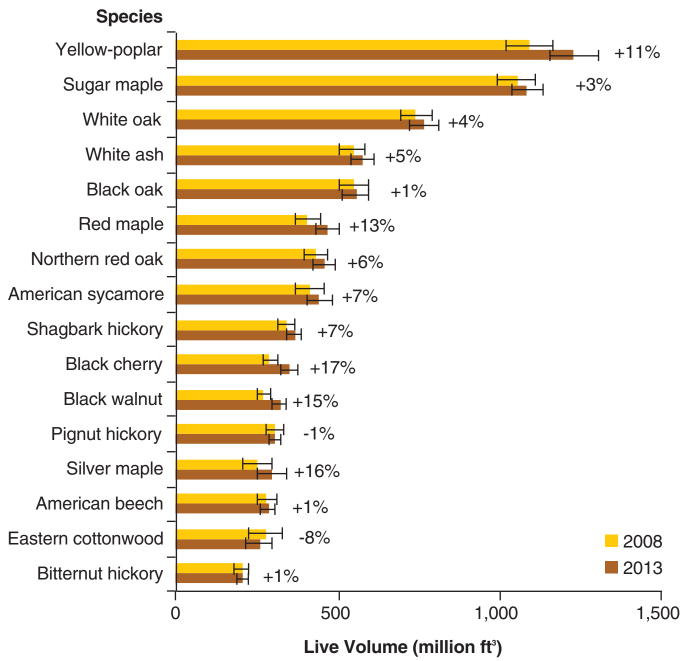

Figure 43.—Live volume of selected species on forest land, Indiana, 2008 and 2013. Percent change shown to right of bar pairs. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

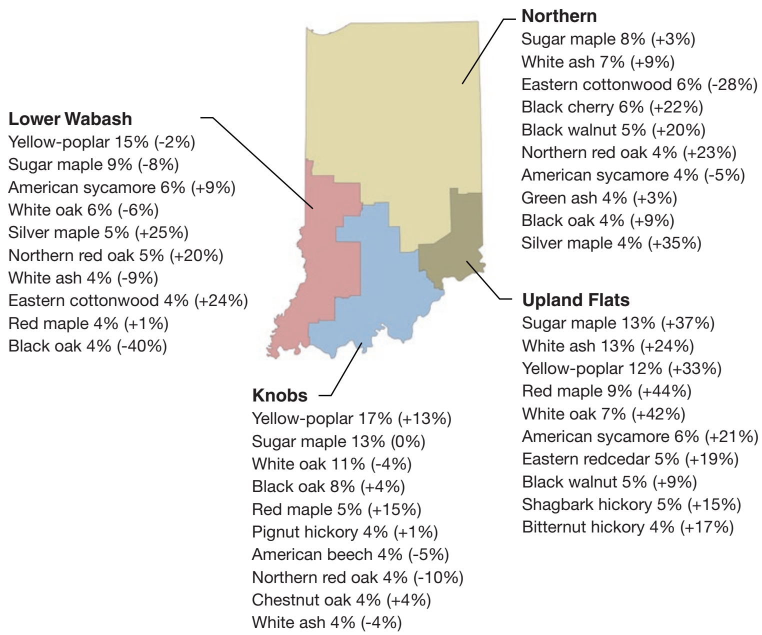

Figure 44.—The 10 most common species in each FIA unit, ranked by 2013 live volume followed by percent of forest land live volume in FIA unit and percent change in volume (+ or -) from 2008 to 2013, Indiana.

Sawtimber volume on timberland increased by nearly 5 percent and totals 36.1 billion board feet (International ¼-inch rule). Yellow-poplar is the leading sawtimber species, by volume, followed by sugar maple, white oak, black oak, and white ash (Fig. 45). White ash is expected to fall from this list of leading sawtimber species, by volume, as ash trees die within the next 10 years as emerald ash borer completes it spread across Indiana. Black cherry (+46 percent) followed by silver maple (+34 percent) and walnut (+14 percent) had the largest percentage increases in board-foot volume since 2008 while eastern cottonwood (-9 percent), American beech (-7 percent), and black oak (-6 percent) had the largest decreases.

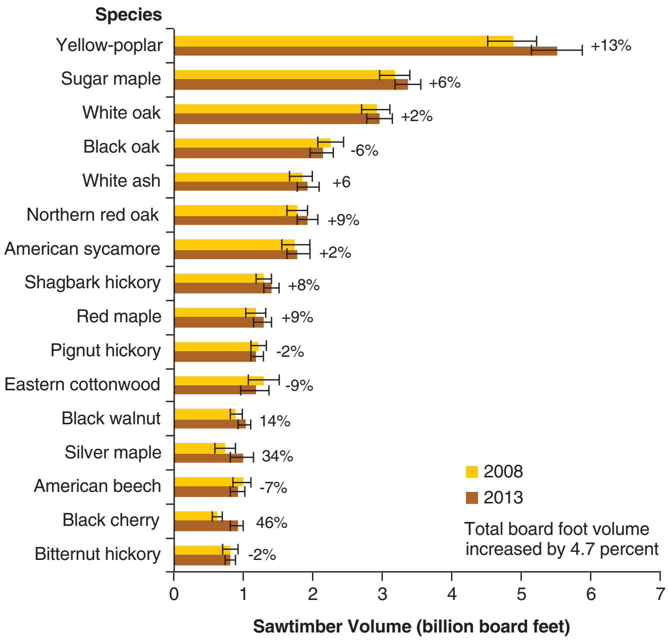

Figure 45.—Sawtimber volume in board feet (International ¼-inch rule) on timberland by species, Indiana, 2008 and 2013. Percent change shown to the right of the bar pairs. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

All units showed gains in cubic foot and board-foot volumes. Average board-foot volume per acre of timberland were highest in the Knobs Unit and lowest in the Upland Flats Unit; however, the Upland Flats Unit had the largest percentage increase in average cubic foot volume per acre of forest land (8 percent) as well as in average sawtimber board-foot volume per acre of timberland (15 percent) since 2008 (Fig. 46).

Statewide, shifts in the relative dominance of tree species are indicated by changes in volume over the last 25 years. Although white oak volume increased by 228 million cubic feet between 1986 and 2013 and red oak increased by 460 million cubic feet, yellow-poplar boomed and had a 179 percent increase in growing-stock volume, increasing by 773 million cubic feet (Fig. 47).

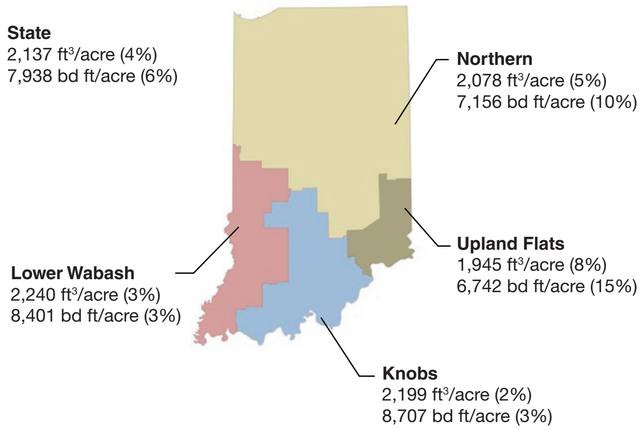

Figure 46.—Average cubic-foot (ft³) volume per acre of live trees on forest land and average board-foot (bd ft) volume per acre on timberland, by FIA unit, 2013, and percent change in volume per acre, Indiana, 2008 to 2013.

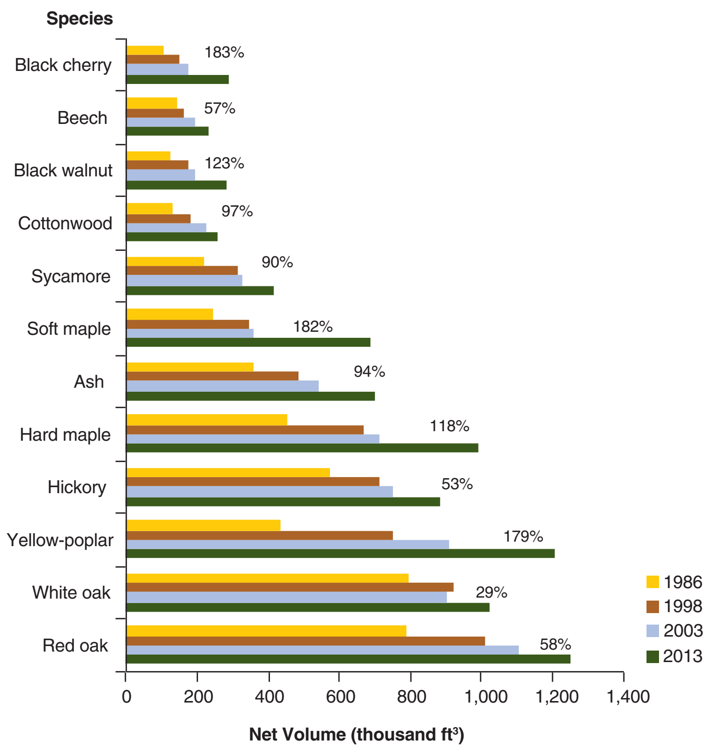

Figure 47.—Growing-stock volume by species/species group and inventory year, Indiana. Percent change in growing-stock volume from 1986 to 2013 is shown beside bars.

The Forest Service commonly reports sawtimber board-foot volume in International ¼-inch rule. In Indiana, the Doyle log rule is commonly used. Due to State and local interest, the following sawtimber volume discussion is presented using the Doyle log rule. To convert between Doyle log rule and International ¼-inch rule, see Appendix 2 or consult Smith 1991. Current statewide estimates of sawtimber net volume by species reflect the trend discussed above, with the following species making up the indicated percentage of the total estimated sawtimber net volume of 24.6 billion board feet (Doyle log rule): yellow-poplar (15.7%), white oak (8.6%), sugar maple (8.4%), black oak (6.2%), northern red oak (5.9%), American sycamore (5.7%), white ash (5.3%), and eastern cottonwood (4.3%). Collectively these eight species make up more than 60 percent of the total net sawtimber volume. Yellow-poplar dominates and has nearly twice the sawtimber volume of any other species. Sugar maple and yellow-poplar dominate in the smallest hardwood sawtimber diameter class (11.0 to 12.9 inches) while yellow-poplar, white oak, black oak, northern red oak, and American sycamore dominate in the larger diameter classes (25 inches plus). Eastern cottonwood, American sycamore, followed by silver maple, red maple, black oak, pin oak, and white oak compose the bulk of tree species over 37 inches in diameter (Table 2). The 25 most common species shown in Table 2 make up more than 93 percent of the State's total net sawtimber volume.

Table 2.—Net volume of the 25 most common sawtimber trees on timberland (Doyle log rule) by species and diameter class, Indiana, 2013

Species name	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-24.9	25.0-28.9	29.0-32.9	33.0-36.9	37+	All Classes
	million board feet											
Yellow-poplar		189	309	417	573	630	756	742	167	88		3,872
White oak		83	153	244	327	347	412	277	169	70	33	2,116
Sugar maple		240	316	400	343	288	334	83	62			2,066
Black oak		59	94	132	270	201	442	194	101		44	1,537
Northern red oak		40	72	127	199	208	370	183	173	58	22	1,454
American sycamore		34	69	114	121	128	330	294	170	81	60	1,400
White ash		90	144	174	203	146	311	175	17	18	23	1,301
Eastern cottonwood		11	18	43	69	83	154	240	183	164	64	1,027
Shagbark hickory		99	132	159	167	130	103	53	17			859
Red maple		91	99	116	88	119	156	91	31	18	46	854
Pignut hickory		75	112	146	153	115	87	23	16			727
Silver maple		42	50	73	96	72	158	109	76		48	725
American beech		33	40	65	114	102	160	57	61	20		651
Black walnut		79	116	107	126	88	50	27	13			607
Black cherry		93	82	90	79	87	81	28				540
Pin oak		19	35	40	52	39	114	110	38	38	37	523
Bitternut hickory		50	78	74	117	108	60					488
Green ash		40	51	72	37	43	68	17	14	15	17	375
Chestnut oak		18	46	70	56	33	88	26				336
American basswood		21	34	30	41	34	73	15	17			265
Hackberry		35	40	48	27	20	36	19	14		21	261
Eastern white pine	10	21	28	39	72	43	31	11				255
Sweetgum		23	37	27	27	35	68	9	15			241
Chinkapin oak		25	30	31	37	19	61	15	16			234
Sassafras		39	59	44	25	30	10	8				215

What this means

The shift in species composition and volume is due in part to long-term patterns of disturbance and regeneration that favor maples and beech more than oaks. Continuous increases in volume have brought Indiana's forest resources to levels not seen in the past 100 years in terms of both total net volume of live trees and board-foot volume. Over the past six decades the area of Indiana timberland increased from 4 to nearly 4.9 million acres; over that same period the volume of growing-stock timber nearly quadrupled from 2.6 to 9.5 billion cubic feet. This gain, combined with a stable forest land base, shows tremendous stewardship and conservation of Indiana's forest resources. Most of the volume is on timberland and in trees that meet minimum requirements to qualify as growing-stock trees. Because most volume increases have occurred on the larger and more valuable trees (notably black cherry and walnut), Indiana forests are likely adding value at a greater rate than increases in volume alone indicate.

In each of the four FIA units, the ten most common species represent over half of the total volume, with no one species representing more than a fifth of the total volume by unit. There are few areas in Indiana where any one species dominates. This diverse mix of species reduces the impact of insects and diseases that target a single species.

The yellow-poplar sawtimber resource in Indiana is booming. Yellow-poplar leads in board-foot sawtimber volume and is concentrated in the hill country of the Lower Wabash, Knobs, and Upland Flats Units, where it is a valuable part of the timber resource. Today, yellow-poplar is the most common tree species in Indiana by volume, and it has experienced a state-wide growth in volume that is more than four times that of any oak species over the last 25 years.

The Northern Unit is experiencing emerald ash borer mortality. As of 2013, all ash in the eastern half of the Northern Unit were dead or dying.

On flood plains, eastern cottonwood requires moist seedbeds or flood disturbances (immersion in water) to reproduce. As the cottonwoods age, a lack of this type of disturbance and poor site conditions may result in little reproduction. As a consequence, the eventual decreases in eastern cottonwood sawtimber volume will result in volume increases by silver maple, a common associate.

Biomass

Background

Trees play an important role in the world's carbon cycle. They act as a sink for carbon, removing it from the atmosphere in the form of carbon dioxide (a greenhouse gas) and storing it as cellulose. In this role, forests help mitigate the effect of burning fossil fuels and the resulting increase of carbon dioxide in the atmosphere. Indiana forests contribute significantly to the sequestration of carbon dioxide due to increases in tree volume.

Tree biomass, a measure of how much carbon is being stored in trees on forest land, is the total weight of both live and dead trees, including branches, roots, and stumps. Typically the carbon content of biomass is equal to half the biomass weight measured in dry tons. Estimates of biomass are important for knowing not only the amount of carbon stored but also the potential amount of biomass available for energy uses.

What we found

Aboveground biomass of all live trees in Indiana forests equals 270.4 million dry tons and averages 55.5 tons per acre. The greatest portion (66 percent) is found in the merchantable boles of commercially important trees representing growing-stock volume (Fig. 48). It is this component that can be converted to high value wood products. Other portions of tree biomass are underutilized and can be considered as potential sources of fuel for commercial power generation. Biomass in live trees has increased by 5 percent since 2008 and is distributed throughout the State, with the largest concentrations in the southern tier of Indiana (Fig. 49).

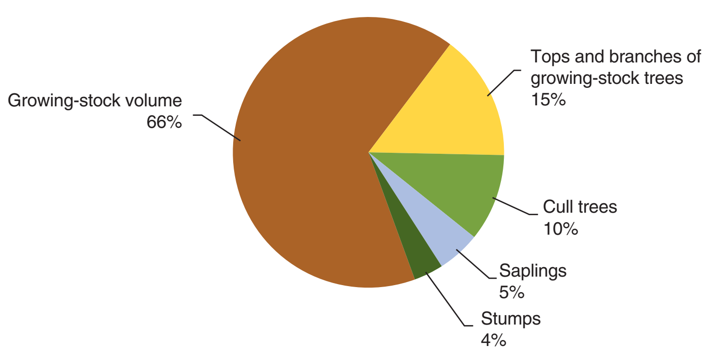

Figure 48.—Components of tree biomass on forest land, Indiana, 2013.

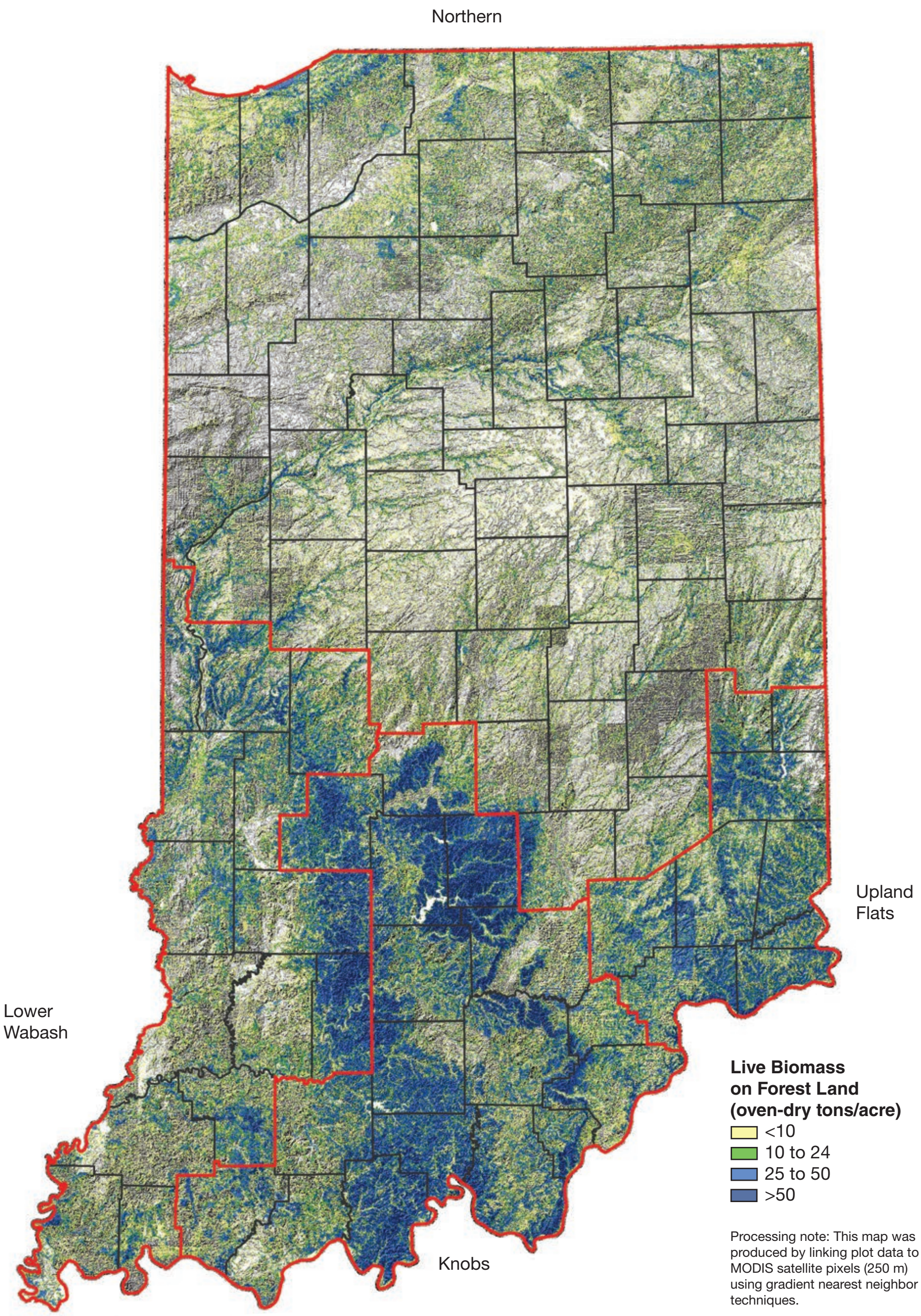

Figure 49.—Distribution of live-tree and sapling biomass on forest land, Indiana, 2013.

What this means

Indiana forests are accumulating substantial biomass. These stores of carbon will receive increasing attention as the Nation seeks sources of renewable energy and ways to offset carbon dioxide emissions. Because biomass is a renewable source of energy, it can help reduce the Nation's dependence on fossil fuels. Utilizing biomass for fuel can provide markets for low grade and underutilized wood. As biomass markets develop, forest managers may need to integrate the harvesting of biomass into their management plans.

The steady rates of increase in both forest area and forest growth have resulted in a sustainable statewide resource of total forest biomass. Because most forest biomass is found in the boles of growing-stock trees on timberland, the management of private forest land strongly influences the future of not only the biomass resource but also carbon cycles and future wood availability. Given the potential increase in demand to manage forest biomass components for both carbon and biofuel uses, the monitoring of Indiana's forest biomass is even more critical.

Privately owned forest land enrolled in the Classified Forest and Wildlands Program, the reversion of agricultural lands to forest, and conservation measures by federal, state, and local agencies contributed to the statewide increase in total biomass. As holders of the majority of Indiana's forests, private forest landowners play an important role in sustaining biomass. The management of both public and private forest land has a strong effect on Indiana's carbon sinks. If the State becomes involved in carbon trading, estimates of biomass and carbon sequestration by forests will become increasingly important.

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

Background

Well-tended forests supply a continuous flow of products without impairing long-term productivity. One way to judge the sustainability of a forest is to examine the components of annual change in inventory volume: growth, removals, and mortality. Net growth includes growth (accretion) on trees measured previously, ingrowth of trees over the 5-inch threshold for volume measurement, deductions for mortality due to natural causes, and volume of trees on lands reverting to forest. Removals include trees that are harvested and trees that are lost because the forest land was developed for a nonforest use. Analysis of these individual components can help us better understand what is influencing net change in volume.

What we found

During the last 60 years in Indiana, the growth of trees has greatly outpaced mortality and removals. The most recent inventory reveals that since 2008, the gross growth in the net volume of live trees totaled 354 million cubic feet annually. Annual mortality averages 118 million cubic feet, resulting in a net growth of 236 million cubic feet per year (Fig. 50). The removal of trees due to both harvesting and land-use change averaged 72 million cubic feet, leaving an annual surplus or net increase of 164 million cubic feet on Indiana forest land. As a percentage of the current inventory, gross growth was 3.4 percent, mortality was 1.1 percent, net growth was 2.3 percent, and removals were 0.7 percent, resulting in a net change in total volume of 1.6 percent annually. Eighty-eight percent of net growth is on trees growing on land that was forested in both 2008 and 2013, and the remaining 12 percent is from trees on land that was previously nonforest and is now forest land.

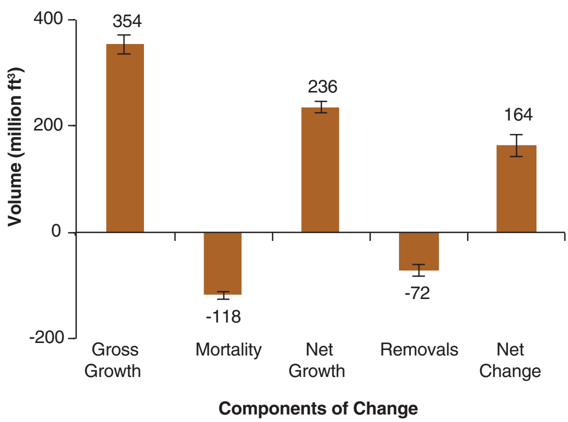

Figure 50.—Annual components of change in live volume on forest land, Indiana, 2008 to 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

On land that was forest in both 2008 and 2013, accretion (growth on trees 5.0 inches d.b.h. and larger) accounted for 86 percent of the net growth; the remaining 14 percent was ingrowth from trees growing into the 5-inch diameter class. Accretion was well distributed across diameter classes. Sixty-six percent of accretion was on trees that were at least 11 inches d.b.h. in the previous inventory (Fig. 51). Average annual net growth of sawtimber trees was highest in the Knobs Unit (197 million board feet), followed by the Northern (152 million board feet), Lower Wabash (144 million board feet), and Upland Flats (79 million board feet) Units (Fig. 52).

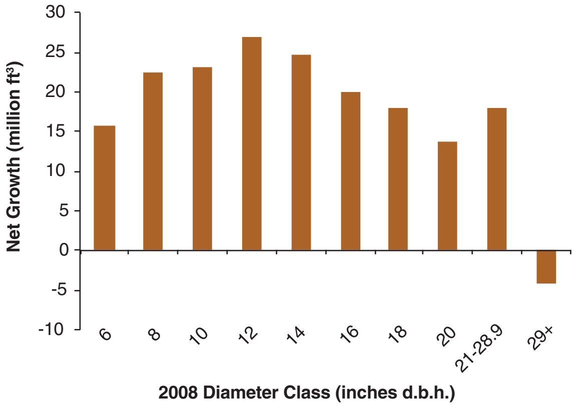

Figure 51.—Net growth volume on previously measured live trees (accretion) by previously measured diameter class on forest land, Indiana, 2008 to 2013.

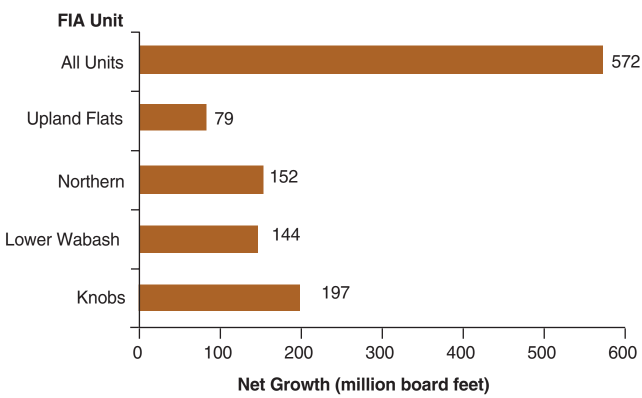

Figure 52.—Average annual net growth of sawtimber trees on timberland, in million board feet (Doyle log rule), by inventory unit, Indiana, 2008 to 2013.

Statewide, 79 percent of the removals were due to the harvesting of trees on land that remained in forest and 21 percent were due to forest land being diverted to nonforest land. Sawtimber removals were highest in the Knobs and Lower Wabash Units (Fig. 53). On land that was forested in both 2008 and 2013, removals during the 2013 inventory were concentrated on the larger trees, with 87 percent of the removals, by volume, being sawtimber-size trees (Fig 54).

On Indiana forest land, the net growth-to-removals ratio (G/R) averaged 3.3:1 from 2009 to 2013 (Fig. 55). Ratios were lower than the State average on the Lower Wabash and Knobs Units and higher on the Upland Flats and Northern Units (Fig. 56). G/R ratios varied considerably between species. Of the top 16 species by volume in Indiana, black walnut and red maple had the largest G/R ratios at 13.4:1 and 10.4:1, respectively (Fig. 57). Net growth exceeded removals for all major species. Yellow-poplar had the largest amount of growth followed by sugar maple and red maple. Yellow-poplar also accounted for the largest share of removals (16 percent), although growth still outpaced removals by a ratio of 2.9 to 1. The 2012 drought and tuliptree scale (*Toumeyella liriodendri* Gmelin) epidemic are two factors that contributed to the high rate of removals in yellow-poplar. Another factor impacting removals occurred in the southern Indiana Knobs Unit and Upland Flat Unit where foresters removed large yellow-poplar after realizing the trees would not make it to the next harvest because of drought intolerance and other site conditions.

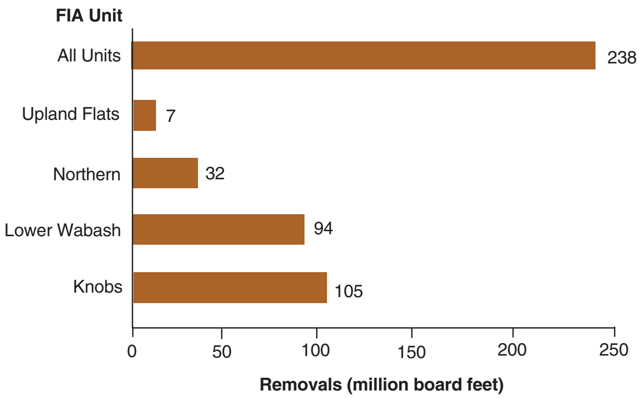

Figure 53.—Average annual removals of growing-stock sawtimber trees on timberland, in million board feet (Doyle log rule), by inventory unit, Indiana, 2008 to 2013.

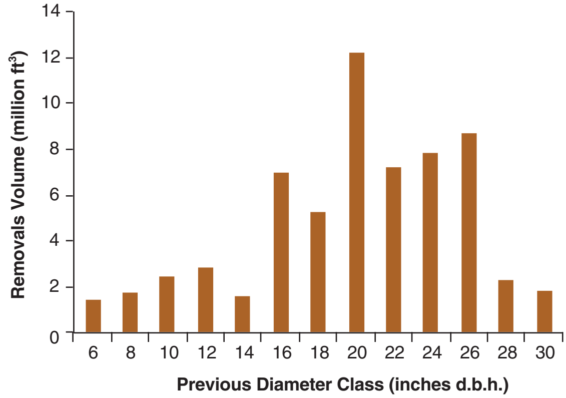

Figure 54.—Average annual removals of live trees (5 inches d.b.h./d.r.c. and larger), by previously measured diameter class (2008) on forest land, Indiana, 2008 to 2013. Data excludes removals due to forest land being diverted to nonforest uses.

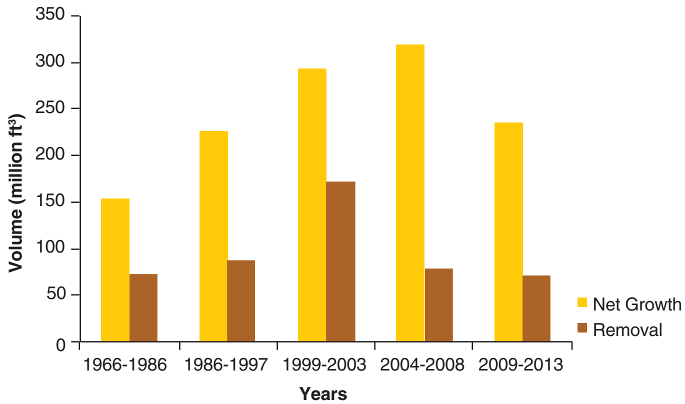

Figure 55.—Comparison of volume of net growth and removal of growing stock by inventory years, Indiana, 1966-2013.

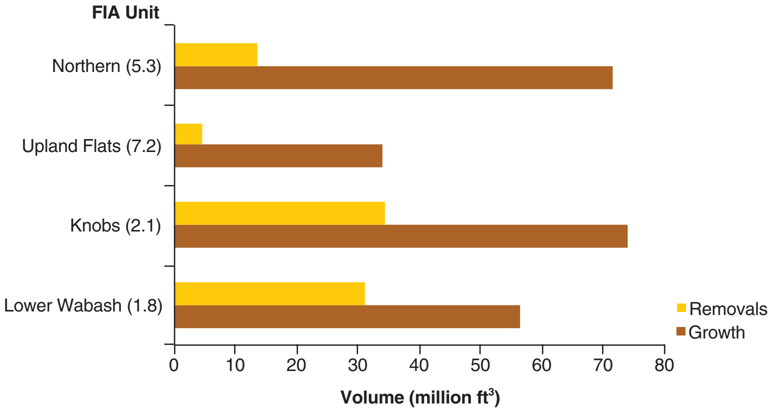

Figure 56.—Average annual growth and removals of live trees (at least 5 inches d.b.h./d.r.c.) on forest land, by FIA unit, Indiana, 2008 to 2013. Growth-to-removals ratio (G/R) is listed in parentheses beside unit name.

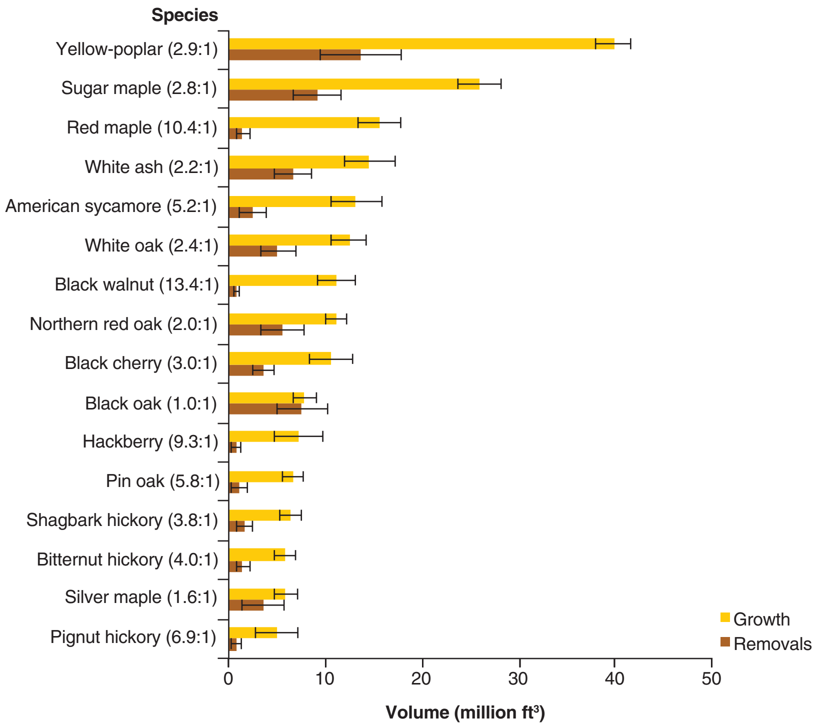

Figure 57.—Average annual growth and removals of net volume on forest land by species, Indiana, 2008 to 2013. Growth-to-removals ratio (G/R) listed beside species name. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

What this means

Today's well-stocked forests are a product of growth consistently outpacing removals during the last half century and the surplus accumulating in the forest. Since 2008, net growth has been twice that of removals, with the net change amounting to an annual increase of 2.8 percent in inventory volume. This finding implies that the current level of removals is sustainable and that increases in volume will continue at the State level as well as in each of the FIA units.

Comparing the G/R ratios of individual species to the average ratio for all species (3.3:1) reveals that the resource is being managed sustainably. The high G/R ratio for walnut indicates that this species will continue to be an important component in Indiana forests.

Mortality

Background

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

What we found

In Indiana, average annual mortality was 118.3 million cubic feet between 2008 and 2013, an annual rate of 1.1 percent of inventory volume. This is similar to rates in the neighboring states of Ohio (1.1 percent), Kentucky (1.0 percent), Illinois (1.6 percent), and Michigan (1.1 percent). By FIA unit, mortality to volume rates were highest in the Northern Unit (1.3 percent) followed by the Knobs Unit (1.2 percent). The Upland Flats and Lower Wabash Units both had mortality rates of 0.9 percent of unit volume (Fig. 58).

Mortality rates were higher for smaller diameter trees than for larger ones, although rates do rise in the largest diameter trees (Fig. 59). The mortality rate in the 6-inch diameter class was 2.1 percent per year, which is nearly twice the average rate across all diameter classes; the 20-inch diameter class had the lowest mortality rate at 0.6 percent. Trees less than 9.0 inches in diameter account for 17 percent of the total mortality, by volume, even though they represent only 11 percent of total volume.

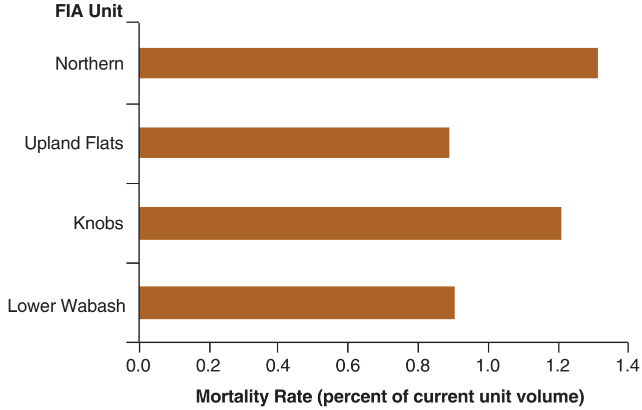

Figure 58.—Average annual mortality rate as a percent of current live tree volume on forest land, by FIA unit, Indiana, 2008 to 2013.

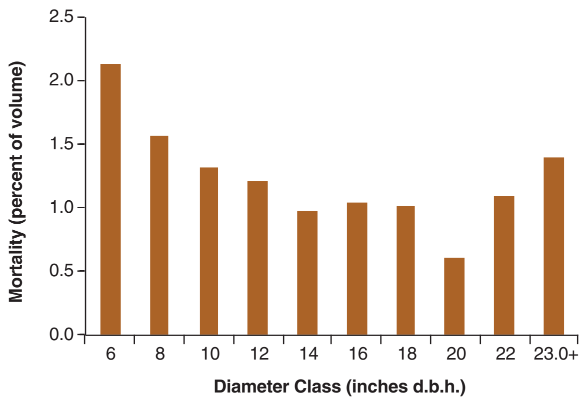

Figure 59.—Average annual mortality rate as a percent of current live tree volume on forest land by diameter class, Indiana, 2008 to 2013.

Species with high annual mortality rates include American elm (4.2 percent), sassafras (1.9 percent), eastern cottonwood (1.9 percent), black oak (1.8 percent), white ash (1.4 percent), and green ash (1.2 percent) (Fig. 60). Yellow-poplar, the leading species in cubic-foot volume, had a lower mortality rate (0.7 percent) and ranked 15th when compared to the other 24 species.

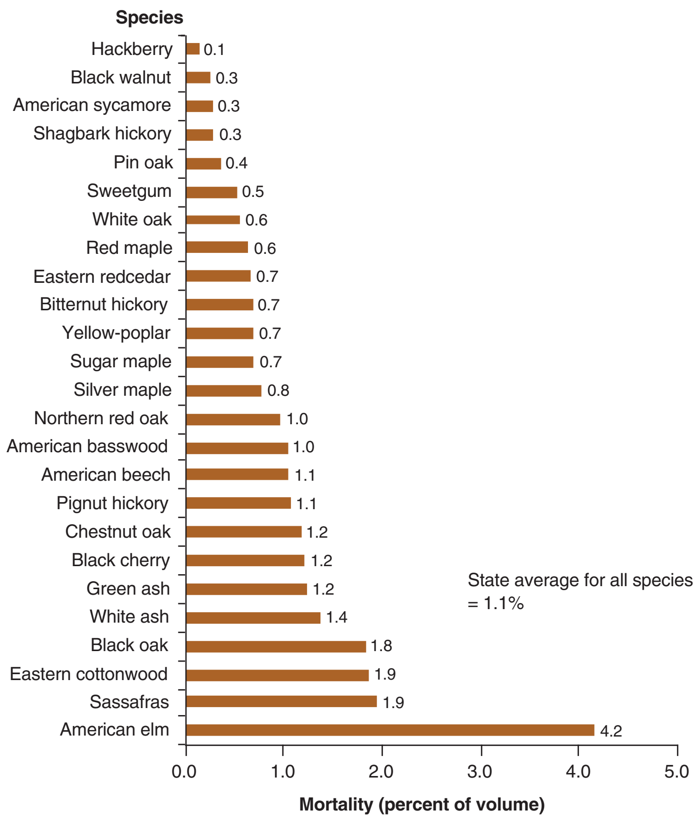

Figure 60.—Average annual mortality rate as a percent of current live tree volume for 25 major species, Indiana, 2008 to 2013.

What this means

The maturing of Indiana forests has resulted in crowded growing conditions. As trees compete for light and growing space, some fall behind their neighbors, lose vigor, and eventually succumb to insects and diseases. This is evident in the condition of trees in the small diameter classes. As discussed in the Tree Condition—Crown Position and Live Crown Ratio section, most trees less than 8.0 inches in diameter grow in the understory, and a fifth of the trees in the 6- and 8-inch diameter classes have live crowns less than 20 percent of their height, a sign of poor vigor in the smaller diameter classes. However, since the tree mortality rates in Indiana are about the same as the surrounding states, they can be considered normal.

Much of the mortality can be explained by stand dynamics or insects and diseases that target specific species. Elm and ash mortality is likely caused by Dutch elm disease and the emerald ash borer impacting these species. As the emerald ash borer infestation continues to spread, ash mortality will likely raise mortality rates throughout the State. Black oak mortality is attributed to oak wilt, old age, drought, poor site conditions, and oak decline. Black oak trees are sensitive to stress, especially as they age. Trees weakened by environmental stresses such as drought or defoliation often readily succumb to secondary agents, including twolined chestnut borer (*Agrilus bilineatus*), hypoxylon canker (*Hypoxylon mammatum*), and shoestring root rot (*Armillaria mellea*). This periodic decline and death of oaks over widespread areas due to an interaction of environmental stresses and pests is referred to as oak decline (Wargo et al. 1983). Thus, as black oak increases in age and volume, an increase in sawtimber mortality and a decrease in sawtimber volume can be expected.

Mortality rates vary among tree species, and many species deviate substantially from the State average. Having a large diversity of species contributes to the resiliency of Indiana forests to the impacts of insects and diseases that attack individual species.

Forest Indicators

Redbud tree flowers in bloom mingle with spring foliage at McCormick's Creek State Park. Photo by Indiana Department of Natural Resources, used with permission.

Urbanization and Fragmentation of Forest Land

Background

Fragmentation occurs naturally from disturbances such as wildfire, wind, and flooding, or as the result of human activities such as conversion to agriculture or urban development/sprawl. Human disturbance has a more severe impact on the remaining forest because it occurs more frequently and results in more permanent land-use changes than natural disturbance events. The expansion of urban lands that accompanies human population growth often results in the fragmentation and urbanization of remaining natural habitat (Wilcox and Murphy 1985). Forest fragmentation and habitat loss diminish biodiversity and are recognized as a major threat to animal populations worldwide (Honnay et al. 2005, Rosenberg et al. 1999). This is particularly true for species that require interior forest conditions for all or part of their life cycle (Donovan and Lamberson 2001), or are wide-ranging, slow-moving, or slow at reproducing (Charry 2007, Forman et al. 2003). Forest fragmentation can also affect forest ecosystem processes through changes in microclimate conditions, and it affects the ability of tree species to move in response to climate change (Iverson and Prasad 1998). Changes in the size of remaining forest patches, in their level of connectivity to other large patches, in the amount of general forest cover surrounding each patch, and in the amount of forest-nonforest edge all directly affect the amount and quality of interior forest and consequently the species and ecosystem functions that depend on these interior conditions. The same factors also affect the ease with which exotic, invasive, or generalist species can gain a foothold; the ability of wildlife species to move across the landscape; and the ability of the forest to protect the quality and quantity of surface and ground water supplies.

Spatial landscape pattern metrics help quantify these different characteristics of fragmentation. In the last Indiana inventory (Woodall et al. 2011), the amount of edge vs. core forest was examined with respect to the most widely used thresholds for interpreting likely impact. The results highlighted the large proportion of Indiana forest in edge conditions (58 percent) and the range of landscape conditions between Indiana's more forested southern half and the dominantly agricultural northern half.

Metric values are sensitive to the resolution of the land cover data source used (Moody and Woodcock 1995), similar to the way that animal species see the landscape very differently depending on the scale at which they operate—e.g., the same patch that supplies interior forest conditions for one species is viewed as an unsuitable fragment by another species with higher quality or larger area requirements. Because important forest ecosystem processes operate at different scales, current levels of fragmentation are examined at two scales by adapting a spatial integrity index (SII) developed by Kapos et al. (2000) for the Global Forest Resources Assessment (FRA). The SII integrates three facets of fragmentation that affect some aspect of forest ecosystem functioning—patch size, local forest density, and patch connectivity to core forest areas—to create a single resulting metric for comparison (Table 3). Since even acceptably low misclassification rates in the source land cover data can be magnified into substantial errors in metric values (Langford et al. 2006, Shao and Wu 2008), spatial integrity is calculated at two scales corresponding to two reliable and widely available source datasets, the 30 m scale of the 2011 National Land Cover Dataset (NLCD) (Jin et al. 2013) and the 250 m scale of the 2009 FIA forest cover dataset (Wilson et al. 2012). Both scales fall within the 10 to 1,000 km^2 scale at which pattern process linkages are often of greatest management interest (Forman and Godron 1986).

Table 3.—Spatial Integrity Index (SII) parameters used in calculations at each scale

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

In the SII calculation, core forest is defined by patch size and local forest density within a defined local neighborhood area. An unconnected forest fragment is defined by its patch size, local forest density, and distance to a core forest area, and the spatial integrity of all other forest lands are scaled between these two ends. Table 3 identifies the thresholds used to define both core forest and unconnected fragments at the 250 m and 30 m scales. These two scales capture a relatively broad range of definitions for core forest and spatial integrity that should encompass the scales appropriate for understanding impacts on a wide range of wildlife species and ecosystem processes affected by forest fragmentation.

The population of Indiana increased by 6.6 percent between 2000 and 2010, to 6.5 million people. During that same time period, the number of housing units increased by 10.7 percent (U.S. Census Bureau 2010). Stated another way, between 2000 and 2010 housing units increased at a pace 1.6 times the rate of increase in population, a trend not unique to Indiana. In recent decades this housing growth has occurred not only in increasing suburban rings around urban areas but also in rural areas. Lepczyk et al. (2007), Theobald (2005), and Hammer et al. (2004) observed that areas currently facing rapid increases in housing density and areas predicted to increase in the future are amenity-rich rural areas around lakes and other forest recreation areas. The 35 percent increase in the number of reported second homes from 2000 to 2010 could be a partial reflection of this trend in Indiana (U.S. Census Bureau 2010). This can put additional pressure on forested areas even above the general increases in population density and housing density.

What SII identifies as core does not represent completely intact forest conditions because it is calculated from forest canopy and does not consider underlying house densities or proximity to roads. Using the definition of wildland-urban interface (WUI) intermix from Radeloff et al. (2005) (greater than 15.5 houses per square mile [6 houses per square km]), the amount of forest, and particularly core or intact forest land, that coincided with these areas was identified. The WUI is described as the zone where human development meets or intermingles with undeveloped wildland vegetation. It is associated with a variety of human-environment conflicts. Radeloff et al. (2005) have defined this area in terms of the density of houses (WUI "intermix" areas), the proximity to developed areas (WUI "interface" areas), and percentage of vegetation coverage. WUI intermix areas intersected with forest land in the 2011 NLCD (Jin et al. 2013) were used to examine changes in the amount of forest land co-occurring with WUI house densities.

Roads are another important impact of urbanization that affect forest lands but are not completely captured by either of the previous two indices. In Indiana as a whole, 43 percent of the forest land was within 650 feet of a road of some sort, and 75 percent was within 1,310 feet when calculated using NLCD 2006 forest (Fry et al. 2011) and U.S. Census Bureau (2000) roads. Roads have a variety of effects: direct hydrological, chemical, and sediment effects; serving as vectors for invasive species; facilitating human access and use; increasing habitat fragmentation; and wildlife mortality. Actual impacts will vary depending on road width, use, construction, level of maintenance, and hydrologic and wildlife accommodations (e.g., Charry 2007, Forman et al. 2003). In general, when greater than 60 percent of the total land area in a region is within 1310 feet of a road, cumulative ecological impacts from roads should be an important consideration (Riitters and Wickham 2003).

What we found

Considering SII classes at the 250 m scale, 21 percent of the forest land in Indiana is core forest, 24 percent has high spatial integrity, 13 percent has medium integrity, 2 percent has low integrity, and 41 percent of the forest is in unconnected fragments. At the 30 m scale, with 22 acres or greater considered core forest, 45 percent of the forest land in Indiana is core forest, 21 percent has high spatial integrity, 9 percent has medium or low integrity, and 24 percent of the forest is in unconnected fragments. Table 4 contains a breakdown of SII values by FIA unit for both scales. Forest

Table 4.—Proportion of forest land for 30 m and 250 m spatial integrity index (SII) classes by FIA unit, Indiana

Unit	Forest by 30 m spatial integrity class					Forest by 250 m spatial integrity class				
	Forest fragment	Low SII	Medium SII	High SII	Core forest	Forest fragment	Low SII	Medium SII	High SII	Core forest
	percent					*percent*				
Lower Wabash	18	1	11	23	46	51	2	11	18	18
Knobs	9	1	7	22	61	19	2	13	33	33
Upland Flats	9	1	9	25	56	27	5	29	27	11
Northern	59	1	8	16	16	91	0	2	4	2
State	24	1	8	21	45	41	2	13	24	21
State after incorporating WUI areas	24	2	9	34	31	41	4	13	27	15

connectivity is highest in the Knobs Unit and lowest in the Northern Unit. Large areas of relatively continuous forest clearly stand out at the 250 m scale (Fig. 61). At the 30 m scale, the lower threshold of 22 acres for defining core forest means that more forest patches are considered core. Figure 62 compares the SII classes between the two scales for an area southwest of Indianapolis. It is important to note that the forest landscape data used here are depicting tree cover only and may not incorporate the presence of local development associated with or underlying this tree cover.

Forest land with a sufficient underlying housing density to qualify as WUI areas has been steadily increasing. In 1990, approximately 20 percent of the forest land was in low and medium density WUI. In 2000 this increased to 24 percent of the forest land, and in 2010 it was 27 percent of the forest land in Indiana. The distribution of forested WUI in Indiana is depicted in Figure 63. Substantial impact to forest land is visible southwest of Indianapolis, in the outskirts of Cincinnati, OH, and near the southern border of Indiana. These underlying house densities are poorly captured by the tree canopy cover data used in the calculation of spatial integrity above. When SII results at the 250 m scale are integrated with the WUI classes, 6 percent of Indiana forest land moves from core forest to lower spatial integrity classes, decreasing the proportion of forest land in the core class from 21 percent to 15 percent. At the 30 m scale, 14 percent of Indiana forest land moves from core forest to a lower spatial integrity class, decreasing the proportion from 45 percent to 31 percent. This represents a substantial impact on core forest land from underlying or nearby house densities. The effects tend to concentrate around the outskirts of major cities and amenity-rich areas, and thus may be locally quite noticeable. Figure 64 depicts the changes in SII that occur when WUI status is incorporated, in the area southwest of Indianapolis.

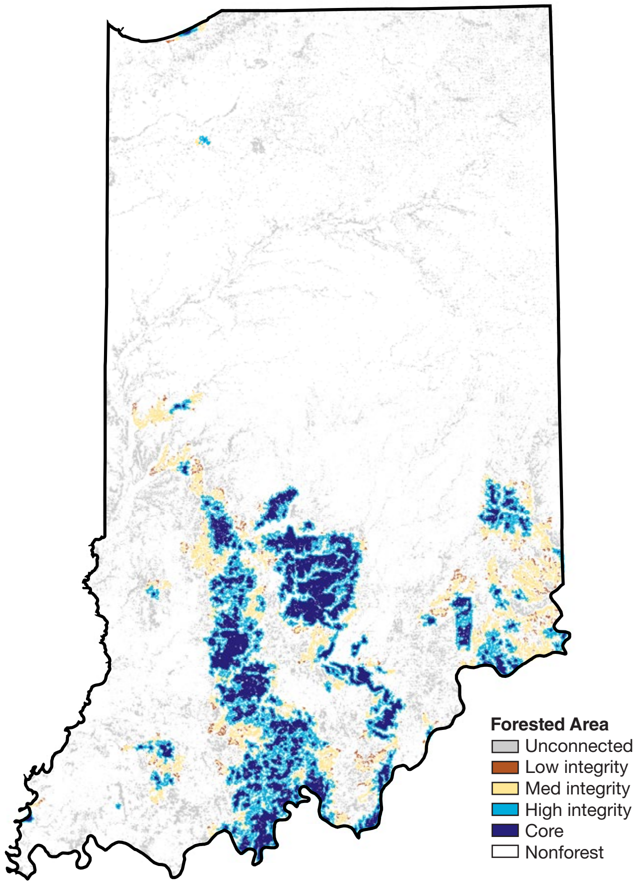

Figure 61.—Forest land by spatial integrity index classes at the 250 m scale, Indiana, 2006.

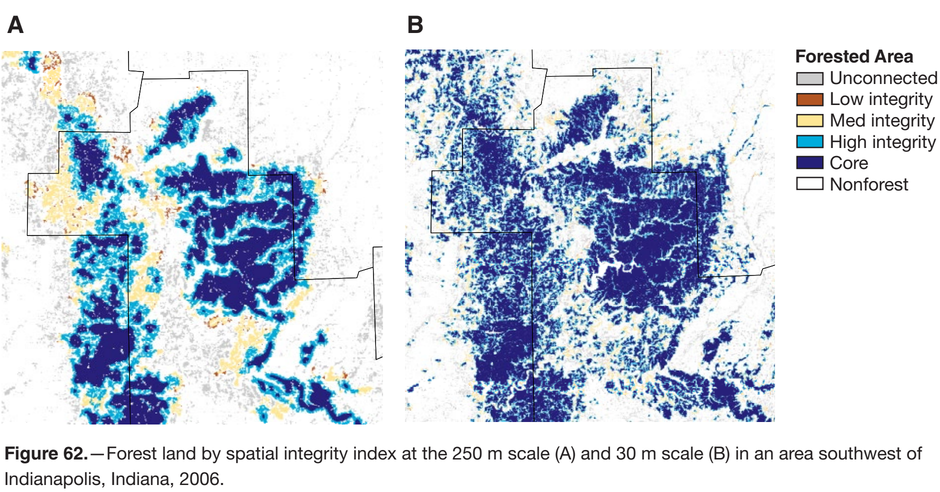

Figure 62.—Forest land by spatial integrity index at the 250 m scale (A) and 30 m scale (B) in an area southwest of Indianapolis, Indiana, 2006.

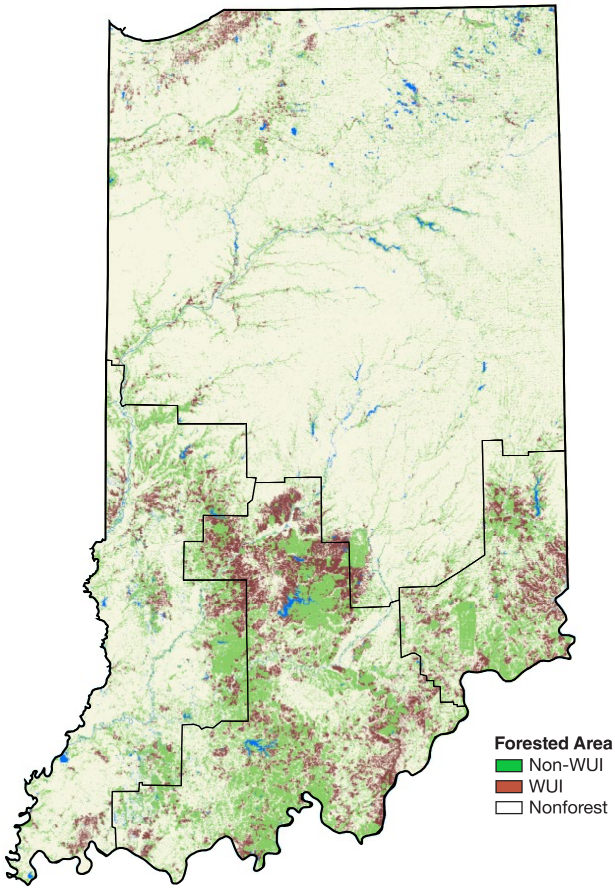

Figure 63.—Forest land by wildland urban interface (WUI status), Indiana, 2006.

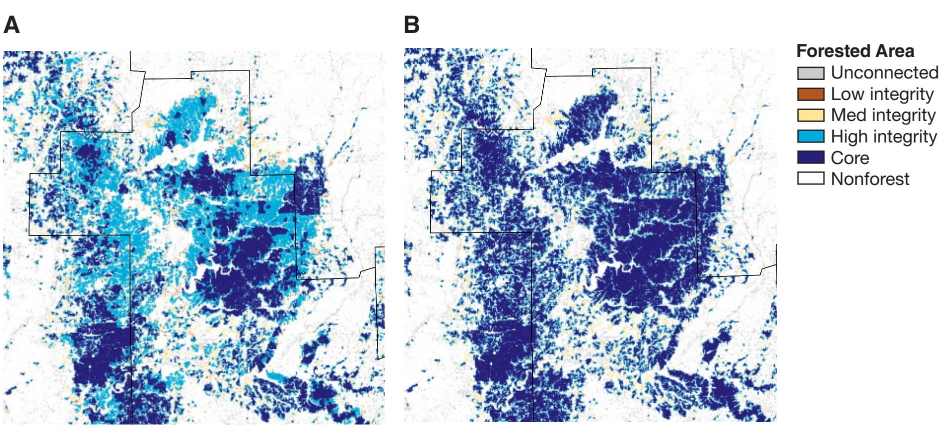

Figure 64.—Forest land by spatial integrity index (SII) at the 30 m scale, with (A) and without (B) incorporating WUI status into SII, in an area southwest of Indianapolis, Indiana, 2006.

Roads remain pervasive in the landscape, existing even in areas that appear to be continuous forest land from the air. In 2000, the proportion of forest area in each unit that was within 650 of a road was 42 percent in the Knobs, 43 percent in Upland Flats, 43 percent in Northern, and 47 percent in Lower Wabash (U.S. Census Bureau 2000) (Table 5 and Fig. 65). Much of this area coincides with areas of current or future housing development. It is also worth noting that the roads included in the U.S. Census Bureau (2000) Tiger data may not include minor roads that are not associated with housing development, and that including these minor roads actually doubles road densities in areas like northern Wisconsin (Hawbaker and Radeloff, 2004).

Table 5.—Distribution of forest land based on several urbanization and fragmentation factors, expressed as a percent of the forest land in each FIA unit, Indiana

FIA unit	Forest of total land in unit[a]	Forest land in wildland urban intermix[b]	Forest land < 650 feet from a road[c]
		percent	
Lower Wabash	30	22	47
Knobs	52	35	42
Upland flats	48	33	43
Northern	11	14	43
State Total	24	27	43

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

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

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

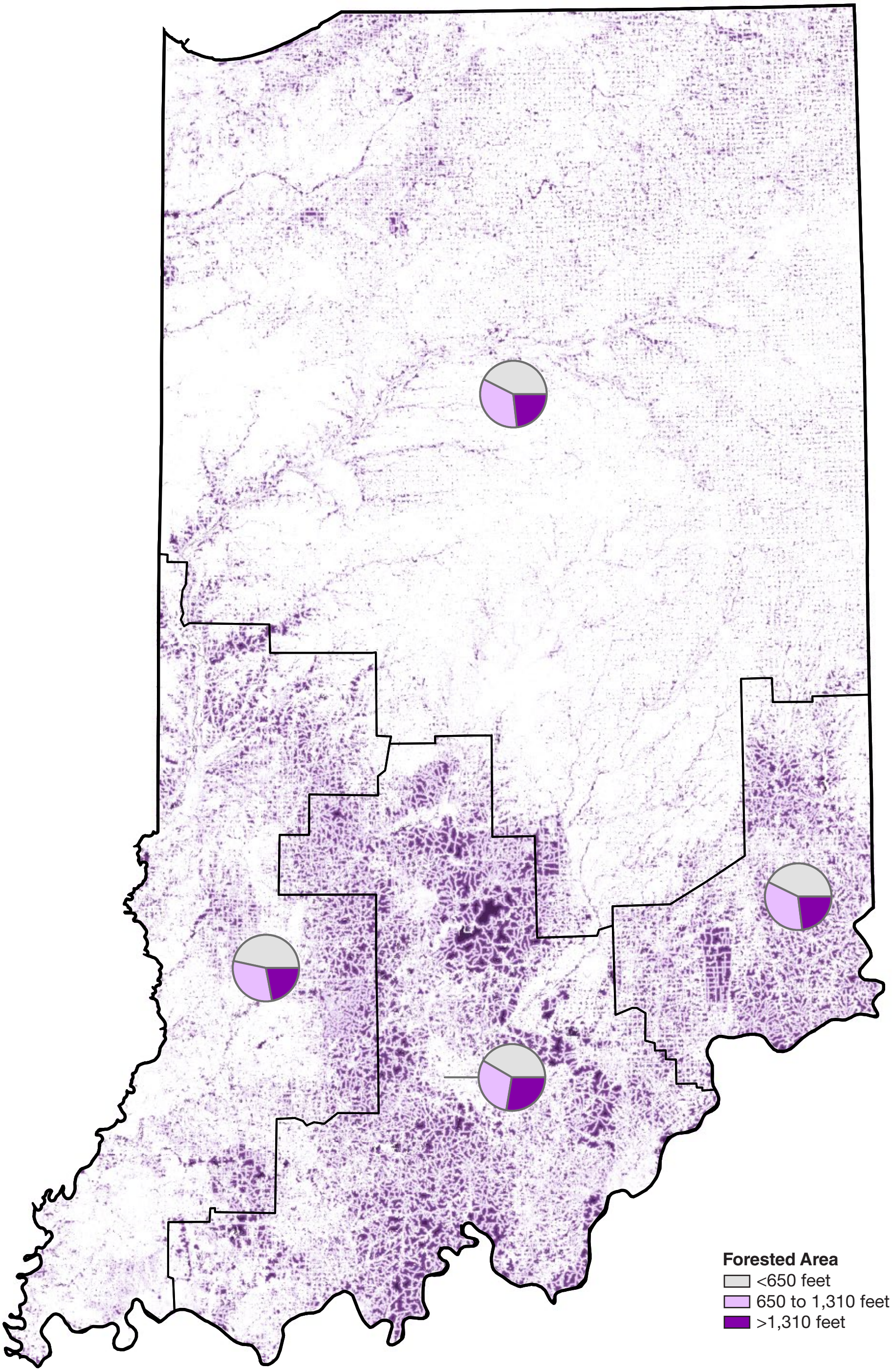

Figure 65.—Forest land by distance from the nearest road, Indiana, 2000.

What this means

At the 250 m and 30 m scales, only 21 to 45 percent of the forest land in Indiana meets the definition of core forest statewide, and between 24 and 41 percent of the forest land is in unconnected fragments. Incorporating WUI areas into the calculation has a substantial effect on what is considered core forest, reducing core forest by almost a third at the 30 m scale. The effect is even greater in several local areas. Bringing roads into the calculation, even at the levels available in the 2000 Census TIGER dataset (U.S. Census Bureau 2000), reduces the integrity of some areas still further.

Forest fragmentation is recognized as a major threat to wildlife populations, particularly for species that require interior forest conditions for all or part of their life cycle or who are wide-ranging or slow-moving, because it increases edge conditions, which can change micro-climate conditions and ecosystem processes, and limits the ability of plants and animals to move in response to climate change (e.g., Forman et al. 2003, Honnay et al. 2005, Iverson and Prasad 1998).

Urbanization increases the proximity of people, development, and other anthropogenic pressures to natural habitats. Both urbanization and forest fragmentation change the way in which humans use forest land, frequently decreasing the likelihood that it will be managed for forest products and potentially increasing its use for outdoor recreation, although urbanization has also been observed to increase the incidence of posting no trespassing signs on forested land, which decreases outdoor recreation opportunities and alters local cultural use of forest land (Butler 2008, Kline et al. 2004, Wear et al. 1999). Continuing fragmentation, parcelization, and urbanization can be barriers to stewardship if they result in forest tracts that are too small or too isolated for effective management (Shifley and Moser 2016).

Invasive species and introduced pests are also a concern, as is the ability of forest systems to adapt to changes in season, temperatures, rainfall patterns, and relative phenological shifts associated with climate change. An intact functioning forest also is critical in protecting both the quantity and quality of surface and groundwater resources (McMahon and Cuffney 2000, Riva-Murray et al. 2010).

Fragmentation and urbanization are changing how Indiana forests function and affect forest sustainability. Fragmentation diminishes the benefits and services forests provide and makes forest management more difficult. As Indiana's population continues to sprawl into rural areas, fragmentation of forest land is a growing concern to land managers. Factors that increase fragmentation, such as development incursions into core and high integrity forest areas, should become the focus of conservation and planning activities. In addition, the characteristics and maintenance of roads and development can play a role in their actual impact on the resilience of forest land and its ability to continue to supply the forest products and ecosystem services we expect and need.

Down Woody Materials

Background

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

What we found

The total carbon stored in down woody materials (fine and coarse woody debris and residue piles) on Indiana forest land exceeded 17 million tons. Downed woody debris carbon was normally distributed by stand-age class (Fig. 66) with moderately aged stands having the highest total carbon (~6 million tons). The downed dead wood biomass within Indiana forests is dominated by coarse woody debris (Fig. 67) at approximately 22 million tons with fine woody debris representing more than a third of statewide totals. The total volume of coarse woody debris was highest in the private ownership category at approximately 2 billion cubic feet (Fig. 68). State and local forests had the second largest totals of coarse woody debris volume (~279 million cubic feet) compared to private ownerships. Given the relatively sparse sample intensity of Phase 3 down dead woody materials plots across Indiana, no dead wood piles were sampled, although there is large sampling uncertainty associated with such an inventory.

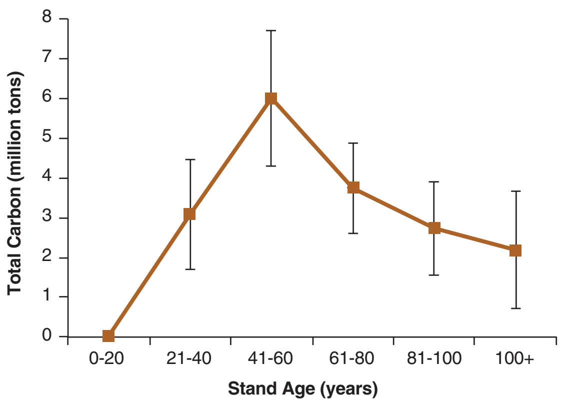

Figure 66.—Total carbon stored in down woody materials (fine and coarse woody debris and residue piles combined) by stand age, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

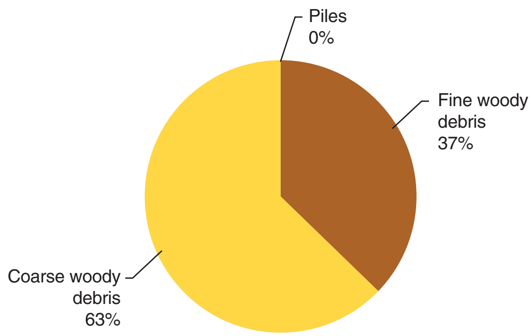

Figure 67.—Percentage of downed dead wood biomass by component, Indiana, 2013.

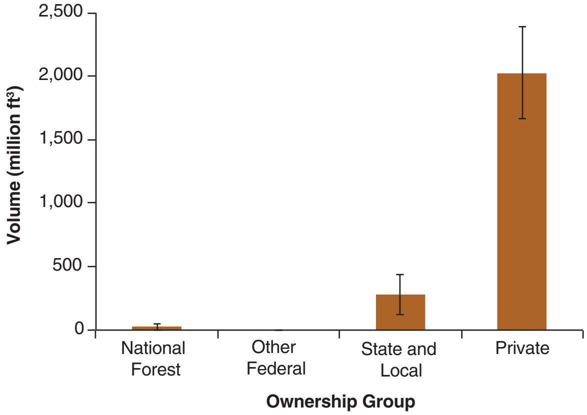

Figure 68.—Total volume of coarse woody debris on forest land by ownership group, Indiana, 2006 to 2010. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

What this means

Given the relatively moist temperate forests across Indiana, only in times of drought would the biomass with down woody materials be considered a fire hazard. Although the carbon stocks of down woody materials are relatively small compared to those of soils and standing live biomass across Indiana, down woody materials are still a critical component of the carbon cycle as a transitory stage between live biomass and other detrital pools such as the litter. Beyond transition of dead wood carbon to other pools, if future temperature and precipitation patterns change, there is a potential for a reduction in these stocks due to increased rates of decay (Russell et al. 2014a, 2014b). The loss of dead wood carbon stocks could indicate the reduction of other pools in the future. Compared to southeastern states where there is more pervasive industrial management of forests (Woodall et al. 2013), no dead wood piles were sampled in this first down woody materials inventory of Indiana forests. Given that the vast majority of coarse woody debris volume was estimated to be in private ownership, it is the management of Indiana's private forests that may affect the future of down woody material contributions to statewide forest carbon stocks and wildlife habitat (i.e., stand structure). Overall, because estimates of fuel loadings are not exceedingly high across Indiana, the numerous ecosystem services provided by down woody materials will likely outweigh possible fire dangers.

Soils

Background

Rich soils are the foundation of productive forest land. Inventory and assessment of the forest soil resource provides critical baseline information on forest health and productivity, especially in the face of continued natural and human disturbance. The forest soils of Indiana were sampled comprehensively from 2000 through 2005. Soils change very slowly, and a remeasurement of the soil was resumed in 2012. Additionally, the soils data require laboratory analyses to provide the complete suite of information (e.g., soil carbon content and nutrient concentrations). Unfortunately, these data are not available for analysis in this report. However, several analyses completed at the regional level are relevant to discussions of land use and forestry interactions with soil resources.

What we found

Peatland soils are found in the northern part of Indiana (Fig. 69). Most of the areas have been converted to nonforest, but some peatland soils continue to support forest cover. Their per-unit-area carbon stocks are exceptionally high; peatlands cover 3 percent of the world's surface area, but they store 30 percent of the globe's soil carbon. They are also sensitive to climate change, and warming temperatures are expected to increase decomposition rates and release large amounts of stored carbon to the atmosphere. The Forest Service examined several methods of estimating peatland carbon and found that peat thickness is the best predictor of total carbon storage.

Several projects are integrating tree measurements with soil chemistry and other factors to evaluate the impacts of atmospheric deposition of nutrients on tree growth and mortality. Sugar maple, one of the trees commonly evaluated, is found in Indiana. Tree basal area and geologic factors are powerful predictors of sugar maple mortality, along with soil chemical attributes like the ratio of magnesium to manganese.

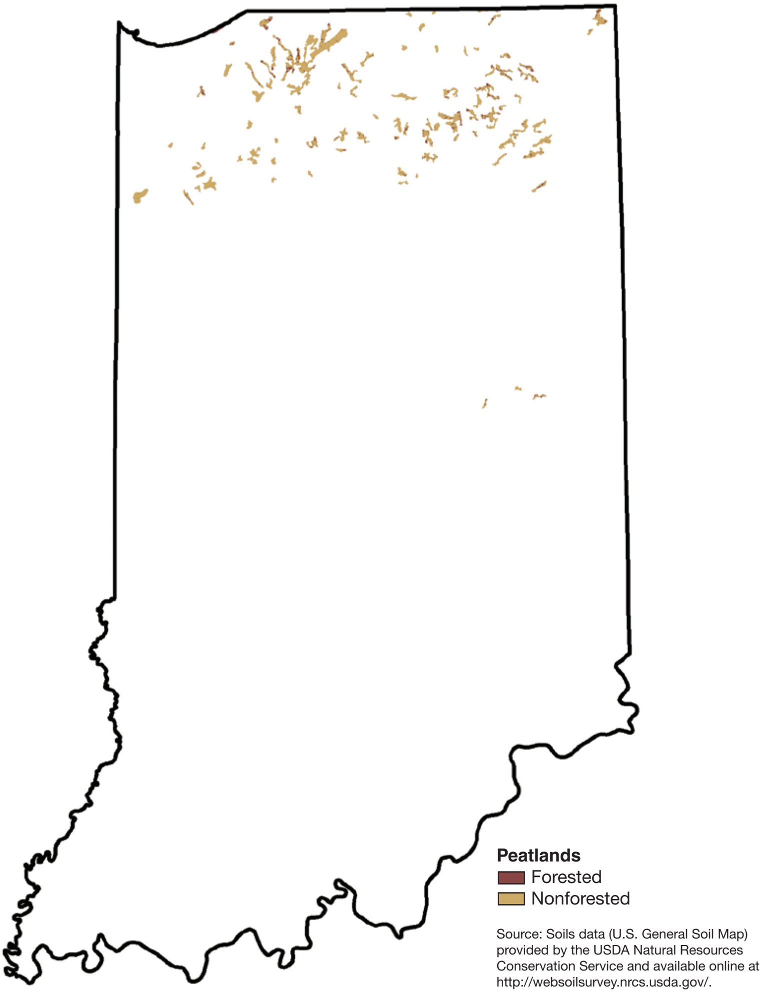

Figure 69.—Distribution of forested and nonforested peatlands, Indiana, 2013.

Several million dollars are being invested to facilitate Great Lakes restoration under the coordination of the U.S. Environmental Protection Agency. To prioritize investments, the Forest Service conducted a thorough analysis to identify which watersheds were the greatest contributors of sediment and phosphorus runoff into Lake Michigan. Land use characteristics like forest cover, forest harvest, agriculture, and watershed storage (the abundance of lakes and wetlands) were useful predictors of stream water quality at river mouths (Figs. 70 and 71).

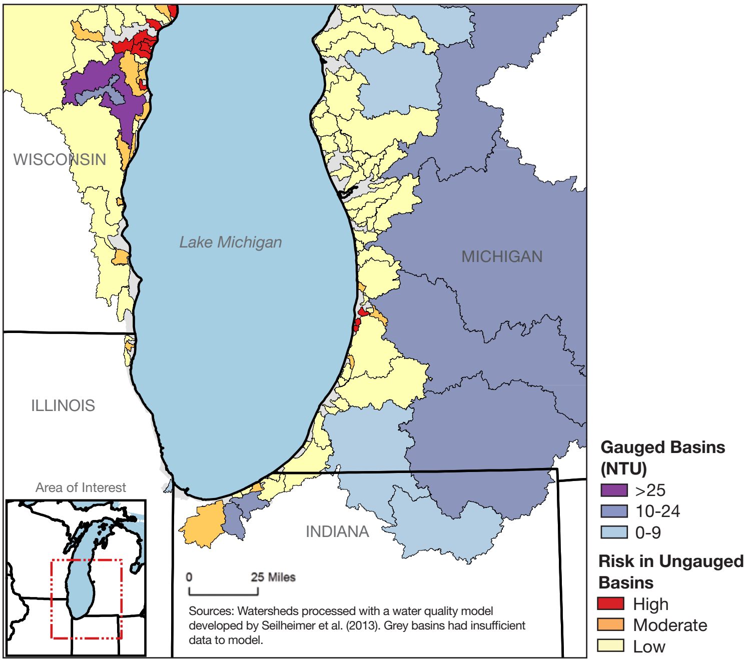

Figure 70.—Predictions of sediment delivery from gauged and ungauged watersheds draining into southern Lake Michigan. Adapted from Seilheimer et al. (2013).

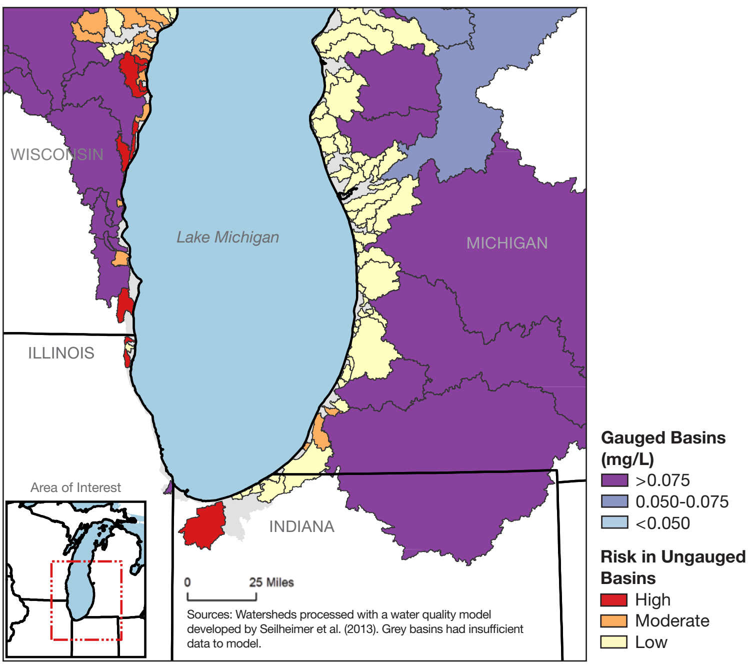

Figure 71.—Predictions of phosphorus delivery from gauged and ungauged watersheds draining into southern Lake Michigan. Adapted from Seilheimer et al. (2013).

What this means

The Forest Service and its partners are evaluating changes to soil inventory protocols which should provide more precise estimates of peatland soil carbon. Integrating studies like the SPRUCE project (http://mnspruce.ornl.gov/) with improved inventories of peatlands will improve our understanding and management of these important soil carbon stocks.

Sugar maple is the second most common tree species found in Indiana. Indiana's location puts it in the upwind side of increased deposition of commercial and residential emissions of nitrogen and sulfur. Atmospheric deposition is linked to altered soil chemistry and sugar maple mortality, particularly when they are found in the oak/hickory forest-type group.

Forest inventory data, when combined with other observations of land use and its characteristics, can help land managers understand patterns of water quality across the broader landscape. When predictors offer significant explanatory power, these are clues to the types of management and policy actions that can be useful in restoration activities.

Tree Condition—Crown Position and Live Crown Ratio

Background

The crown position of a tree indicates how well it is competing for light with neighboring trees. A tree crown in an intermediate or overtopped position is below the general level of the canopy and is shaded by its dominant and codominant neighbors. Intermediate and overtopped trees generally have slower growth and higher mortality rates than trees in more dominant positions. The live crown ratio defined as the percentage of a tree's height in live crown, is an indication of its vigor. Live crown ratios of less than 20 percent are typically a sign of poor vigor. In the understory, trees with low live crown ratios have fallen behind in their struggle to compete with the surrounding trees for light and space and are unlikely to recover or grow into an overstory position unless their crowns are released from the competition with their neighbors by timber harvesting or another disturbance.

What we found

In Indiana, most trees in the 2-, 4-, 6- and 8-inch diameter classes are in an overtopped or intermediate crown position. Ninety-six percent of 2-inch trees and 80 percent of 6-inch trees are considered suppressed (Fig. 72). Conversely, 92 percent of trees with diameters 14 inches or larger are dominant, codominant, or open grown. Fourteen percent of all trees in the 10-inch diameter class and below have live crown ratios of less than 20 percent. For the 6-inch class, 12 percent have live crown ratios below 20 percent and 40 percent have crown ratios below 30 percent (Fig. 73).

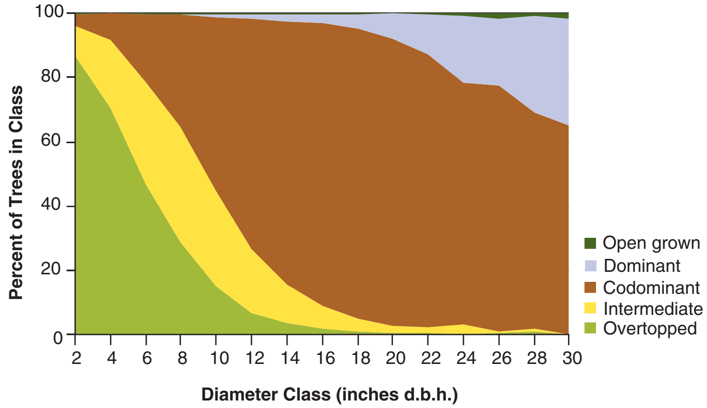

Figure 72.—Distribution of trees on forest land, by diameter class and crown position, Indiana, 2013.

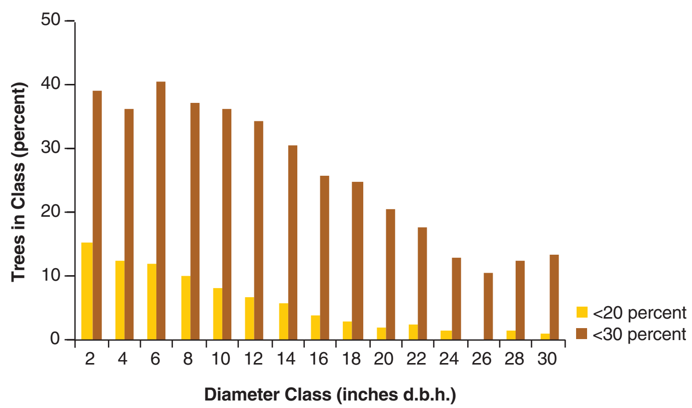

Figure 73.—Distribution of trees on forest land with a live crown ratio <20 percent or <30 percent, by diameter, Indiana, 2013.

What this means

Shaded conditions created by overstory trees are stressing a large portion of trees less than 10 inches in diameter. This finding is consistent with the maturing of Indiana forests and is the likely cause of the observed smaller increases in the number of trees in diameter classes less than 12 inches when compared to changes in larger trees. Shaded conditions favor the growth of shade tolerant species such as sugar maple over that of less shade tolerant species such as black cherry, yellow-poplar, oaks, and hickories.

Crown Health

Background

The crown condition of trees is influenced by various biotic and abiotic stressors. Abiotic stressors include drought, flooding, cold temperatures or freeze injury, nutrient deficiencies, soil physical properties that affect soil moisture and aeration, and toxic pollutants. Biotic stressors include native or introduced insects, diseases, invasive plant species, and animals. Invasions by exotic diseases and insects are one of the most important threats to the productivity and stability of forest ecosystems around the world (Liebhold et al.1995, Pimentel et al. 2000, Vitousek et al. 1996). Over the last century, Indiana forests have suffered the effects of native insect pests including forest tent caterpillar (*Malacosoma disstria*) and the looper complex (half winged geometer [*Phigalia titea*] and linden looper [*Erannis tiliaria*]), and well-known exotic and invasive agents such as Dutch elm disease and oak wilt (*Ceratocystis fagacearum*). More recent invasions include the emerald ash borer.

Tree-level crown dieback is collected on Phase 2-plus (P2+) plots. Crown dieback, defined as recent mortality of branches with fine twigs, reflects the severity of recent stresses on a tree. A crown is labeled as "poor" if crown dieback is greater than 20 percent. This threshold is based on findings by Steinman (2000) that associated crown ratings with tree mortality. Crown dieback has been shown to be the best crown variable to use for predicting tree survival (Morin et al. 2012).

What we found

The incidence of poor crown condition is low across Indiana with no discernable spatial pattern (Fig. 74). White ash and black oak are the only species in which 10 percent or more of the live basal area contains poor crowns (Table 6). Mean dieback ranges from 5 percent for red maple to approximately 13 percent for white ash (Table 7).

An analysis of trees that were remeasured from the previous inventory revealed that the proportion of the trees that die increases with increasing crown dieback in the previous inventory (Fig. 75). More than 65 percent of trees with crown dieback greater than 20 percent during the 2008 inventory were dead when visited again during the 2013 inventory.

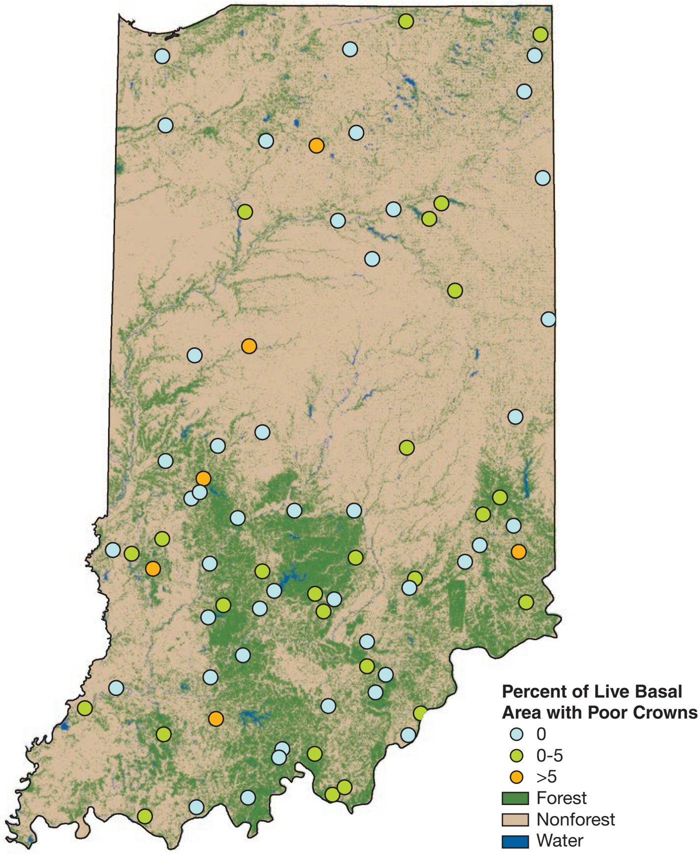

Figure 74.—Percentage of live basal area for all species on FIA plots with poor crowns, Indiana, 2013. Depicted plot locations are approximate.

Table 6.—Percentage of live basal area with poor crowns for the 10 most common tree species by net volume, Indiana, 2008 and 2013

Species	Basal area with poor crowns	
	2008	2013
	percent	
White ash	15.6	10.2
Black oak	0	10
Black cherry	0.5	6.9
Yellow-poplar	3.7	5.9
Red maple	0	0
Sugar maple	0.5	0
Shagbark hickory	2.7	0
American sycamore	9	0
White oak	0	0
Northern red oak	4.1	0

Table 7.—Mean crown dieback and other statistics for live trees (>5 inches d.b.h.) on forest land by species, Indiana, 2013

	Trees	Mean	SE	Minimum	Median	Maximum
Species	*number*	--------	--------	*percent*	--------	--------
White ash	92	12.8	2.3	5	5	99
Northern red oak	32	11.8	4.1	5	5	99
Yellow-poplar	98	10.7	2.3	0	5	99
Shagbark hickory	23	9.3	4.1	5	5	99
Black cherry	81	6.7	1.2	0	5	99
American sycamore	22	6.4	1.9	0	5	45
Black oak	27	5.7	0.6	0	5	15
White oak	39	5.4	0.3	0	5	15
Sugar maple	141	5.1	0.4	0	5	50
Red maple	58	5	0.3	0	5	10

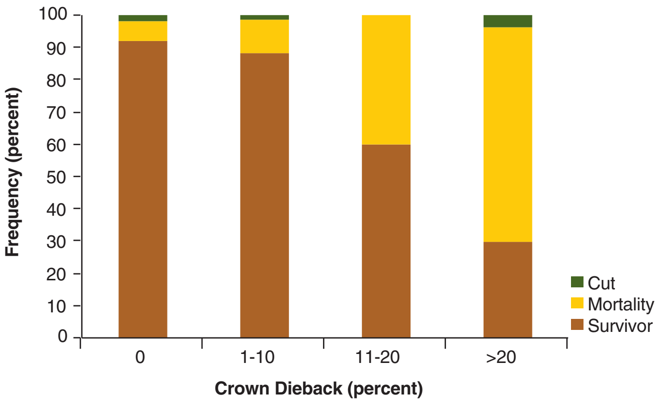

Figure 75.—Crown dieback distribution by tree survivorship for remeasured trees, Indiana, 2008 to 2013.

What this means

The most important tree species in the forests of Indiana are generally in good health, but substantial dieback was observed in white ash and black oak. Emerald ash borer is the likely agent causing decline in the crown health of white ash (see subsequent section), and the health of black oak may be related to oak decline and oak wilt. Additionally, maple is at risk due to the recent invasions (and eradication) by Asian longhorned beetle (*Anoplophora glabripennis*) in neighboring Illinois, and walnut is at risk because of the recent finding of thousand cankers disease in Ohio (see subsequent sections).

Tree Damage

Background

Tree damage is assessed for trees at least 5.0 inches in diameter. Up to three damages can be recorded. If more than three damage agents are observed, decisions about which three are recorded are based on the relative abundance of the damaging agents and potential severity to the health of the tree. In general, agents that affect the roots or bole tend to be most threatening because they have the capacity to affect the entire tree. Damage to peripheral parts of the tree may be temporary because leaves, shoots, and reproductive structures may be replaced. The types of damage that are recorded include general insects, bark beetles, defoliators, chewing insects, sucking insects, boring insects, general diseases, root/butt rot diseases, cankers (non-rust), stem decays, parasitic/epiphytic plants, decline complexes/dieback/wilts, stem rusts, broom rusts, fire, wild animals (from birds to large mammals), domestic animals, abiotic factors (e.g., broken branches from wind, snow, or ice), competition (suppression of overtopped shade intolerant tree species), human activities (including poor pruning, vandalism, and logging injury), harvest, as well as unknown damage agents.

What we found

Damage was recorded on approximately 26 percent of the sampled trees in Indiana (Table 8), but the frequency of damage varied among species. Decay was the most frequently observed damage on all species (22 percent of trees) but ranged from 13 percent on yellow-poplar up to 27 percent on sugar maple. Other damages were split nearly evenly between insect damage, decay, other animal, weather, and logging/human (3 percent or less for each). Notably, insect damage was recorded on 3 percent of white ash trees and 90 percent of those damages were attributed to bole borers.

Table 8.—Percentage of trees with damage by species, Indiana, 2013

	Damage type							
	None	Animal	Cankers	Decay	Insect damage	Logging/ human	Other	Weather
All	74	1	0	22	1	2	2	3
American sycamore	75	1	0	22	0	1	2	2
Black cherry	71	1	1	25	0	1	3	4
Black oak	81	0	0	15	1	2	2	2
Northern red oak	82	1	0	15	0	2	1	1
Red maple	72	1	0	25	0	2	2	4
Shagbark hickory	85	1	0	13	0	2	1	1
Sugar maple	69	1	0	27	0	3	2	3
White ash	73	2	0	20	3	2	3	2
White oak	85	1	0	12	0	2	1	1
Yellow-poplar	83	1	0	13	0	1	2	3

Note that columns do not sum to 100 because multiple damages can be recorded on each tree.

What this means

As in most eastern forests, decay is the most commonly observed damage in Indiana forests. This is not unusual given that the majority of the forests are composed of mature trees. The incidence of bole borer damage on white ash trees was observed most frequently in counties in the Northern Unit and is due to emerald ash borer infestations (see subsequent emerald ash borer section).

Forest Invaders: Invasive Plants

Background

Invasive plant species (IPS) are both native and nonnative species that can cause negative ecological effects. These species can quickly invade forests and change light, nutrient, and water availability. IPS can form dense monocultures which not only reduce regeneration but also impact wildlife quality by altering forest structure and forage availability. While there are beneficial uses for some invasive plants, including culinary and medicinal uses and soil contaminant extraction (e.g., reed canary grass) (Kurtz 2013), the negative effects are worrisome. Each year inspection, management, and mitigation of IPS costs billions of dollars.

Invasive species can also impact agriculture systems. Common barberry is an alternate host for wheat stem rust which can cause the complete loss of some grain fields (Kurtz 2013). Common buckthorn is also a troublesome invader as it is one of the alternate hosts for the soybean aphid (*Aphis glycines*). To aid in monitoring these species, FIA assesses the presence of 43 IPS and one undifferentiated genus (nonnative bush honeysuckles). However, since nonnative bush honeysuckles are sometimes coded by field crews at the genus level and other times at the species level, this section discusses the monitoring of 40 IPS (39 species plus nonnative bush honeysuckles, hereafter referred to as "invasive species," "invasive plants," "invasives," or "IPS") and focuses on the 321 P2 invasive plots that were measured in Indiana from 2009-2013, highlighting changes from the previous inventory.

What we found

Of the 40 invasive species monitored by FIA (Table 9), 25 were observed on plots measured between 2009 and 2013 (Table 10). Multiflora rose was the most commonly observed IPS and was found on 239 plots (74.5 percent of P2 Invasive plots) that were distributed throughout the State (Fig. 76). Nonnative bush honeysuckle (120 plots) and

Table 9.—List of 39 invasive plant species and one undifferentiated genera monitored by the Northern Research Station on FIA P2 Invasive plots, 2007 to present

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

Table 10.—Invasive plant species observed on FIA P2 plots, Indiana, 2013

Name	Observances	Percentage of plots
Multiflora rose	239	74.5
Nonnative bush honeysuckles	120	37.4
Japanese honeysuckle	103	32.1
Nepalese browntop (Japanese stiltgrass)	95	29.6
Garlic mustard	63	19.6
Autumn olive	55	17.1
Black locust	38	11.8
Reed canarygrass	32	10
European privet	22	6.9
Creeping jenny	20	6.2
Oriental bittersweet	20	6.2
Canada thistle	12	3.7
Dames rocket	12	3.7
Bull thistle	10	3.1
Tree of heaven	7	2.2
Japanese barberry	6	1.9
Common barberry	5	1.6
Common buckthorn	3	0.9
Glossy buckthorn	3	0.9
Japanese meadowsweet	2	0.6
European cranberrybush	2	0.6
Siberian elm	1	0.3
Japanese knotweed	1	0.3
Russian olive	1	0.3
English ivy	1	0.3

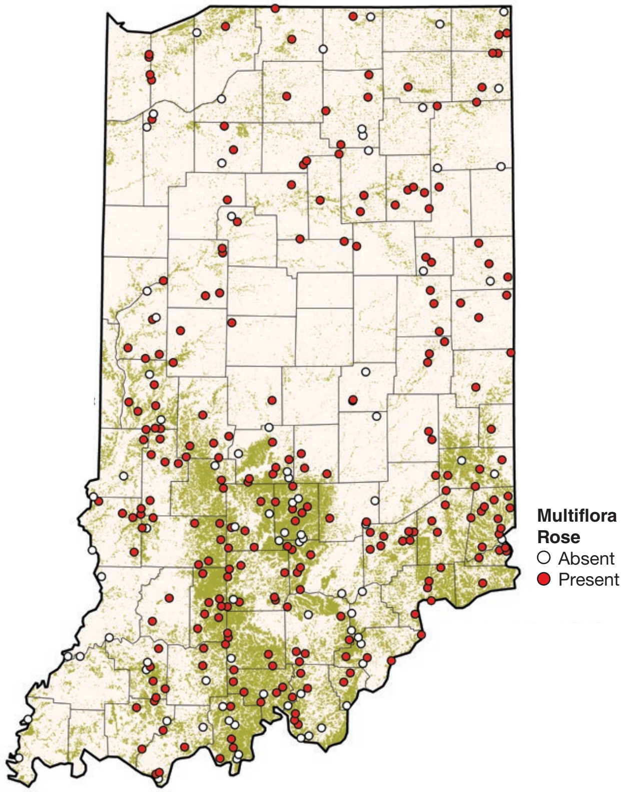

Figure 76.—Distribution of multiflora rose on FIA P2 Invasive plots, Indiana, 2013.

Japanese honeysuckle (103 plots) were also found on a large number of plots. Eight of the 40 monitored IPS were found on 10.0 percent or more of the P2 Invasive plots.

Overall, 90.7 percent of the monitored plots had one or more IPS with the number of IPS per plot ranging from 0 to 10. The largest percentage of plots had two monitored invasive plants present (Fig. 77). The distribution of plots with five or more IPS present is fairly homogeneous throughout the State (Fig. 78). When comparing invasive plant species in Indiana from the 2013 inventory cycle to previous reports from 2007-2008, the three most common invasive species (multiflora rose, nonnative bush honeysuckles, and Japanese honeysuckle) remained the same for this inventory. However, the fourth and fifth most common species switched. Previously the fourth most commonly observed species was garlic mustard; currently it is Nepalese browntop. In addition, there was an increase in the percentage of plots where the 12 most commonly recorded invasive plant species were observed. The actual increase in number of plots varied by species.

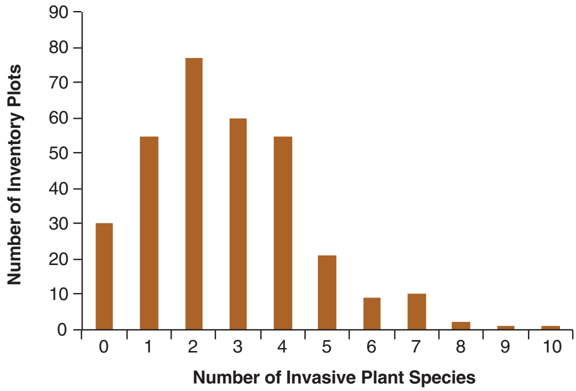

Figure 77.—Number of invasive plant species per P2 Invasive plot, Indiana, 2013.

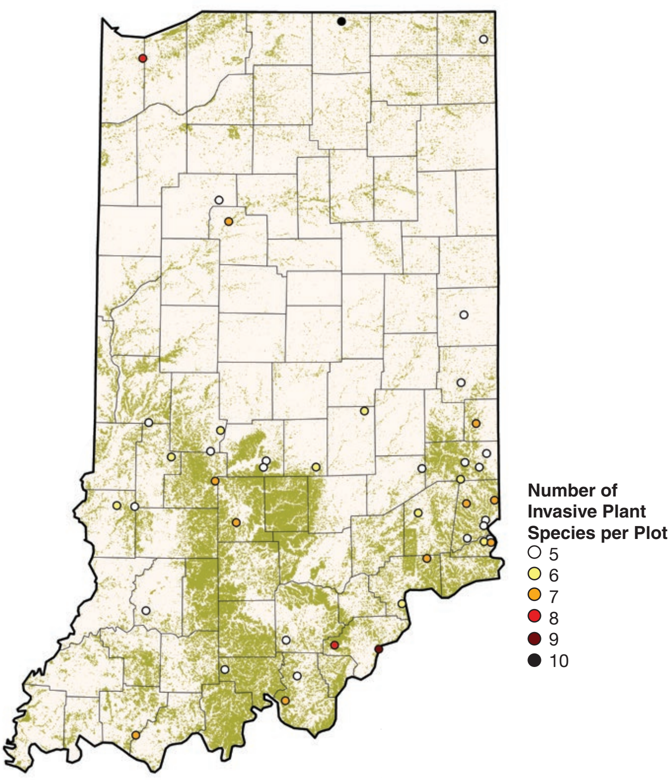

Figure 78.—P2 Invasive plots with five or more invasive plant species, Indiana, 2013.

What this means

The number of invaded plots in Indiana forests is similar to neighboring Ohio where 93.2 percent of the plots had one or more of the monitored invasive plant species (Widmann et al. 2014). The substantial presence of IPS within Indiana's rich forests is a concern, and it is important that these species are monitored over time to ensure that managers and the general public are aware of their occurrence and spread. Further investigation of the inventory data may help to reveal influential site and regional trends. Invasive plants are good competitors and are able to alter forested ecosystems by displacing native species and impacting the fauna that depend upon them. Several factors contribute to their success such as prolific seed production, ability to propagate vegetatively, rapid growth rate, and ability to survive in harsh conditions. Many factors contribute to forest invasion including ungulates, development, fragmentation, and timber harvesting. When forests are invaded, they negatively affect the carbon budget by reducing future tree cover. Furthermore, these species can have negative economic implications by reducing timber yield and aesthetic beauty.

Forest Related Injurious Agents

Background

Insect and disease activity as well as abiotic factors shape the structure and composition of forests. Status monitoring is an important part of assessing the current state and monitoring changing trends in Indiana forests. It also provides a valuable means of maintaining healthy, vigorous forests and managing future forest resources.

What we found

A number of common injurious tree insect pests, tree diseases, and other tree related injurious agents were present in Indiana forests during the 2013 survey period (Table 11). The recurring forest health issues of most concern include gypsy moth (*Lymantria dispar*) management in northern tier counties spanning to Michigan, oak wilt (*Ceratocystis fagacearum*) in northwestern Indiana, emerald ash borer (*Agrilus planipennis* Fairmaire) spread and ash mortality, yellow-poplar mortality in southern Indiana, and the impacts of butternut canker (*Sirococcus clavigignenti-juglandacearum*), ash yellows (*Candidatus fraxinii*), white pine root decline (procera root rot) caused by the fungus *Leptographium procerum* (syn. *Verticicladiella procera*), aging pine plantations, and aging hardwood forests across the State.

Table 11.—Common injurious tree insect pests, diseases, and other related agents found in Indiana forests during the 2013 survey period

Insects	Diseases and other related agents
Emerald ash borer (*Agrilus planipennis Fairmaire*)	Dogwood anthracnose (*Discula destructiva*)
Introduced pine sawfly (*Diprion similis*)	Sycamore, oak, maple, ash anthracnose (*Apiognomonia* spp.)
Red Headed pine sawfly (*Neodiprion lecontei*)	Hickory mortality (*Scolytus quadrispinosus* and *Ceratocystis* sp.)
Eurpean pine sawfly (*Neodiprion sertifer*)	Redbud canker (*Botryosphaeria dothidea*)
Gypsy moth (*Lymantria dispar*)	Verticillium wilt (*Verticillium albo-atrum*)
Forest tent caterpillar (*Malacosoma disstria*)	Diplodia tip blight (*Diplodia pinea*)
Eastern tent caterpillar (*Malscosoma Americana*)	Nutrient deficiency symptoms on pin oak and red maple
Looper complex (Linden Looper *Erannis tiliaria*)	Herbicide injury
Half winged geometer (*Phigalia titea*)	Oak tatters
Slug oak sawfly (*Caliroa quercuscoccineae*)	Ash yellows/ash decline
Walnut caterpillar (*Datana integerrima*)	Yellow-poplar decline
Yellownecked caterpillar (*Datana ministra*)	Oak wilt (*Ceratocystis fagaecarum*)
Fall webworm (*Hyphantria cunea*)	Dutch elm disease (*Ophiostoma novo-ulmi*)
Mimosa webworm (*Homadaula anisocentra*)	Elm yellows (elm phloem necrosis)
Lacebugs (*Corythucha* spp.)	Spruce needle cast (*Rhizosphaera, Stigmina,* and *Setomelanomma*)
Spider mite (*Oligonychus* spp.)	
Horned/Gouty oak gall (*Callirhytis cornigera, C. quercuspunctata*)	White pine root decline (*Verticicladiella procera*)
Jumping oak gall (*Neuroterus* sp.)	
Tuliptree scale (*Toumeyella liriodendri*)	
Oystershell scale (*Lepidosaphes ulmi*)	
Japanese beetle (*Popillia japonica*)	
Locust leafminer (*Odontata dorsalis*)	
Zimmerman pine moth (*Dioryctria zimmermani*)	
Red oak borer (*Enaphalodes rufulus*)	
Carpenter worm (*Prionoxystus robiniae*)	
Sugar maple borer (*Glycobius speciosus*)	
Ips bark beetle (*Ips pini* or *Ips grandicollis*)	
Turpentine beetle (*Dendroctonus tenebrans* and *D. valens*)	
Larger pine shoot beetle (*Tomicus piniperda*)	

Other forest pests not yet encountered in Indiana but of concern for the future include exotic pests such as sudden oak death (*Phytophthora ramorum*), Asian longhorned beetle (*Anoplophora glabripennis*), gold spotted oak borer (*Agrilus auroguttatus*) and other *Agrilus* spp., the beech bark disease complex (*Cryptococcus fagisuga* Lind and *Nectria coccinea* var. f*aginata* Lohman), and the red bay wilt complex (*Raffaelea lauricola* and redbay ambrosia beetle [*Xyleborus glabratus*]) risk to Indiana sassafras and spicebush.

Also of concern are invasive plants that have the potential to affect or are already affecting Indiana forest regeneration and biodiversity. One native forest pest epidemic, forest tent caterpillar (*Malacosoma disstria* Hubner), causes extensive defoliation. The tent caterpillar resulted in extensive forest mortality in south eastern Indiana 5-10 years ago (Marshall 2012), which has increased the regeneration of tree-of-heaven (*Ailanthus altissima*) to the detriment of native species. Kudzu (*Pueraria montana* var. *lobata*) also continues to be a problem, and the kudzu eradication program run by the Indiana Department of Natural Resources, Division of Entomology and Plant Pathology continues to eradicate this invasive plant from locations in southern Indiana to the Ohio River and eventually out of Indiana.

Seasonal or prolonged drought periods have long been a significant and historical stressor in Indiana (Fig. 79). The worst drought on record occurred in 1936. Significant drought has not occurred in the State since 1988, but moderate to extreme summer droughts occurred in 1999, 2005, 2007, 2008, 2010, and 2012. The drought periods were intermittent with some of the wettest summers on record in 1979 (wettest on record), 1998, 2004, 2009, and 2011 (NCEI 2015). These periods of extreme drought or precipitation can produce conditions that facilitate insect and/or disease outbreaks and can be even more devastating to trees previously stressed by pest damage or other agents. Droughts can cause timber mortality that can occur during the year of the drought and for 1 to 5 years after the event. In addition to mortality, radial growth loss is another drought impact. The loss of radial growth varies with the species and the site conditions (mesic vs. xeric) (Orwig and Abrams 1997) and has forest management implications. For example, the 2012 drought and tuliptree scale *(Toumeyella liriodendri* [Gmelin]) epidemic in southern Indiana may have lessened the total amount of growth; thus without the drought and scale, yellow-poplar growth may have been greater. The drought and scale are also factors that contribute to yellow-poplar having the largest amount of removals.

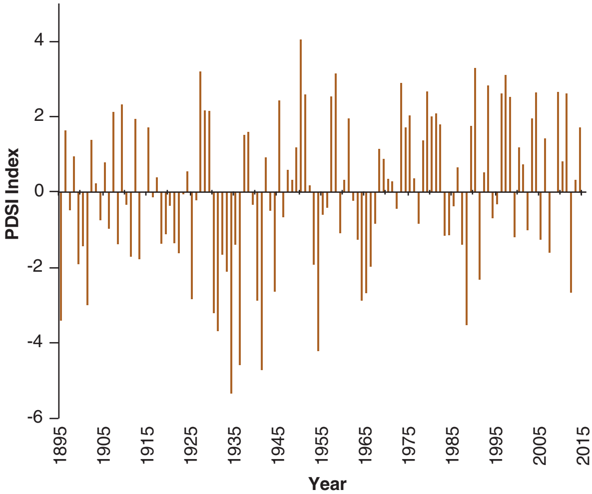

Figure 79.—Palmer Drought Severity Index (PDSI) 3-month average (June-August), Indiana, 1895-2014.

The forest management implication from drought is the stress that trees experience. This stress exposes trees to attack by other organisms, such as twolined chestnut borer, shoestring root rot, hypoxylon canker, ips bark beetles, red oak borers (*Enaphalodes rufulus*) and other insects and diseases. Thus, drought becomes an inciting factor that can lead to tree decline, loss of growth, and mortality (Starkey, et al. 1989).

Tuliptree scale dripping honey dew. Photo courtesy of Indiana Department of Natural Resources, used with permission.

Wet periods of heavy rains and flooding can also cause health problems. Storms and tornados can include wind damage, such as the Henryville tornado in 2012, that can result in increased foliage disease, uprooting, and other impacts.

What this means

During the survey period, Indiana forests were affected by native and exotic insects, disease, floods, winds, and drought. These stressors create weakened trees that are vulnerable to secondary attack by other insects and diseases or are the direct cause of tree mortality. In combination, there may be significant impacts to tree growth and increased risk of forest fire. While efforts to eradicate Asian longhorned beetle in neighboring Illinois have proven successful, Indiana forests are experiencing the impact of emerald ash borer (see next section) which is dramatically affecting the future composition of Indiana forests. For more information about Indiana forest insects and diseases, visit http://www.in.gov/dnr/entomolo/.

Ash and Emerald Ash Borer

Background

Emerald ash borer (EAB) was first detected in the United States in the summer of 2002 near Detroit, MI. Two years later, EAB was found in Steuben County in northeastern Indiana, and by the end of 2013, EAB was present in 68 counties, nearly 75 percent of Indiana. EAB is an exotic beetle that feeds on the inner bark of ash trees (Poland and McCullough 2006). Rapid tree mortality, natural spread, and artificial transport of infested materials has resulted in the decline and mortality of millions of ash trees across 25 states and 2 Provinces (as of December 2014) (Herms and McCullough 2014). EAB represents a major threat to the State's ash resource, typically killing host trees within 3 to 5 years of infestation.

What we found

Indiana forest land contains an estimated 148.4 million ash trees greater than 1 inch in diameter, a 5 percent increase from 2003. While there is no real spatial pattern to gains and losses of ash trees at the county level, fewer counties experienced ash increases in 2013 than in 2003; thus the rise in ash statewide was the result of gains that occurred in a relatively small number of counties (Fig. 80). Ash is present on approximately 2.4 million acres, and while total acreage has remained constant, the percentage of ash on Indiana forest land has steadily decreased from 52 percent in 2003 to 49 percent in 2013. Rarely the most abundant species in a stand, ash generally makes up less than 25 percent of the total live-tree basal area (Fig. 81). Ash is found across most of Indiana, with the highest densities in the southeast corner of the State (Fig. 82).

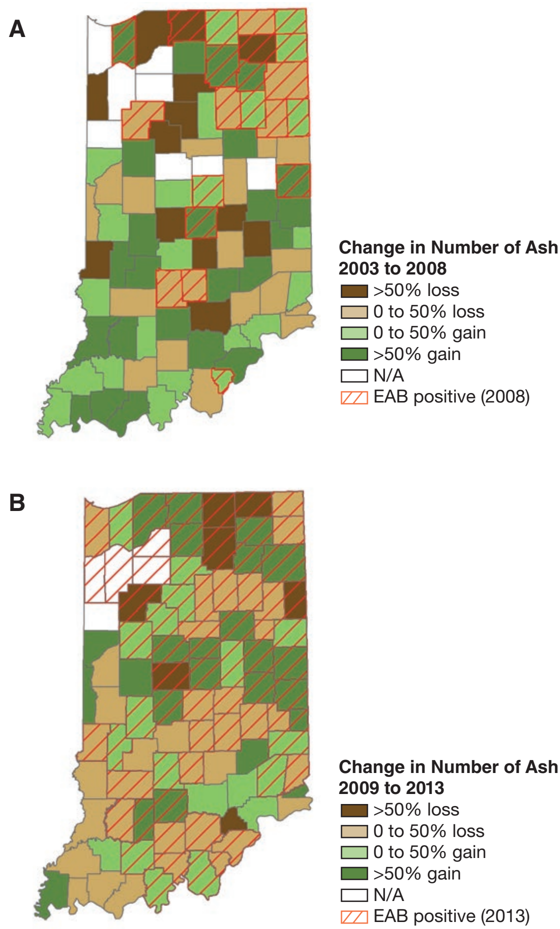

Figure 80.—Change in the number of ash trees on forest land by county, and counties positive for EAB, Indiana, (A) 2003 to 2008 and (B) 2009 to 2013.

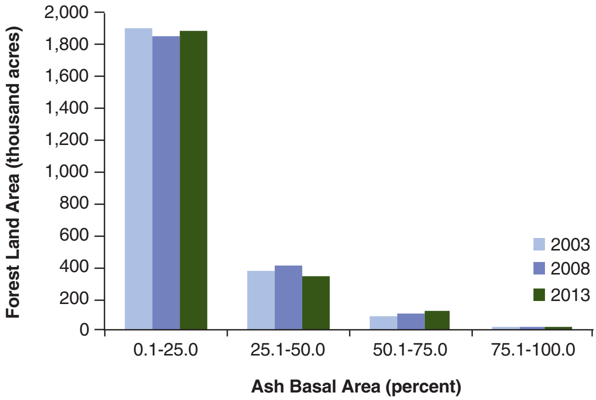

Figure 81.—Forest land area by ash basal area, as a percentage of total basal area, by inventory year, Indiana.

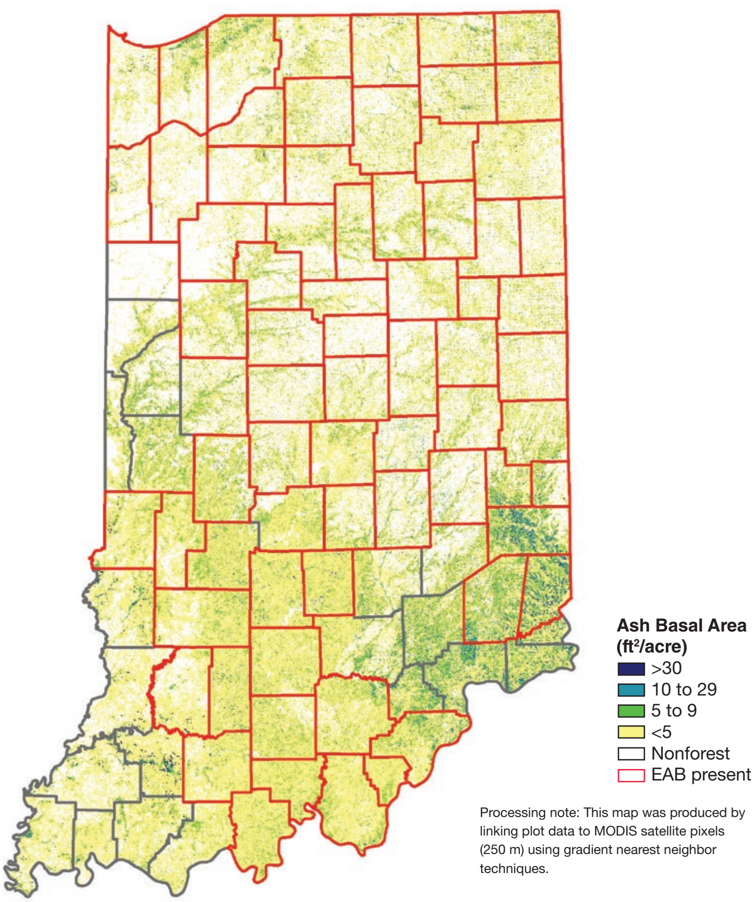

Figure 82.—Ash density on forest land, and counties positive for EAB, Indiana, 2013.

Since 2008, mortality of ash trees on forest land has increased by nearly two-thirds, averaging close to 1 million trees per year. By volume, this mortality represents an annual loss of 11 million cubic feet, an increase of more than 25 percent from 2008. Ash mortality occurred across much of Indiana; however, it was largely concentrated in counties containing EAB infestations and in the northeast quadrant (Fig. 83). This rate of mortality and volume loss is expected to continue through the next 5-year inventory cycle (through 2018) and then decrease to normal mortality levels as EAB completes its mortality wave through Indiana, which is expected to be completed between 2018 and 2020. In most counties, ash mortality accounted for less than 25 percent of total mortality.

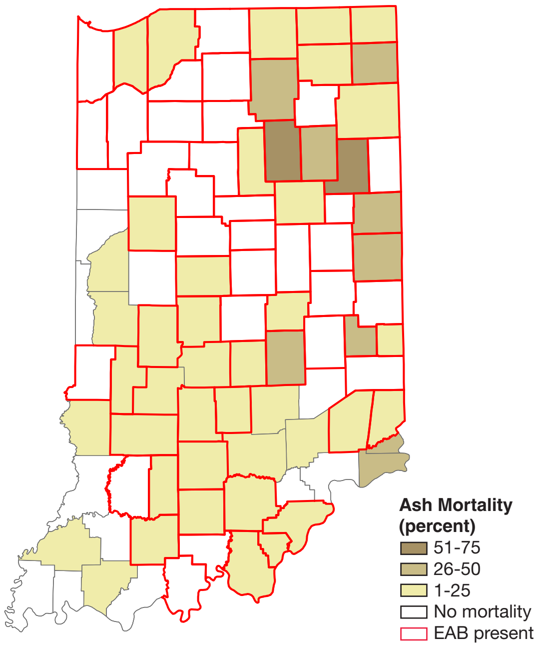

Figure 83.—Percent ash mortality on forest land by county, Indiana, 2013, and counties positive for EAB.

What this means

Emerald ash borer is a significant threat to Indiana's urban, rural, and riparian ash resource. EAB is causing significant financial costs to municipalities, property owners, and the forest products industry. Although ash yellows disease is present in Indiana, EAB is likely to be the largest contributor to ash mortality throughout the State. Despite increasing tree numbers, ash mortality continues to rise across the State. In some counties where EAB is not yet known to occur, moderate amounts of ash mortality are present, suggesting there may be areas with undetected EAB populations. Ash mortality and the continued identification of new EAB infestations will have a considerable impact on the future makeup of Indiana forests. Species composition and forest structure will likely undergo changes as ash gives way to more maple dominated stands. Continued monitoring of ash resources will help to identify the long-term impacts of EAB in Indiana. Overall, EAB may have an impact similar to that of Dutch elm disease or chestnut blight.

Black Walnut and Thousand Cankers Disease

Background

Thousand cankers disease (TCD) is a recently described disease complex that is considered endemic to the western United States (USDA APHIS 2009). Affecting walnut species, TCD results from the interaction between the *Geosmithia morbida* fungus and the walnut twig beetle (*Pityophthorus juglandis*). The beetles bore into walnut branches, and while feeding on the tree's tissues, they deposit the fungus that creates a canker, or dead area, under the bark. Multiple feedings cause the formation of thousands of cankers under the bark and destroy the tree's ability to transport water and nutrients. Gradually the tree dies. TCD has been introduced to several eastern states including Tennessee, Virginia, Ohio, and Pennsylvania. In Indiana, the U.S. Forest Service confirmed the fungus in December 2013 from a 2011 study of pests coming to stressed black walnut. The *Geosmithia morbida* fungus was detected on a small weevil (*Stenomimus pallidus*) collected from a stressed black walnut, but the fungus was not detected in the tree. The walnut twig beetle, the known insect vector of the fungus, was not detected in the stressed walnut trees; however, the walnut twig beetle was detected at a sawmill in Franklin County in 2015.

What we found

The density of black walnut is low across Indiana, with areas of higher concentration in the northwest and southeast (Fig. 84). There are an estimated 40.3 million black walnut trees greater than 1 inch in diameter on forest land, which account for 317.6 million cubic feet of volume. Average annual harvest removals of black walnut sawtimber total approximately 2 million board feet. Mortality of black walnut growing stock on timberland has increased by 16 percent since 2003 and currently totals approximately 510,000 cubic feet per year (Fig. 85); however, the ratio of mortality to volume is low at 0.2 percent.

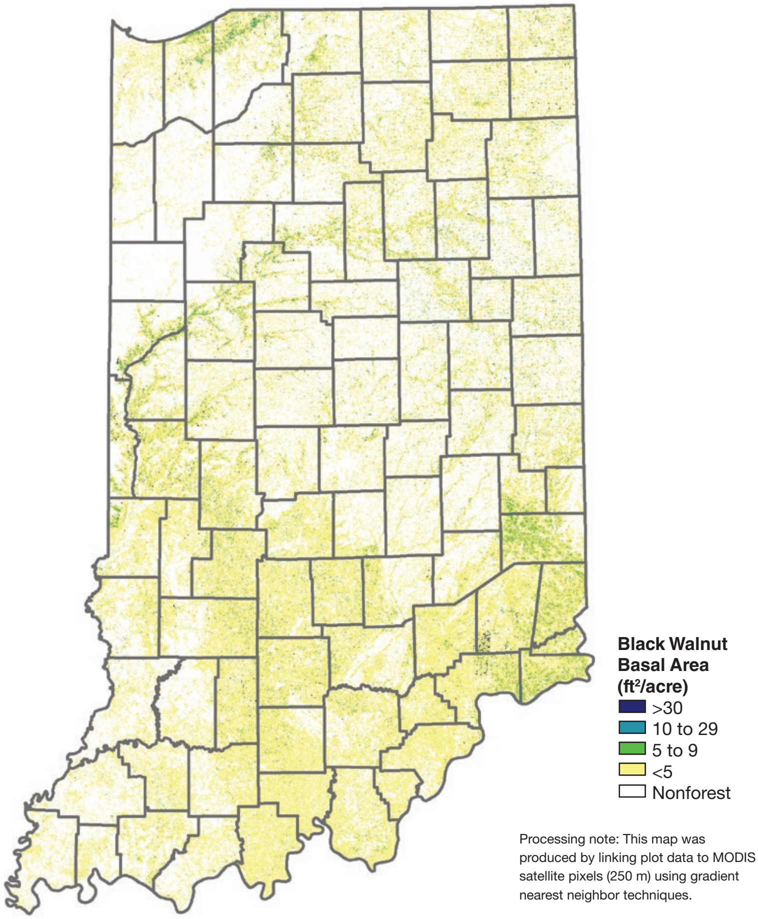

Figure 84.—Black walnut density on forest land, Indiana, 2013.

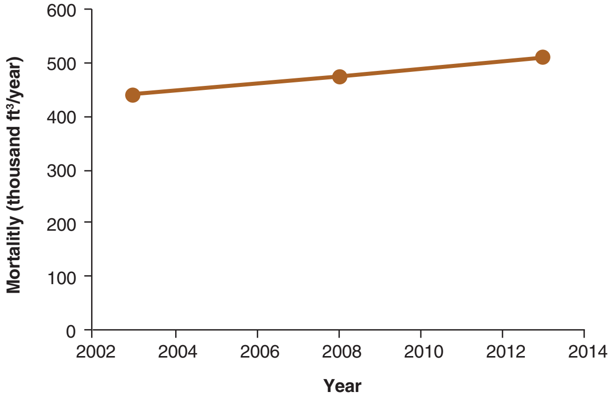

Figure 85.—Average annual mortality of black walnut growing-stock volume on timberland by inventory year, Indiana.

What this means

Black walnut is widely distributed, and therefore makes up an important piece of Indiana's forested landscape. Walnut trees affected by the thousand cankers disease typically die within 2 to 3 years after symptoms are noticed.

As a commercial species, black walnut is considered a high value tree species in the State based on the dollar value of wood produced, mainly as walnut veneer, timber, and nuts. Approximately 17.7 million board feet of black walnut is harvested annually with a value of $21.4 million. If all forest walnuts in Indiana were lost because of TCD, it would represent a $1.7 billion loss. The estimates do not include the value of urban trees and investments in black walnut plantations and tree improvement made by landowners over the past 30 years. Therefore, the introduction of TCD has the potential to cause extensive walnut mortality and dramatically impact Indiana's forest ecosystem and timber industry. Landowners and homeowners are encouraged to visually inspect their walnut trees for presence of thousand cankers disease. The earliest symptom is yellowing foliage that progresses rapidly to brown wilted foliage, and finally branch mortality. Other major symptoms of this disease are numerous small cankers on branches and the bole, and evidence of tiny bark beetles. Additional information about thousand cankers disease and quarantine restrictions in Indiana can be found at http://www.thousandcankers.com/state-info.php?state=Indiana, http://www.in.gov/dnr/entomolo/index.htm, and www.thousandcankers.com/.

Regeneration Status

Background

The composition and abundance of tree seedlings drives the sustainability of forest ecosystems in the early years of stand development and sets the stage for future composition and structure, and hence, the viability of timber and ecosystem services provided, including clean water, carbon sequestration, and sense of place. Forest systems of Indiana face numerous regeneration stressors (e.g., invasive plants, insects, diseases, herbivory, and weather). As stands that make up these systems mature and undergo stand replacement disturbances, it is imperative to know the viability of the regeneration component. Although artificial methods (planting or seeding) are an option in some stands, Indiana is dominated by forest systems that regenerate naturally. In most situations, establishing desirable reproduction is the key to replacing stands in need of replacement with high-canopy species that meet manager's objectives (Nyland 2002, Smith et al. 1997, Wenger 1984). Tending of young stands to control composition and stocking levels is also an important consideration. Regeneration data are critical for understanding and projecting future forest characteristics that ultimately determine sustainability of the full suite of forest values available from Indiana forests.

To address the need for more detailed information on regeneration, the Northern Research Station, Forest Inventory and Analysis program has added advance tree seedling regeneration (ATSR) sampling protocols to collect data on a subset of NRS-FIA sample plots measured during the growing season (McWilliams et al. 2015). The procedures measure all established tree seedlings less than 1 inch in diameter at breast height by height class and include a browse assessment for the area surrounding the sample location. Results and analysis presented are for regeneration data collected on 48 sample plots in 2012 and 2013.

What we found

White-tailed deer impact the abundance and composition of the regeneration component of Indiana forests through selective browsing of tree seedlings that removes more palatable species (oaks) and leaves less palatable species to occupy growing space (Wakeland and Swihart 2009). Browsing also has parallel impacts on vegetation of the forest understory. Results of the browse impact assessment indicated a medium level of browse impact on understory plants for 86 percent of the samples (Fig. 86a). Examination of the spatial distribution of browse impact did not reveal any distinct pattern other than localized impacts and a few samples with high impact in southern Indiana (Fig. 86b).

The total number of seedlings in Indiana is estimated at 18.2 billion, or an average of 1,051 seedlings per acre (Fig. 87a, b). Sixty-two percent of the seedlings are less than 1 foot tall, 32 percent are 1.0 to 4.9 feet, and 6 percent are 5.0 feet and taller. Overall, seedling abundance appears to be higher in southern Indiana; however, the number of samples is relatively small (Fig. 88).

White ash, sugar maple, black cherry, slippery elm, and sassafras are the top five seedlings in terms of abundance (Fig. 89a, b). Black willow is a top species but is subject to a sampling error of 98 percent that precludes meaningful analysis. Other species ranked in the top 20 most abundant seedlings that typically have the ability to reach the dominant overstory are yellow-poplar, red maple, bitternut and pignut hickory, American beech, black oak, and chinkapin oak (Burns and Honkala 1990). Species that are less desirable or do not form high canopy forests are eastern hophornbeam, hackberry, blackgum, eastern redbud, boxelder, and flowering dogwood. These species are most prevalent in smaller height classes.

A

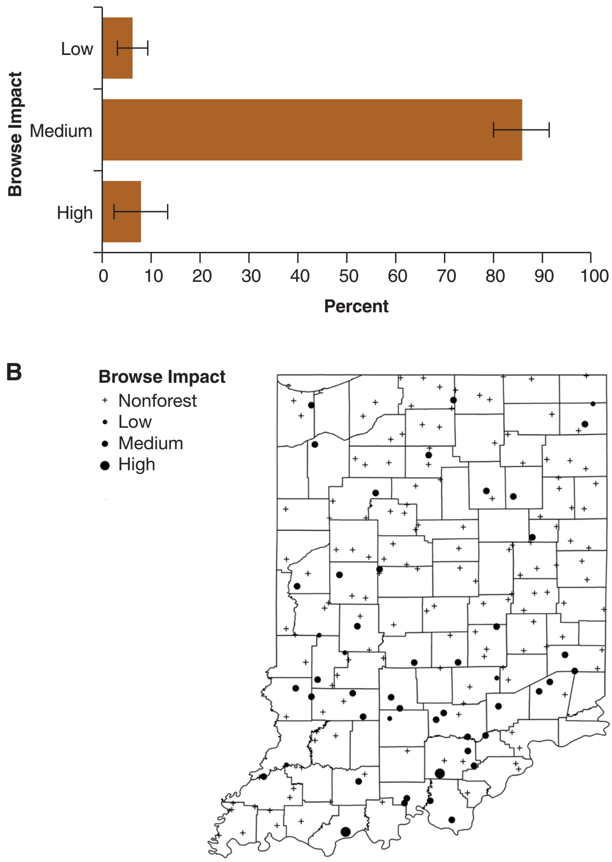

Figure 86.—Percentage (A) and distribution (B) of forested P2+ samples on forest land by browse impact class, Indiana, 2012-2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

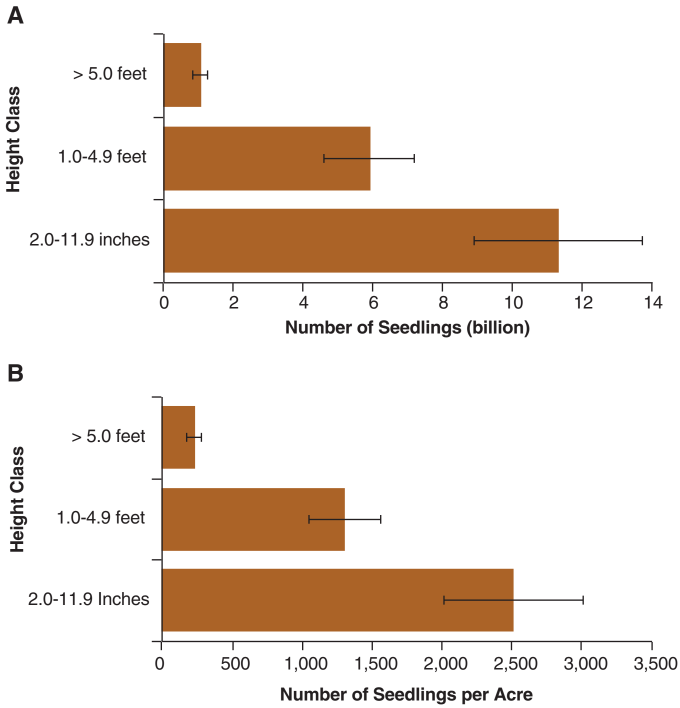

Figure 87.—Total number of seedlings (A) and average number of seedlings per acre (B) on forest land by height class, Indiana, 2012-2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

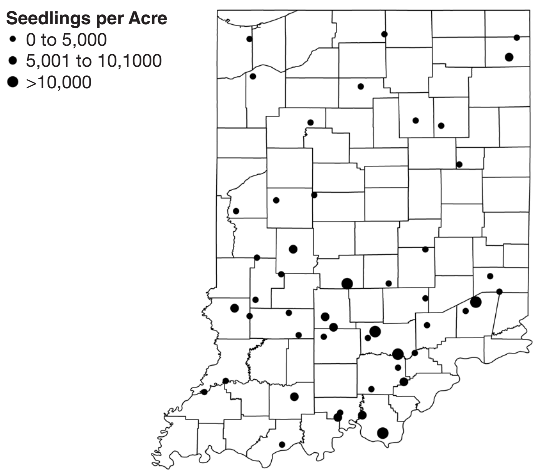

Figure 88.—Distribution of forested P2+ samples on forest land by number of seedlings per acre, Indiana, 2012-2013.

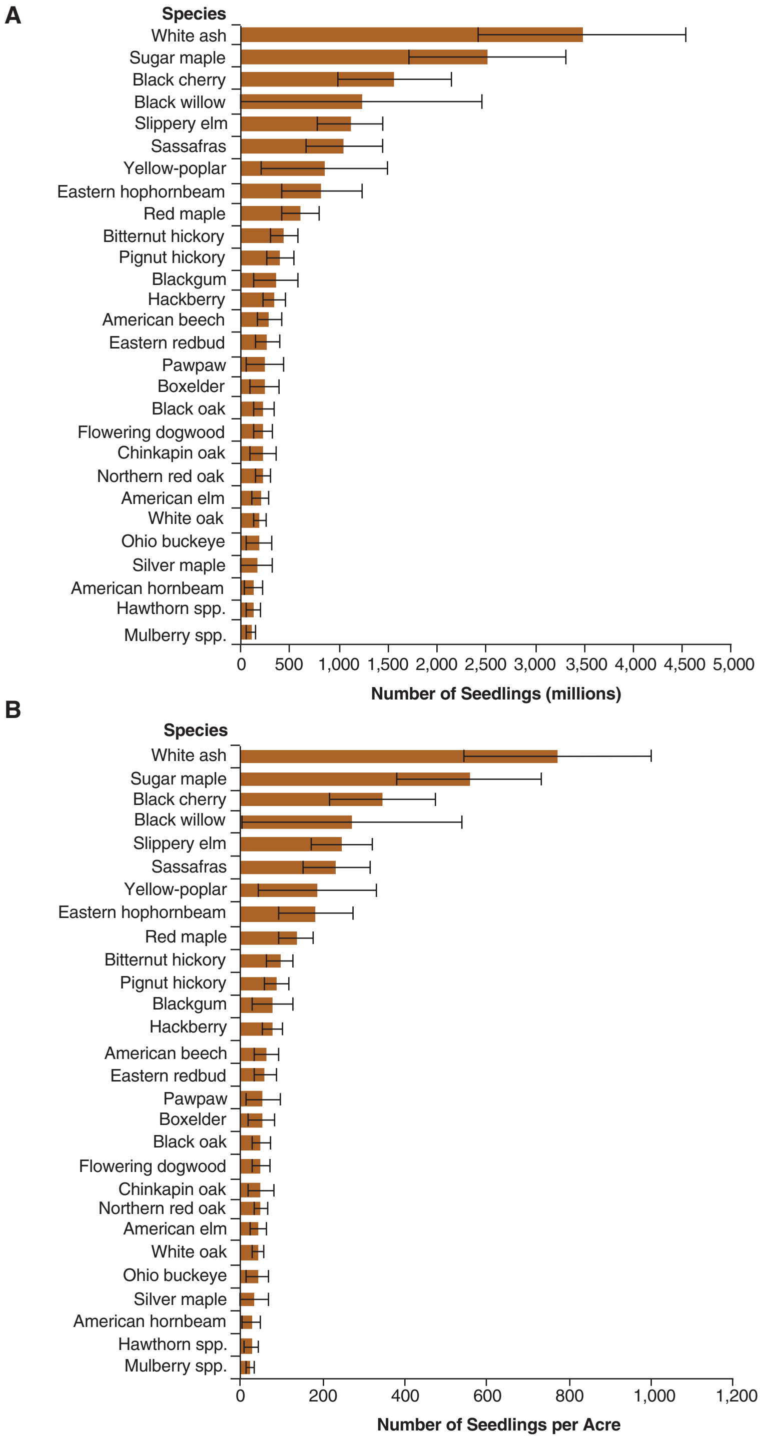

Figure 89.—Number of seedlings (A) and average number of seedlings per acre (B) on forest land by species for species with at least 1 percent of the total number of seedlings, Indiana, 2012-2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

Comparing species abundance using the percentage of the total number of trees by height and diameter class highlights potential pathways for future canopy dominants. The 10 most common species of dominant/codominant saplings and growing-stock trees using aboveground biomass as the importance value are depicted in Figure 90. Prospective "gainers" are those species with relatively high percentages of stems in the regeneration pool of seedlings and saplings compared to adult trees. Sugar maple, white ash, and red maple are the most apparent gainers. Expectations for white ash should be tempered with information on the demise of ash due to impacts of the emerald ash borer. Prospective "losers" in the process of developing future canopy dominants are species with lower percentages in the regeneration pool than the canopy pool. Potential losers are yellow-poplar, white oak, black oak, northern red oak, and shagbark hickory. American sycamore and pignut hickory fall between the gainer and loser categories.

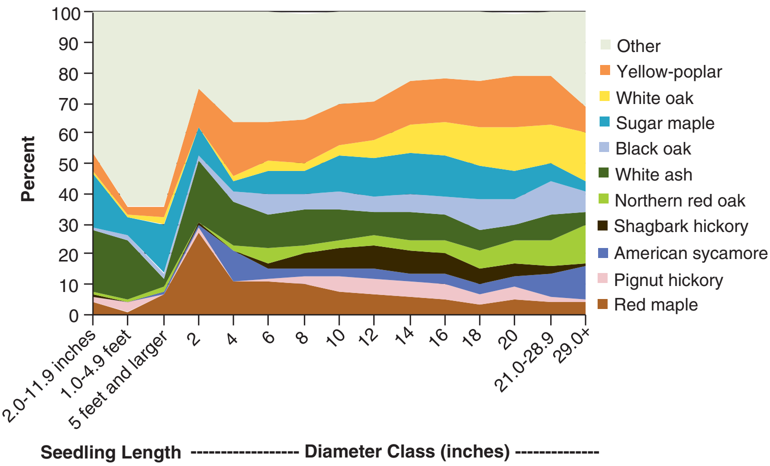

Figure 90.—Species composition for seedlings, dominant/codominant saplings, and growing-stock trees on forest land for select species, Indiana. Seedling estimates are for 2012-2013. Sapling and tree estimates are for 2009-2013. Species shown are the top 11 in terms of total aboveground biomass.

What this means

Early successional forest habitat is critically important for providing unique plant biota, wildlife food and cover, and landscape heterogeneity (Greenberg et al. 2011). Stambaugh (2014) lists native species of small reptiles, mammals, moths, butterflies, ruffed grouse (*Bonasa umbellus*), American Woodcock (*Scolopax minor*), and migratory songbirds as dependent on young forest habitat. A variety of bat species are also known to feed on insects common to young forests (Loeb and O'Keefe 2006). The quality of Indiana's early successional stands depends on the composition of the regeneration component that sets the stage for future benefits from mature forests, such as timber, carbon sequestration, and water quality.

An abundance of seedlings and saplings suggest that the forests of Indiana will be resilient as existing young forests develop and as new stands are established following harvest or other stand replacement events. This coupled with the finding that most of the regeneration indicator samples have medium browse impact sets the stage for positive results; however, some local areas are under heavy pressure from deer and this is a serious threat to successful regeneration (Rathfon and Farlee 2002, Stewart 2011). So far, indications are positive for sugar maple, red maple, and white ash. The situation with ash will require monitoring because it is found in several forest types, but especially because it is a principal cohort of the elm/ash/cottonwood forest-type group, Indiana's second most important group found on 13 percent of the forest land. The most important regeneration issue revealed by the regeneration indicator is that black oak, northern red oak, yellow-poplar, and white oak are currently underrepresented in the seedling and sapling regeneration component. This is important because these four species contribute more than one-fourth of the aboveground biomass of the oak/hickory forest-type group, which accounts for nearly three-fourths of Indiana forest land. Oak and hickory regeneration is well known as an issue (Abrams 1992, Holt and Fischer 1979, Lorimer 1993) and management techniques for successful regeneration have been described (Brose et al. 2008, Dey et al. 2010, Weigel et al. 2012). Another concern is the impact that regeneration has on the future of species important for spring, summer, and fall roosting of Indiana bats (*Myotis sodalis*), particularly in proximity to hibernacula. Along with the oaks mentioned, shagbark hickory is preferred by Indiana bats for maternity colonies (Menzel et al. 2001, Pruitt and TeWinkel 2007) and is underrepresented in the regeneration component. Loss of habitat has been listed as an important factor in population reductions in the past (Pruitt and King 2013, Womack et al. 2013), so forest management will need to consider these and other preferred species during the regeneration phase of forest development.

As Indiana forests grow older, the area of young forest continues to shrink. The sapling-seedling (small) stand-size class is a useful surrogate for young forests. The current distribution of timberland by size class is 7 percent small (seedling/sapling), 15 percent medium (poletimber), and 78 percent large (sawtimber). This compares with the 12 percent and 8 percent small stand-size class in the adjoining central states of Ohio and Illinois, respectively. The area of timberland in the small stand-size class decreased from 24 percent of the State's timberland in 1967 to only 7 percent currently (Spencer 1969). The current distribution of stand-size classes is not sustainable over the long term because of a lack of healthy young forest to replace Indiana's aging forests. This means that at some point, mature forests will experience either anthropogenic or natural stand replacement events, such as harvest or mortality, and will require regeneration to establish new young forests. A more balanced distribution of stand-size classes that would support a more diverse mix of flora and fauna, as well as improve timber production, would be 20 percent of timberland in small stands, 30 percent medium, and 50 percent large. This equates to roughly a three-fold increase in the area of young forests. Using age as the surrogate for young forest, only 3 percent of Indiana forest land is in the 0 to 10 year age class. Clearly, forest regeneration will be the key to successful establishment of new young forests. Sound forest management, policy, and planning will ensure a sustainable future for Indiana's treasured forest resources and values for the rest of this century.

The results presented here reflect only two of the seven panels of measurements (48 sample plots) that will eventually make up the first full baseline dataset for the regeneration indicator. The full dataset will allow more detailed analyses by improving the level of statistical confidence in the estimates (i.e., narrower confidence intervals) and will facilitate research to evaluate plot-level regeneration adequacy for the major forest-type groups and future trends in composition, structure, and health of Indiana forests.

Wildlife Habitat

Forests, woodlands, and savannas provide habitats for many species of Indiana birds (117), mammals (44), and amphibians and reptiles (61) (NatureServe, n.d.). Different forest types at different structural stages provide natural communities (habitats) at a coarse filter scale of conservation. Rare, imperiled, or wide-ranging wildlife species may not be fully served at this scale, so a fine filter approach is used to identify species-specific conservation needs. Representing an intermediate, or meso-filter, scale of conservation are specific habitat features (e.g., snags, riparian forest strips) which may serve particular habitat requirements for multiple species.

Like all states, Indiana has developed a State wildlife action plan (SWAP), known as the "Indiana Comprehensive Wildlife Strategy" (Gremillion-Smith 2005), supplemented by "Forests: Habitat Summary" (IDNR and IFW, n.d.). The summary lists 45 species of greatest conservation need (SGCN) in forests, including 18 birds, 16 mammals, 7 reptiles, and 4 amphibians. High-priority conservation actions for forests are also listed: maintain or create landscapes dominated by forest in order to provide for needs of area sensitive species, retain forest corridors to connect forest blocks, and encourage sustainable timber management practices to provide a variety of forest stages for the wide variety of forest-dependent species. We report on the condition and trends in forest attributes of forest age and size. Of particular note are the State's 11 bat SGCN, including Indiana bat, a federally listed endangered species, and northern long-eared bat (*Myotis septentrionalis*), a federally listed threatened species. Both species hibernate in caves during the winter but roost during the summer under peeling bark, in cavities, or in crevices of both live and dead trees. To address conservation issues associated with the presence and abundance of snags and nest cavities, we report on the quantity and distribution of standing dead trees.

Forest Age and Stand Size

Background

Some species of wildlife depend upon early successional forests consisting of smaller, younger trees, while others require older, interior forests containing large trees with complex canopy structure. Yet other species inhabit the ecotone (edge) between different forest stages, and many require multiple structural stages of forests to meet different phases of their life history needs. Abundance and trends in structural and successional stages serve as indicators of population carrying capacity for wildlife species (Hunter et al. 2001). Historical trends in Indiana forest habitats are reported for timberland, which makes up almost 97 percent of all forest land in the State. For current habitat conditions, estimates are reported for all forest land.

What we found

Timberland area in the small-diameter stand-size class decreased substantially in Indiana between 1986 and 1998 and has decreased slightly more in the past 15 years (Fig. 91). In contrast, area in the large diameter stand-size class has increased consistently since 1986, exceeding the rate of increase in total timberland area. The current area in the medium diameter stand-size class is similar to 1986, with slight increases during the intervening years. The current area of timberland under 20 years of age is nearly identical to 1998, but only one-third the abundance in 1986 (Fig. 92). Timberland older than 100 years represents the smallest area of any age class, decreasing in abundance between 1986 and 2003, but increasing since then. The greatest increase in timberland area was in the 61-80 year age class, which added over 800,000 acres.

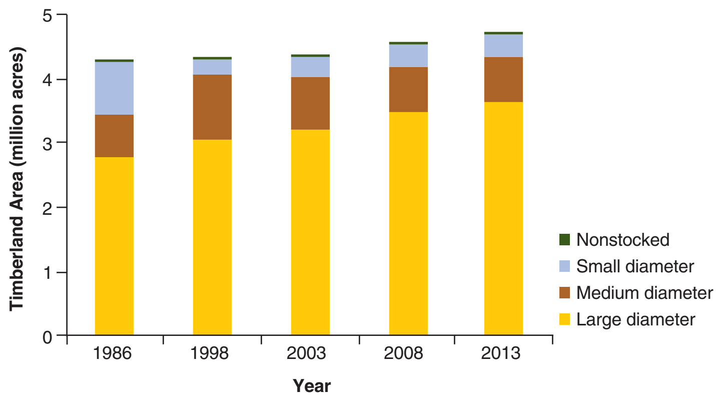

Figure 91.—Area of timberland by stand-size class and inventory year, Indiana.

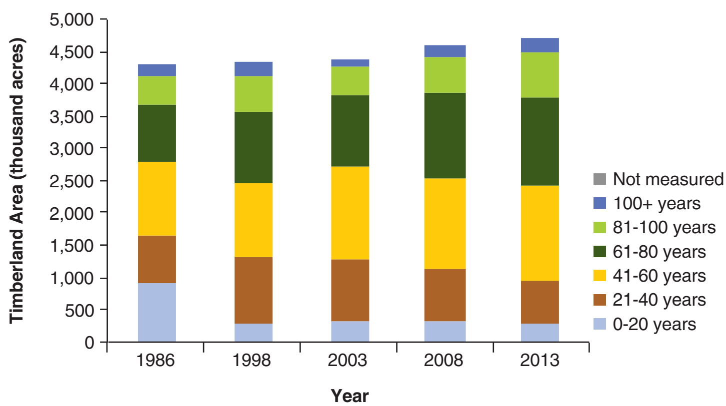

Figure 92.—Area of timberland by stand-age and inventory year, Indiana.

In Indiana, all three stand-size classes contain forests from at least four age classes. The medium stand-size class is predominated by forests 21 to 60 years of age, with lower amounts of both younger and older forest. The large stand-size class has an age distribution skewed further to the right, predominated by trees in the 61-80 year age class. Young forest (0-20 years) makes up the greatest area in the small diameter stand-size class, with decreasing area in successively older age classes (Fig. 93).

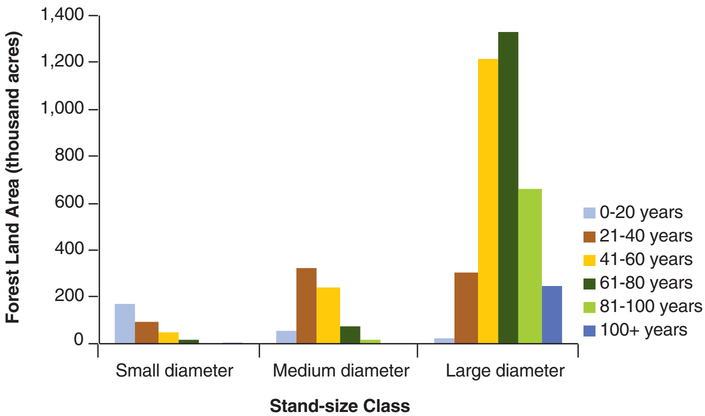

Figure 93.—Area of forest land by stand-size class, Indiana, 2009-2013.

What this means

In Indiana, an increase in the area of timberland in the large diameter stand-size class comes at the expense of area in the medium diameter stand-size class. Similarly, the area of timberland of at least 60 years of age increased while the abundance of timberland less than 40 years of age decreased. The small diameter stand size-class and 0-20 year age class provide two similar, but not identical, indicators of early successional habitat. More than 68 percent of 0-20 year old forest is in the small diameter size class, and 51 percent of small diameter forest is 0-20 years of age. Although both indicators have been relatively stable during the past 15 years, both are substantially lower in abundance than in 1986. Two bird SGCN are used to illustrate potential effects of changing forest structure. Mature forest species like cerulean warbler (*Dendroica cerulea*) benefit from increases in late-successional habitat, while early successional species, like golden-winged warbler (*Vermivora chrysoptera*), suffer from losses to their required habitats. As expected, there is almost no small forest in stand ages over 60 years of age and very little in forest older than 40 years; these age classes are predominated by the large diameter stand-size class. The 21-40 year old class is predominated by the medium diameter stand-size class but also contains substantial area in both large and small diameter classes. Such mixtures of different aged or sized trees provide a vertical diversity of vegetation structure that can enhance habitat conditions for some species. Managing forest conditions in both younger and older age classes (and smaller and larger structural stages) to maintain both early and late successional habitats may conserve habitat and viable populations of many forest-associated wildlife species. Another important benefit of offering a variety of successional stages across landscapes is that many species that are known to use late successional forest for nesting also use early successional forest patches for foraging. This is true for many bird species such as ovenbird and wood thrush that are typically thought of as late successional species. Also bats that roost in mature forests within snags and cavities (e.g., Indiana bats, northern long-eared bats, and little brown bats [*Myotis lucifugus*]) will often forage over early successional openings (little brown bats), or along forest edges between early and late successional stands (Indiana and northern long-eared bats). Therefore, even species that use late successional habitat often use early successional areas to fulfill life requirements, typically for foraging, further supporting the need to manage for a variety of forest conditions across landscapes.

Standing Dead Trees

Background

Specific habitat features like nesting cavities and standing dead trees provide critical habitat components for many forest-associated wildlife species. Standing dead trees that are large enough to meet habitat requirements for wildlife are referred to as “snags”. According to one definition, “for wildlife habitat purposes, a snag is sometimes regarded as being at least 10 inches (25.4 cm) in diameter at breast height and at least 6 feet (1.8 m) tall” (Society of American Foresters 1998). However, both federally listed tree roosting bats in Indiana (Indiana and northern long-eared bat) will often use snags with smaller diameters, even as small as half the diameter in the above definition. Standing dead trees serve as important indicators not only of wildlife habitat, but also for past mortality events and carbon storage. They also serve as sources of down woody material (discussed elsewhere in this report), which 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 Indiana forests.

What we found

FIA collects data on standing dead trees (5 inches d.b.h. and larger) of numerous species and sizes in varying stages of decay. More than 54 million standing dead trees are present on Indiana forest land. This equates to an overall density of 11.1 standing dead trees per acre of forest land, with slightly higher densities on public (11.9) than on private (10.9) forest land. The density of standing dead trees per acre of timberland on private ownerships has declined from 15.1 in 1986 to 11.1 in 2013, with even greater declines on public forest ownerships (Fig. 94).

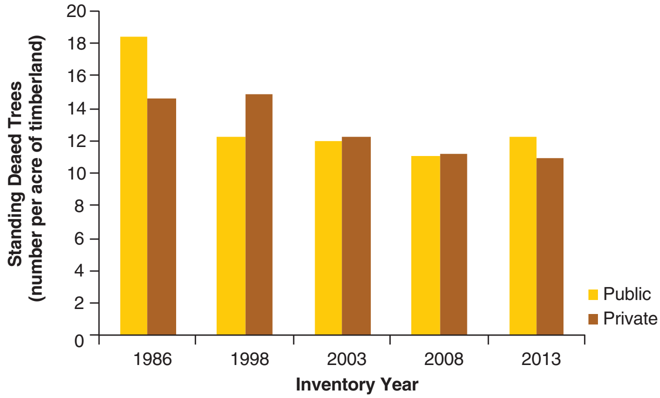

Figure 94.—Number of standing dead trees per acre of timberland by ownership and inventory year, Indiana.

Thirteen species groups each contributed more than 1 million standing dead trees. The top group, other eastern soft hardwoods, contributed more than 21 million standing dead trees (Fig. 95). Eight species groups exceeded 10 standing dead trees per 100 live trees (5 inches and larger d.b.h./d.r.c) (Fig. 96). More than 77 percent of standing dead trees were smaller than 11 inches d.b.h., 43 percent were between 5 and 6.9 inches d.b.h., and only 6 percent were over 17 inches (Fig. 97). The predominant dead tree decay class for most diameter classes was "only limb stubs present," which was observed on 31 percent of the trees, on average. Only 6 percent of the dead trees had the highest decay class, "no evidence of branches remain" (Fig. 97).

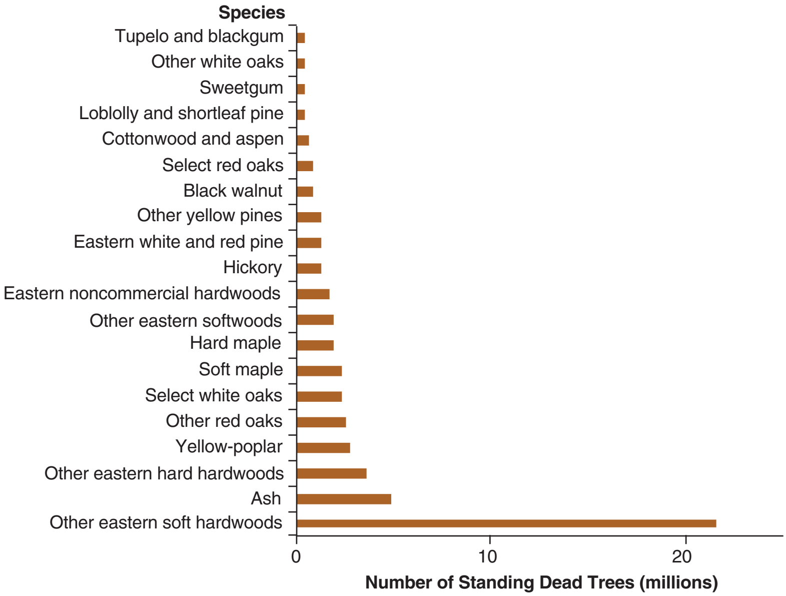

Figure 95.—Number of standing dead trees (5 inches d.b.h. and larger) by species group, Indiana, 2013.

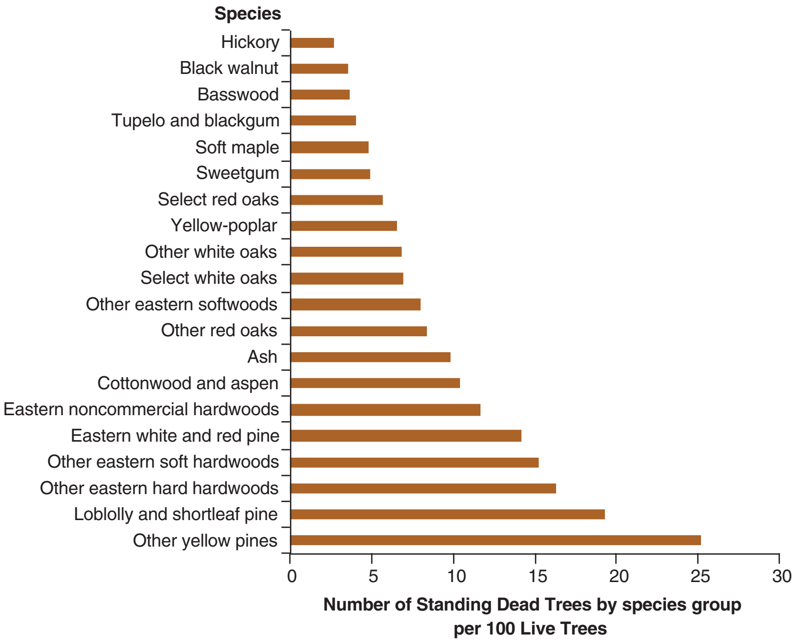

Figure 96.—Number of standing dead trees (5 inches d.b.h. and larger) per 100 live trees by species, Indiana, 2013.

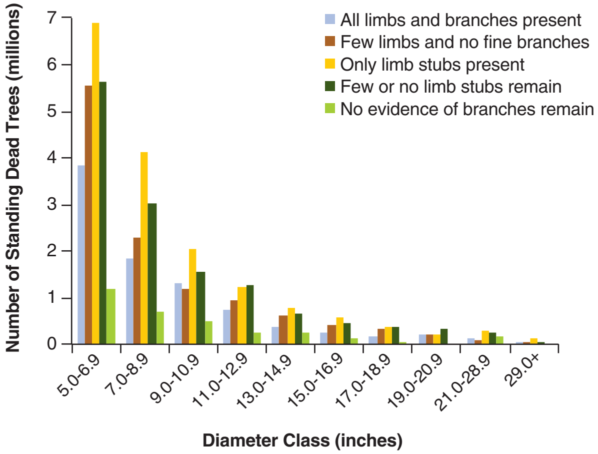

Figure 97.—Distribution of standing dead trees (5 inches d.b.h. and larger) by decay and diameter classes, Indiana, 2013.

What this means

Standing dead trees result from a variety of potential causes, including diseases, insects, weather damage, fire, flooding, drought, and competition. Frequency of standing dead trees has decreased over the past 25 years, on both public and private timberland. Because dead trees may contain significantly more cavities per tree than occur in live trees (Fan et al. 2003), they provide habitat for foraging, nesting, roosting, hunting perches, and cavity excavation for a range of wildlife, including primary colonizers such as insects, bacteria, and fungi to birds, mammals, and reptiles. Most cavity nesting birds are insectivores which help to control insect populations. The availability of very large standing dead trees (snags) in Indiana may be a limiting meso-scale habitat feature for some species of wildlife. For example, the Indiana bat clearly uses snags more than live trees, and the most important roosts used in maternity colonies (i.e., primary roosts) are often snags typically greater than 12 inches d.b.h. (Pruitt and TeWinkel 2007). In contrast, the northern long-eared bat is not limited or specialized in roost selection and is described as a roost generalist since it roosts in a wide variety of conditions (e.g., live or dead trees, under bark or in cavities/crevices, small or large diameter trees). See the next section for more information about bat habitat. Providing a variety of forest structural stages and retaining specific features like snags on both private and public lands are ways that forest managers can maintain the abundance and quality of habitat for forest-associated wildlife species in Indiana.

Bat Forest Habitat

Background

Although many bat species hibernate in caves during winter months, forests provide critical habitat to these fauna during their active seasons. Habitat selection in part occurs based on site-specific, stand-level, and landscape-scale levels of habitat perception. All bats in Indiana use forests (or woodlands, woodlots, riparian corridors, etc.). Eastern red (*Lasiurus borealis*) and hoary (*Lasiurus cinereus*) bats produce young in foliage of trees. Silver-haired bats (*Lasionycteris noctivagans*) migrate through Indiana and produce their young farther to the north. Indiana and northern long-eared bats regularly form maternity colonies under the loose bark of trees. Also, any of the bats that form maternity colonies in buildings may presumably use hollow trees as well. Indiana's cave bats include: the gray (*Myotis grisecens*), eastern small-footed (*Myotis leibii*), little brown, northern long-eared, Indiana, tricolored (*Perimyotis subflavus*), southeastern (*Myotis austroriparius*) and big brown (*Eptesicus fuscus*). Indiana's tree bats include: silver-haired, eastern red, hoary, evening (*Nycticeius humeralis*), and Rafineque's big-eared (*Corynorhinus rafinesquii*).

Habitat requirements for bats of Indiana are not completely understood. For example, the Indiana bat summer habitat includes small to medium river and stream corridors with well-developed riparian woods, woodlots within 1 to 3 miles of small to medium rivers and streams, and upland forests. The Indiana bat is a tree bat that requires forested areas for foraging and roosting; however, at a landscape level Indiana bat maternity colonies occupy habitats ranging from completely forested to areas of highly fragmented forest (Pruitt and TeWinkel 2007). Studies by Menzel et al. (2001) and King (2006) have identified at least 33 tree species that Indiana bats use during the summer. Roost trees are mainly in the oak/hickory cover type, but include a variety of species (Luensmann 2005, Pruitt and TeWinkel 2007, Rommé et al. 1995).

Tree structure is probably more important than the species in determining if a tree is a suitable roost site. Tree species that develop loose, exfoliating bark as they age and die are likely to provide roost sites. Male bats disperse throughout the range and roost individually or in small groups. In contrast, reproductive females form larger groups, referred to as maternity colonies, in which they raise their offspring (Pruitt 2001). Although some alternate roosts occur in living trees (e.g., shagbark hickory), most Indiana bats roost in dead or dying trees. The Indiana bat forages around tree canopies, within open forest, along forest edges, forest openings, and riparian areas; typically less than 2.5 miles from the roost. Rommé et al. (1995) suggests that foraging habitat would ideally have 50 to 70 percent tree canopy closure. The 2007 Indiana bat recovery plan provides a good reference for foraging habitat (Pruitt and TeWinkel 2007).

The species, size, solar orientation, and live/dead status of trees as well as bat gender, also appear to contribute to preferred Indiana bat habitat. The Indiana female bat generally prefers large, standing dead hardwood species, especially for maternity roosting trees. Male roosts do not seem to show a diameter class preference. Both genders seemingly roost in snags more often than live trees, but it is not clear if this is due to preference or if it is more dependent on availability of better quality roosting sites in snags. Although researchers have found it difficult to predict where maternity colonies may occur relative to forested habitat, it is a reliable prediction that once Indiana bats colonize maternity habitat, they will return to the same maternity areas annually (Pruitt and TeWinkel 2007).

When active, all bat species must have daily access to clean water for drinking, especially during lactation and periods of increased activity. Bats typically drink on the fly. Several species will also arouse to drink during hibernation. Some Indiana bat species usually roost near or forage over water. Gray myotis, little brown myotis, southeastern myotis, and tri-colored bats prefer to forage over lakes, rivers, and ponds. Eastern red bats, hoary bats, Indiana myotis, and big brown bats are known to use waterways for travel and foraging.

Bat threats

Bats are exceptionally vulnerable to extinction, in part because they are the slowest-reproducing mammals on Earth for their size, most producing only one young (pup) annually. More than half of American bat species are in decline or already listed as endangered. Losses are occurring at alarming rates worldwide. Major historic and chronic threats include natural predation (e.g., raccoons, feral cats, and snakes), habitat loss and fragmentation, cave and mine disturbance, toxicants (pesticides), and pollutants (including light pollution). Many bats die by accident. They can get impaled on barbed wire and burdocks or drown in floods during hibernation. Timber harvesting is not considered a primary threat to bat populations. When properly designed, many types of timber management do not impact, and may actually improve, bat habitat. Generally, forest management is considered compatible with maintenance of bat summer habitat, provided that key components of summer habitat are part of the forest management system (Pruitt and TeWinkel 2007). Other threats include turbines for wind energy, and for cave dwellers, the most severe and immediate threat is white-nose syndrome.

White-nose syndrome in bats

White-nose syndrome (WNS) has devastated bat populations across the eastern United States in the years since it was first discovered in a New York cave in February 2006. It has caused the most precipitous wildlife decline in the past century in North America (Bat Conservation International 2014). White-nose syndrome is an infectious disease associated with the fungus *Pseudogymnoascus destructans.* WNS is named for a hideous cold-loving white fungal growth that invades the skin tissue on the muzzle, wings, and

A cluster of little brown bats exhibiting the symptoms of white-nose syndrome. Photo from New York Department of Environmental Conservation, used with permission.

ears of cave-dwelling bats during winter hibernation. Airflow between a cave's entrance and exit spreads the disease. As the spores circulate, they land on the bodies of the bats in the cave, and when conditions are right, the spores develop into hyphae, which are threadlike structures that can invade the skin tissue of the bat.

The disease has caused the death of an estimated 5.7 to 6.7 million bats across eastern North America, with estimates of mortality often exceeding 90 percent in caves that have experienced multiple years of infection (U.S. FWS 2012). While the prolific white fungal growth on the bat's muzzle may be the most striking sign of infection, it is their wings that may be the most injurious target. During hibernation, the large surface area of a bat's wings performs critical physiological requirements such as regulating the animal's body temperature, water balance, and gas exchange with its external environment. These life processes, which are vital to survival, are disrupted when healthy wing membranes are invaded by the fungus. Consequently, the hibernation strategy of WNS-infected bats often includes a number of harmful behaviors. An example is exiting caves during cold winter days, which appears to be triggered by their inability to regulate essential metabolic activities. White-nose syndrome causes bats to awaken more often during hibernation and use up the stored fat reserves that are needed to get them through the winter. Infected bats often emerge too soon from hibernation and fly around in midwinter, which can lead to them freezing or starving to death. For more information, visit http://www.in.gov/dnr/fishwild/.

What we found

With an average of less than one standing dead tree per acre for trees with a d.b.h. in excess of 15.0 inches, the density (number per forest land acre) of standing dead trees in Indiana forests is limited for larger diameter trees (Fig. 98). As an alternative to roosting in snags, Indiana bats may roost under the naturally exfoliating bark of living shagbark and shellbark hickories, which average more than one per forest land acre for trees with a d.b.h. in excess of 12 inches (Fig. 99). An assessment of potential future bat habitat found that the current d.b.h. distribution of live trees of bat preferred roost species in Indiana (Pruitt and TeWinkel 2007) averages more than 12 live trees per forest land acre for trees with a d.b.h. in excess of 12.5 inches (Fig. 100).

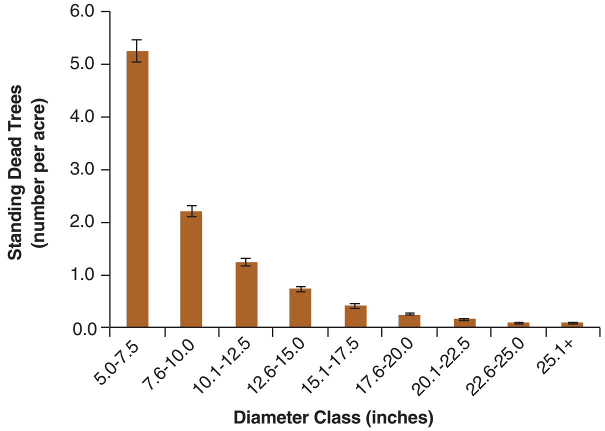

Figure 98.—Density (number/acre) of standing dead trees (i.e., snags) by d.b.h. class on forest land, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

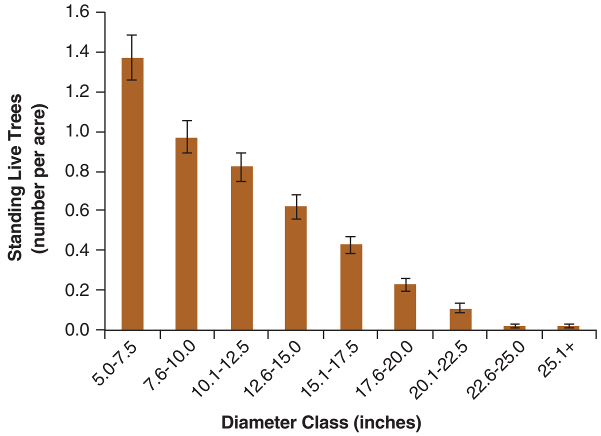

Figure 99.—Density (number/acre) of standing live shagbark and shellbark hickories by d.b.h. class on forest land, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

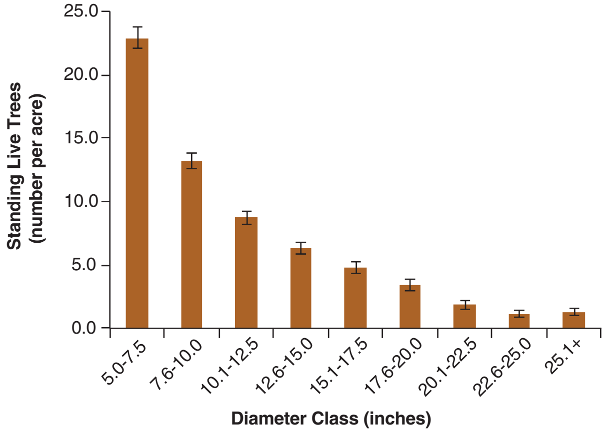

Figure 100.—Density (number/acre) of standing live oaks, maples (excluding boxelder), hickories, eastern cottonwood, American elm, slippery elm, and black locust by diameter class on forest land, Indiana, 2013. Error bars represent 1 standard error or a 68 percent confidence interval around the mean.

What this means

Relatively low densities of large snags may affect the distribution of Indiana bat maternity colonies in Indiana but would be less of a concern for northern long-eared bat maternity colonies. The female Indiana bat prefers larger standing dead trees, and although the current density is relatively low when compared to smaller diameter snags, it is not known what density of roosts is necessary to sustain a summer population of Indiana bats. There is the potential to increase bat habitat through selective management of tree species and/or retention of snags.

Forest Economics

Knob Lake Campground offers inexpensive, primitive, and quiet camping. Nearby Starve Hollow State Recreation Area has modern campsites with electric hookups and restrooms with showers. Photo by Indiana Department of Natural Resources, used with permission.

Carbon Stocks

Background

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

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

The carbon pools discussed in this report include living plant biomass (live trees ≥1 inch d.b.h. and understory vegetation), dead wood and litter (nonliving plant material including standing dead trees, down dead wood, and forest floor litter), and soil organic matter exclusive of coarse roots and estimated to a depth of 1 meter (3.28 feet). Carbon that is stored in harvested forest products such as lumber, plywood, and paper, is not included. Carbon estimates by ecosystem pool are based on sampling and modeling; for additional information on current approaches to determining forest carbon stocks, see U.S. Environmental Protection Agency (2015), U.S. Forest Service (2014a, 2014b), and O'Connell et al. (2014). The level of information available for making carbon estimates varies among pools. For example, the estimate of live tree carbon has the greatest confidence due to the level of sampling and the availability of allometric relationships applied to the tree data. Limited data and high variability result in lower confidence in the soil organic carbon estimates, which limits the interpretation of these estimates. Ongoing research is aimed at improving the estimates (U.S. EPA 2015). The carbon estimates provided here for Indiana forests are consistent with the data and methods used to develop the forest carbon reported in "U.S. Environmental Protection Agency's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013" (U.S. EPA 2015).

What we found

Total forest carbon stocks in Indiana are estimated to be 314 million tons, a 4 percent increase from 2008 to 2013. Overall, forest carbon per acre increased by 1.6 percent relative to 2008, and live tree carbon values increased by 2.5 percent. Live trees and soil organic carbon account for nearly 90 percent of forest carbon stocks, and almost one-third of the carbon is in the wood and bark of the bole of trees 5 inches d.b.h. and larger (Fig. 101). This represents the average distribution of carbon stocks within Indiana forest ecosystems, but individual stands will vary with site conditions and forest types.

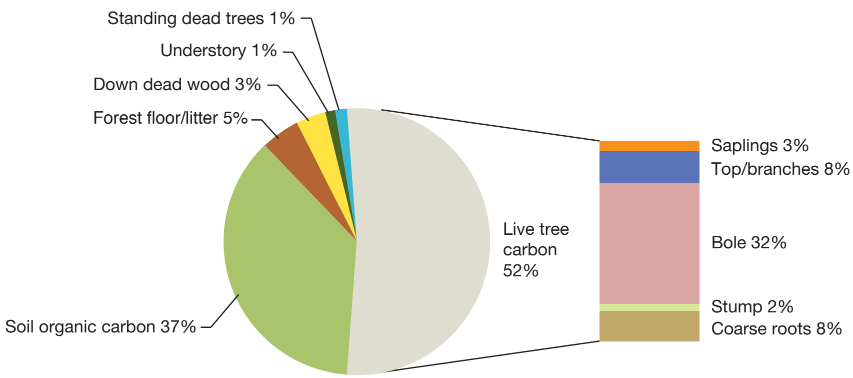

Figure 101.—Forest carbon stocks on forest land by carbon pool, Indiana, 2013.

Average aboveground carbon per acre increases with stand age, and the greatest net accumulation is within aboveground biomass (Fig. 102). More than 60 percent of total aboveground carbon stocks are represented by the middle two age classes (over 30 percent each); in contrast, the 0 to 20 year age class accounts for a little over 10 percent of the forest carbon stocks.

The oak/gum/cypress forest-type group, followed by the elm/ash/cottonwood, maple/beech/birch, white/red/jack pine, and oak/hickory forest-type groups yielded the highest average carbon short tons per acre (Fig. 103). Note that the sometimes considerable variability among forest-type groups is most closely associated with variability in biomass (which is essentially live tree; see Fig. 101). More than 95 percent of the total carbon stocks of Indiana forests are in the four most common forest-type groups: oak/hickory, elm/ash/cottonwood, maple/beech/birch, and oak/pine. The largest single pool of biomass is within the oak/hickory forest-type group, with 225 million short tons of carbon or nearly 70 percent of all Indiana forest carbon stocks.

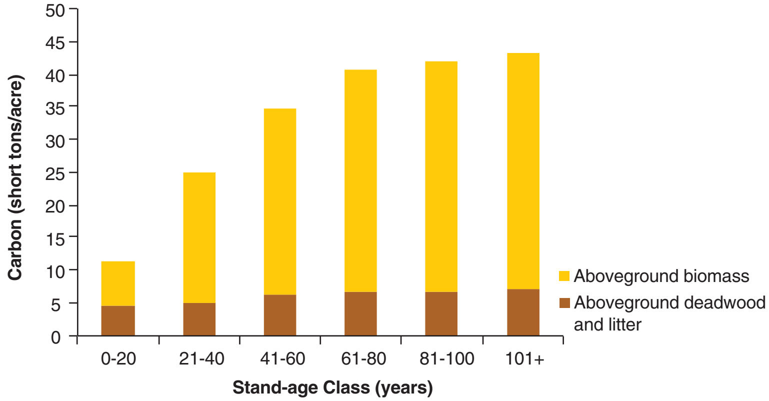

Figure 102.—Carbon by stand-age class for aboveground living plant biomass (live tree ≥1 inch d.b.h. and understory) versus dead wood (standing dead and down dead) and litter pools, Indiana, 2013.

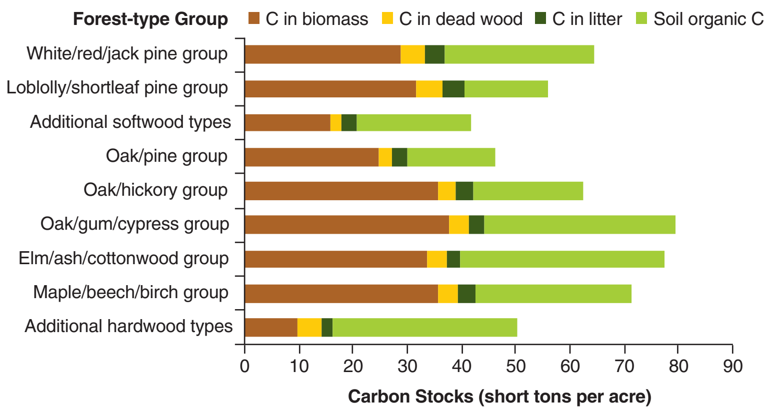

Figure 103.—Carbon stocks by forest-type group and component: biomass (live tree and understory), dead wood (standing dead trees and down dead wood), litter, and soil, Indiana, 2013. The less common forest-type groups are pooled as additional softwood or hardwood types.

What this means

In general, forest carbon stocks or differences in carbon stocks broadly reflect other measures of forest resources such as stand age, volume, or stocking. However, these summaries provide a useful reference measure of carbon stocks for the State relative to published regional or national forest carbon reports and offer a ready estimate of the role of Indiana forests. In brief, the carbon summaries show: (1) most of the carbon is in live trees, followed by soil organic carbon; (2) the majority of carbon is in stands of 40 to 80 years; (3) specific stand-level carbon varies; and (4) overall forest carbon in Indiana has increased over the past 5 years.

Timber Products Output

Background

Indiana forests contribute over $16 billion annually to Indiana's economy. In 2008, Indiana's primary wood-using industry included 155 sawmills, 8 veneer mills, one handle plant, and 21 mills producing other products. Direct employment within the industry accounted for over 35,000 people and indirectly, the industry supported around 90,000 jobs. Forest-based manufacturing provided $2.4 billion in value-added, $7 billion in value of shipments, and a payroll of $1.2 billion to Indiana's economy in 2008. More than two-thirds of the 68.4 million cubic feet of industrial roundwood harvested in 2008 came from south-central and southwestern Indiana. Saw logs accounted for 90 percent of the total harvest, with other minor products—primarily veneer logs, pulpwood, handles, and cooperage—making up the rest (Walters et al. 2012). The harvesting and processing of timber products produces a stream of income shared by timber owners, managers, marketers, loggers, truckers, and processors. In 2013, the wood products and paper manufacturing industries in Indiana employed 12,592 people (U.S. Department of Labor 2015), with an average annual payroll of $996 million (U.S. Census Bureau 2015). To better manage the State's forests, it is important to know the species, amounts, and locations of timber being harvested.

What we found

A canvass of Indiana's wood-processing mills is conducted periodically to estimate the amount of wood that is harvested and processed into products. The active primary wood processing mills in Indiana were last canvassed in 2013. The 2013 canvass found that the 143 active primary wood processing mills in Indiana processed 80.2 million cubic feet of industrial roundwood, an increase of 17 percent from 2008 (Walters et al. 2012), but still 8 percent below the 2005 level (Piva and Gallion 2007). Eighty-five percent of the industrial roundwood processed by Indiana mills came from Indiana forest lands. In 2013, 67.8 million cubic feet of industrial roundwood was harvested from Indiana forest land, an increase of 7 percent from 2008 (Fig. 104).

Saw logs accounted for more for than 93 percent of the total industrial roundwood harvested. Other products harvested were veneer logs, pulpwood, cooperage, and other miscellaneous products. Yellow-poplar accounted for 20 percent of the total industrial roundwood harvest (Fig. 105). Other important species groups harvested were the red oaks, white oaks, ash, hard maple, hickory, and black walnut.

In the process of harvesting industrial roundwood, 54.4 million cubic feet of harvest residues were left on the ground, of which nearly a third was merchantable material.

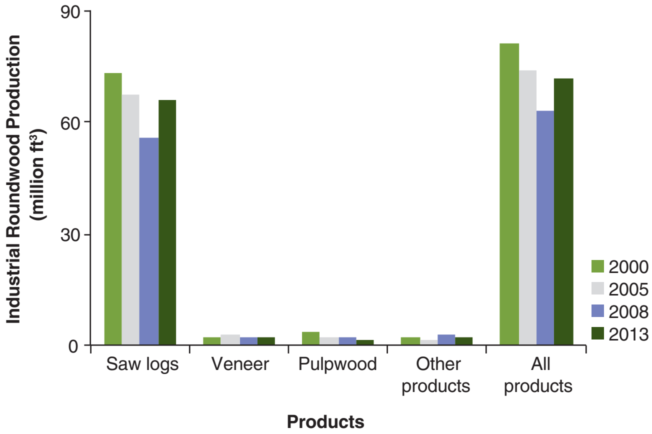

Figure 104.—Industrial roundwood production by product and year, Indiana.

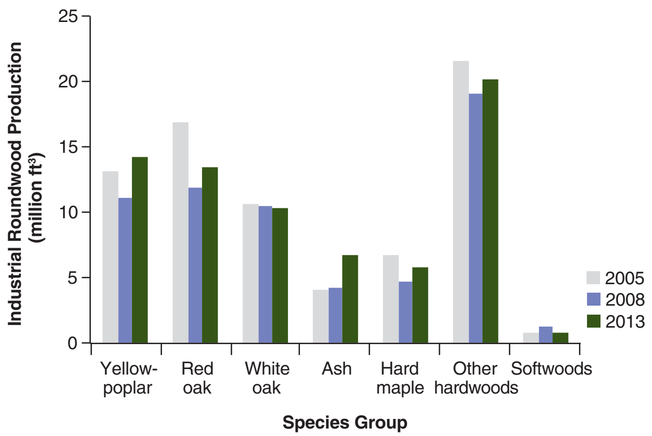

Figure 105.—Industrial roundwood production by species group and year, Indiana.

The processing of industrial roundwood generated 1.1 million green tons of wood and bark residues. Thirty-three percent of the mill residues generated were used for fiber products at pulp and composite panel mills. Another 18 percent of the mill residues were used for industrial and residential fuelwood, 11 percent were used for animal bedding, 32 percent were used for mulch, and 5 percent were used for other miscellaneous products. Only 1 percent of the mill residues generated were not used (Fig. 106).

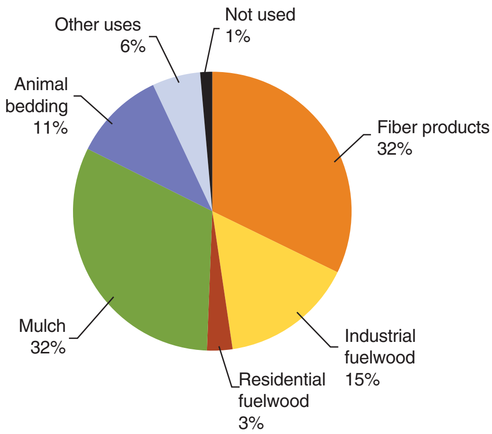

Figure 106.—Disposition of mill residues generated by primary wood-using mills, Indiana, 2013.

During the recent recession, the number of employees hit its lowest level in 2010, while annual payroll (actual dollars) and the total value of shipments (actual dollars) bottomed out in 2009. After decreasing by 44 percent between 2004 and 2010, the number of employees working in the forest products industry increased by 13 percent between 2010 and 2013 (Fig. 107). The annual payroll decreased by 23 percent between 2004 and 2009, while the total value of shipments only decreased by 13 percent. From 2009 and 2013, the annual payroll increased by 15 percent and the total value of shipments increased by 21 percent.

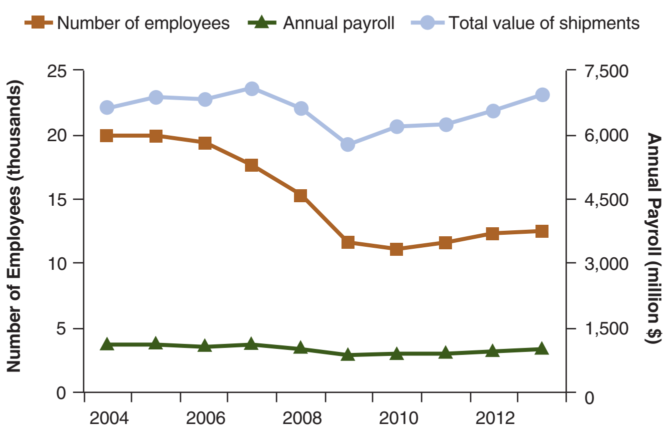

Figure 107.—Number of employees, annual payroll, and total value of shipments for the forest products industry in Indiana, 2004-2013.

What this means

Between 2004 and 2010, the number of employees working in the forest products industry decreased 44 percent, but the annual payroll decreased by only 20 percent and the total value of shipments by only 6 percent. The demand for higher value forest products, such as white oak cooperage and black walnut veneer, much of which is being exported out of the Country, kept the overall annual payroll and total value of shipments from decreasing as much as the number of employees. As the economy improves and the demand for wood products increases, the forest product mills that were able to withstand the recession are beginning to increase their production, resulting in an increase in the number of employees in the forest products industry.

Another important issue is the volume of harvest residues that are generated in the State that go unused. More than 30 percent of the harvest residue is from growing-stock sources (wood material that could be used to produce products). Indiana's primary forest products industry is the processing of saw logs. The last pulp mill in the State closed in 2007. This leaves a large volume of usable, small dimension wood material above the saw log top that could be utilized by small, localized, industrial fuelwood or wood pellet manufactures, leading to better utilization of the forest resource.

Future Forests

Yellow-poplar regeneration. Photo by Rich Widman, U.S. Forest Service.

Future Land Projections

Background

This section focuses on anticipated changes to the forests of Indiana between 2010 and 2060. The Northern Forest Futures study (Shifley and Moser 2016) examined several alternative future scenarios that cover a range of different assumptions about the economy, population, climate, and other driving forces that will affect the future conditions of forests. The assumptions were incorporated into analytical models that estimate how northern forests are likely to change under each alternative scenario. The seven scenarios can be grouped by climate model (or "general circulation model"), storyline, and storyline variation. Two climate models, three storylines, and three variations were used to produce the seven scenarios (Table 12). Additional details on methods can be found in Shifley and Moser (2016).

Table 12.—Scenarios used to project future forest conditions for Indiana

General circulation model	IPCC[a] Storyline A1B	IPCC Storyline A2	IPCC Storyline B2
CGCM3.1[b]	Scenario A1B-C	Scenario A2-C	
	Scenario A1B-BIO	Scenario A2-BIO	
		Scenario A2-EAB	
CGCM2[c]			Scenario B2-C
			Scenario B2-BIO

[a] IPCC is the Intergovernmental Panel on Climate Change.
[b] Canadian Centre for Climate Modelling and Analysis, n.d.b.
[c] Canadian Centre for Climate Modelling and Analysis, n.d.a.

A large component of future forest change will be the result of normal forest growth, aging, natural regeneration, and species succession. In addition, external forces are expected to drive forest change:

- Population increases will cause roughly 370,000 acres of forest land to be converted to urban land (Nowak and Walton 2005).
- Economic conditions will affect forest products consumption, production, and harvest rates.
- Invasive species will spread and affect forest change.
- Changes in population, the economy, energy consumption, and energy production will affect future climate change.
- Climate change will affect patterns of forest growth and species succession.

Following are the three storylines, as developed by the Intergovernmental Panel on Climate Change (IPCC 2000), with a brief description of the characteristics of each:

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

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

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

The tree storylines use the following scenarios:

1) C—Variations of the A1B, A2, and B2 storylines examine effects resulting from a continuation of the observed recent rates of forest removals due to timber harvesting and land use conversion from forest to another land use. These variations are referred to as scenarios A1B-C, A2-C, and B2-C.

2) BIO—Variations of the A1B, A2, and B2 storylines look at impacts of increased harvest and utilization of woody biomass for energy. They are referred to as scenarios A1B-BIO, A2-BIO, and B2-BIO.

3) EAB—A variation of the A2 storyline examines the potential impact of the continued spread of the emerald ash borer with associated mortality of all ash trees in the affected areas. This is referred to as scenario A2-EAB.

What we found

The anticipated decline in forest land, which totals in the hundreds of thousands of acres, reverses the long-term trend of increasing forest area in Indiana observed since the late 1930s (Fig. 108). Specifically, over the next 50 years forest land area is projected to decline from an estimated 4.7 million acres in 2010 to 4.2 million acres (-12 percent) in 2060 under scenario A1B-C; to 4.4 million acres (-8 percent) under scenario A2-C; and to 4.5 million acres (-6 percent) under scenario B2-C. The projected losses of forest land are still relatively small compared to the cumulative increase in forest area since 1938 (Smith et al. 2009). Only three scenarios are represented in Figure 108 as the climate model and variations on the storylines do not impact the area of forest land under this model. Only the storylines (developed around differing demographics and levels of economic activity) alter the area of forest land in the model. Scenarios with increasing population and economic activity have less forest land over the time period.

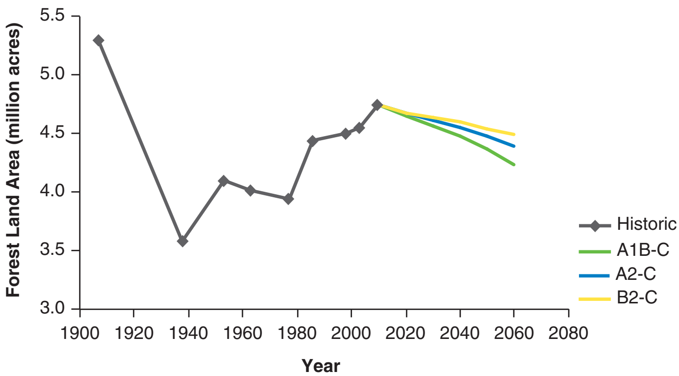

Figure 108.—Past and projected forest land area by scenario, Indiana, 2010-2060.

Emerald ash borer (EAB) was initially detected in Indiana on April 21, 2004. Ash species make up 8 percent of the total live tree volume on forest land in Indiana and 12 percent of the volume in the elm/ash/cottonwood forest-type group. Under scenario A2-EAB, ash species live volume is projected to decline from 767 million cubic feet in 2010 to zero cubic feet by 2030. Under scenario A2-C, ash volume is expected to decline from 767 million cubic feet in 2010 to 668 million cubic feet by 2060. There is a decline in the area of the elm/ash/cottonwood forest-type group from 2010 to 2060 under both scenario A2-C (-13 percent) and A2-EAB (-16 percent) (Fig. 109). The loss of the ash component in the elm/ash/cottonwood forest-type group in scenario A2-EAB is partially offset by increases in other associated species in this forest-type group. The negative impacts of EAB are more apparent in Figure 110 where the volume under scenario A2-EAB is projected to be 7 percent less than the volume under scenario A2-C in 2060.

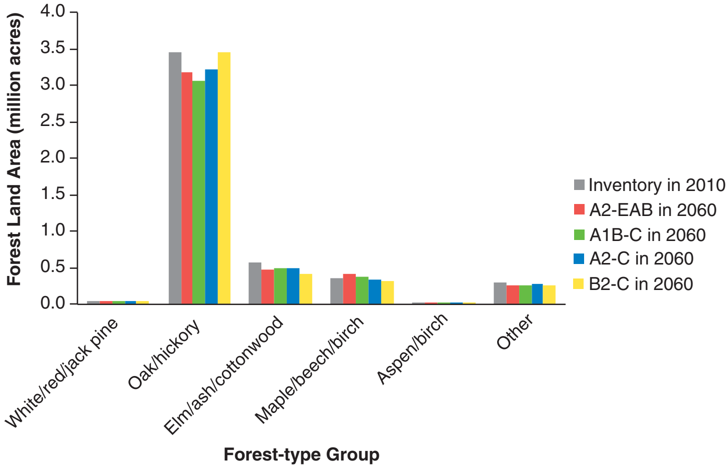

Figure 109.—Forest land area by forest-type group, Indiana, 2010 and by scenario in 2060.

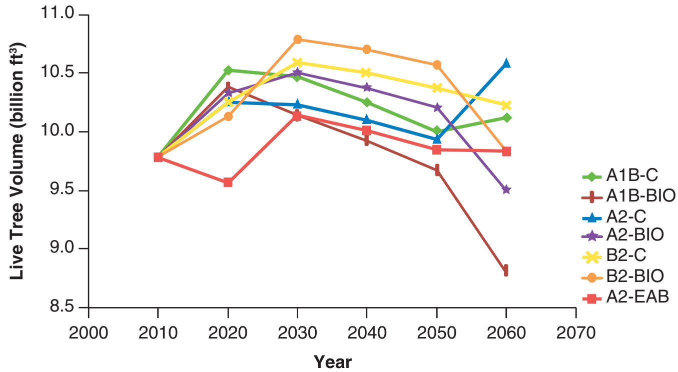

Figure 110.—Past and projected live-tree volume on forest land by scenario, Indiana, 2010-2060.

The scenarios with accelerated biomass removal for energy production (A1B-BIO, B2-BIO, and A2-BIO) have lower levels of live tree volume in 2060 than do their corresponding normal biomass utilization scenarios (A1B-C, B2-C, and A2-C) (Fig. 110), but surprisingly live tree volume on forest land in 2060 is projected to be less than the 2010 volume under only the A1B-BIO and A2-BIO scenarios. The area of forest land is expected to decrease, but the volume per acre for all but the A1B-BIO and A2-BIO scenarios are expected to increase as forests continue to mature. This trend results from the combined effects of gradually decreasing forest area and an aging forest resource with high volume but low net growth per acre.

What this means

The projected losses of forest land are relatively small compared to the cumulative decrease in forest area from the early 1900s to 1968. In fact the increase in forest area from 1968 to 2010 is only expected to be partially offset by projected forest land area losses from 2010 to 2060.

Even though live tree volume on forest land in 2060 is projected to be less than the 2010 volume under the A1B-BIO and A2-BIO scenarios, this does not mean that increased utilization of biomass for energy is ill advised. Rather, forest managers will need to be prudent about how much biomass is utilized and how it is obtained and replenished. In the past 60 years, forest managers have had the luxury of rapidly increasing forest volume with growth greatly exceeding removals. If projections hold true, that may not be the case for future generations of forest managers and wood-using industries.

Data Sources and Techniques

National Woodland Owner Survey

Information about family forest owners is collected annually 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. Individuals and private groups identified as woodland owners by FIA are invited to participate in the NWOS. Each year, questionnaires are mailed to 20 percent of private owners, with more detailed questionnaires sent out in years that end in 2 or 7 to coincide with national census, inventory, and assessment programs. Data presented here are based on survey responses from 232 randomly selected families and individuals who own forest land in Indiana. For additional information about the NWOS, visit www.fia.fs.fed.us/nwos.

Insects and Disease

Information about the insects and diseases affecting Indiana forests was gathered from the U.S. Forest Service, Northeastern Area State and Private Forestry (http://www.na.fs.fed.us), the national Forest Health Monitoring program (http://fhm.fs.fed.us/), and the Indiana Department of Natural Resources (http://www.in.gov/dnr/forestry/).

Timber Products Output Inventory

This study was a cooperative effort between the Indiana Department of Natural Resources (INDNR) Division of Forestry and NRS-FIA. Using a questionnaire designed to determine the size and composition of Indiana's forest products industry, its use of roundwood (round sections cut from trees), and its generation and disposition of wood residues, INDNR personnel contacted all primary wood-using mills in the State either by mail, phone calls, personal mill visits, or a combination of the three. Completed questionnaires were sent to NRS-FIA 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.

National Land Cover Data Imagery

Derived from Landsat Thematic Mapper satellite data (30-m pixel), the National Land Cover Dataset (NLCD) is a land cover classification scheme (21 classes) applied across the United States by the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (EPA). The NLCD was developed from data acquired by the Multi-Resolution Land Characteristics (MRLC) Consortium, a partnership of Federal agencies that produce or use land-cover data. Partners include the USGS, EPA, U.S. Forest Service, and National Oceanic and Atmospheric Administration.

Mapping Procedures

A geographic information system (GIS) and various geospatial datasets were used to generate the maps in this report. Unless otherwise indicated, forest resource data are from FIA and base map layers, e.g., state and county boundaries were obtained from the National Map (U.S. Geologic Survey, n.d.). Depicted FIA plot locations are approximate. Sources of other geospatial datasets are cited within individual figures. Maps in this report were constructed using (1) categorical coloring of Indiana counties and units according to forest attributes (such as forest land area), (2) a variation of the k-nearest-neighbor (KNN) technique to apply information from forest inventory plots to remotely sensed MODIS imagery (250 m pixel size) based on the spectral characterization of pixels and additional geospatial information (Wilson et al. 2012), or (3) colored dots to represent plot attributes at approximate plot locations. Most Indiana maps are portrayed in the Universal Transverse Mercator Coordinate System, Zone 16N, North American Datum of 1983.

Sources for Additional Information

Detailed information on forest inventory methods, data quality estimates, important resource statistics, and a glossary of terms can be found in Statistics, Methods, and Quality Assurance which is available online at http://dx.doi.org/10.2737/NRS-RB-107. Data used in this report are accessible through the included software Evalidator (requires Microsoft Access). Some graphs and tables in the printed portion of this report show only a sample of the prominent categories and values available for summarizing data. Tables online have more categories, summary values, and custom tables. The main Web page for FIA is at http://www.fia.fs.fed.us/, and additional resources, including publications (http://www.nrs.fs.fed.us/pubs/) and data http://apps.fs.fed.us/fiadb-downloads/datamart.html, are also available. A primary Web tool is FIDO or Forest Inventory Data Online (http://apps.fs.fed.us/fido/). Other tools, including a Web version of Evalidator, are available (http://www.fia.fs.fed.us/tools-data/). Field guides are at http://www.fia.fs.fed.us/library/field-guides-methods-proc/. State-level reports are available at http://nrs.fs.fed.us/fia/data-tools/state-reports/default.asp. In addition to FIA forest information and tools, i-Tree is a state-of-the-art, peer-reviewed software suite from the U.S. Forest Service that provides urban forestry analysis and benefits assessment tools. The i-Tree Tools help communities of all sizes to strengthen their urban forest management and advocacy efforts by quantifying the structure of community trees and the environmental services that trees provide. Visit https://www.itreetools.org/ for more information.

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Appendixes

Appendix 1.—Tree species observed on FIA plots, Indiana, 2013

Common name	Scientific Name
Eastern redcedar	*Juniperus virginiana*
Tamarack (native)	*Larix laricina*
Norway spruce	*Picea abies*
Blue spruce	*Picea pungens*
Jack pine	*Pinus banksiana*
Shortleaf pine	*Pinus echinata*
Austrian pine	*Pinus nigra*
Red pine	*Pinus resinosa*
Eastern white pine	*Pinus strobus*
Scotch pine	*Pinus sylvestris*
Virginia pine	*Pinus virginiana*
Baldcypress	*Taxodium distichum*
Boxelder	*Acer negundo*
Black maple	*Acer nigrum*
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
Sugar maple	*Acer saccharum*
Ohio buckeye	*Aesculus glabra*
Ailanthus	*Ailanthus altissima*
European alder	*Alnus glutinosa*
Common serviceberry	*Amelanchier arborea*
Serviceberry spp.	*Amelanchier* spp.
Pawpaw	*Asimina triloba*
Yellow birch	*Betula alleghaniensis*
River birch	*Betula nigra*
American hornbeam, musclewood	*Carpinus caroliniana*
Mockernut hickory	*Carya alba*
Water hickory	*Carya aquatica*
Bitternut hickory	*Carya cordiformis*
Pignut hickory	*Carya glabra*
Pecan	*Carya illinoinensis*
Shellbark hickory	*Carya laciniosa*
Red hickory	Carya ovalis
Shagbark hickory	*Carya ovata*
Northern catalpa	*Catalpa speciosa*
Sugarberry	*Celtis laevigata*

(Appendix continued on next page.)

(Appendix continued)

Common name	Scientific Name
Hackberry	*Celtis occidentalis*
Eastern redbud	*Cercis canadensis*
Flowering dogwood	*Cornus florida*
Cockspur hawthorn	*Crataegus crus-galli*
Hawthorn spp.	*Crataegus* spp.
Common persimmon	*Diospyros virginiana*
American beech	*Fagus grandifolia*
White ash	*Fraxinus americana*
Black ash	*Fraxinus nigra*
Green ash	*Fraxinus pennsylvanica*
Blue ash	*Fraxinus quadrangulata*
Honeylocust	*Gleditsia triacanthos*
Kentucky coffeetree	*Gymnocladus dioicus*
Butternut	*Juglans cinerea*
Black walnut	*Juglans nigra*
Sweetgum	*Liquidambar styraciflua*
Yellow-poplar	*Liriodendron tulipifera*
Osage-orange	*Maclura pomifera*
Apple spp.	*Malus* spp.
White mulberry	*Morus alba*
Red mulberry	*Morus rubra*
Mulberry spp.	*Morus* spp.
Blackgum	*Nyssa sylvatica*
Eastern hophornbeam	*Ostrya virginiana*
Sourwood	*Oxydendrum arboreum*
American sycamore	*Platanus occidentalis*
Eastern cottonwood	*Populus deltoides*
Bigtooth aspen	*Populus grandidentata*
Swamp cottonwood	*Populus heterophylla*
Quaking aspen	*Populus tremuloides*
American plum	*Prunus americana*
Black cherry	*Prunus serotina*
Cherry and plum spp.	*Prunus* spp.
White oak	*Quercus alba*
Swamp white oak	*Quercus bicolor*
Scarlet oak	*Quercus coccinea*
Northern pin oak	*Quercus ellipsoidalis*
Shingle oak	*Quercus imbricaria*

(Appendix continued on next page.)

(Appendix continued)

Common name	Scientific Name
Bur oak	*Quercus macrocarpa*
Blackjack oak	*Quercus marilandica*
Swamp chestnut oak	*Quercus michauxii*
Chinkapin oak	*Quercus muehlenbergii*
Cherrybark oak	*Quercus pagoda*
Pin oak	*Quercus palustris*
Chestnut oak	*Quercus prinus*
Northern red oak	*Quercus rubra*
Shumard oak	*Quercus shumardii*
Post oak	*Quercus stellata*
Black oak	*Quercus velutina*
Black locust	*Robinia pseudoacacia*
Black willow	*Salix nigra*
Willow spp.	*Salix* spp.
Sassafras	*Sassafras albidum*
American basswood	*Tilia americana*
Winged elm	*Ulmus alata*
American elm	*Ulmus americana*
Siberian elm	*Ulmus pumila*
Slippery elm	*Ulmus rubra*
Rock elm	*Ulmus thomasii*

Appendix 2.

Mulipliers for converting between International ¼-inch rule volume and Doyle log rule volume for hardwoods and softwoods (modified from Smith 1991)

Tree Diameter 2-inch class	To convert International ¼-inch rule volume to Doyle log rule volume, mutiply by:	
	Hardwood	**Softwood**
12	0.4172	0.478
14	0.5118	0.5992
16	0.5882	0.6908
18	0.6569	0.7685
20	0.718	0.8573
22	0.7829	0.8645
24	0.8324	0.9276
26	0.8736	0.9493
28	0.9473	0.971
30 +	1.1349	1.1065

* Result of multiplication will be volume in Doyle log rule.

Mulipliers for converting between Doyle log rule volume and International ¼-inch rule volume for hardwoods and softwoods (modified from Smith 1991)

Tree Diameter 2-inch class	To convert Doyle log rule volume to International ¼-inch rule volume, mutiply by:	
	Hardwood	**Softwood**
10		2.8944
12	2.3969	2.0921
14	1.9539	1.6689
16	1.7001	1.4476
18	1.5223	1.3012
20	1.3928	1.1665
22	1.2773	1.1567
24	1.2013	1.0781
26	1.447	1.0534
28	1.0556	1.0299
30 +	0.8811	0.9038

* Result of multiplication will be volume in International ¼-inch rule.

Fall foliage reflects in Beanblossom Lake, Morgan-Monroe State Forest. Photo by Indiana Department of Natural Resources, used with permission.

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This report summarizes the third full annualized inventory of Indiana forests conducted from 2009 to 2013 by the Forest Inventory and Analysis program of the Northern Research Station in cooperation with the Indiana Department of Natural Resources, Division of Forestry. Indiana has nearly 4.9 million acres of forest land with an average of 454 trees per acre. Forest land is dominated by the white oak/red oak/hickory forest type, which occupies 72 percent of the total forest land area. Most stands are dominated by large trees. Seventy-eight percent of forest land consists of sawtimber, 15 percent contains poletimber, and 7 percent contains saplings/seedlings. Growing-stock volume on timberland has been rising since the 1980s and currently totals 9.1 billion cubic feet. Annual growth outpaced removals by a ratio of 3.3:1. Additional information on forest attributes, changing land use patterns, timber products, and forest health is included in this report. Detailed information on forest inventory methods and data quality, a glossary of terms, tabular estimates for a variety of forest characteristics, and additional resources are available online at http://dx.doi.org/10.2737/NRS-RB-107.

KEY WORDS: Indiana, inventory, forest statistics, forest land, volume, biomass, riparian, growth, removals, mortality, forest health, forest management, bats.

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