Indiana's Forests 2008

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Abstract

The second full annual inventory of Indiana's forests reports more than 4.75 million acres of forest land with an average volume of more than 2,000 cubic feet per acre. Forest land is dominated by the white oak/red oak/hickory forest type, which occupies nearly a third of the total forest land area. Seventy-six percent of forest land consists of sawtimber, 16 percent contains poletimber, and 8 percent contains sapling/seedlings. The volume of growing stock on timberland has been rising since the 1980s and currently totals more than 8.5 billion cubic feet. The average annual net growth of growing stock on forest land from 2004 to 2008 is approximately 312 million cubic feet per year. This report includes additional information on forest attributes, land use change, carbon, timber products, forest health, and statistics and quality assurance of data collection.

Acknowledgments

The authors would like to thank the many individuals who contributed both to the inventory and analysis of Indiana's forest resources. Primary field crew and QA staff over the 2004-2008 field inventory cycle included Gary Stachowicz, Dan Johnson, Mark Webb, Jason Stephens, Joey Gallion, Greg Yapp, Aaron Hawkins, Matt Goeke, Kasey Krouse, Lance Dye, Dominic Lewer, Will Smith, and Pete Koehler. Data management personnel included Gary Brand, Mark Hatfield, Jay Solomakos, and James Blehm. Report reviewers included Joey Gallion and Carl Hauser of Indiana's DNR.

Cover: Autumn in the deciduous forest. Photo used with permission of Indiana Dept. of Natural Resources.

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Indiana's Forests 2008

Christopher W. Woodall, Mark N. Webb, Barry T. Wilson, Jeff Settle, Ron J. Piva, Charles H. Perry, Dacia M. Meneguzzo, Susan J. Crocker, Brett J. Butler, Mark H. Hansen, Mark A. Hatfield, Gary J. Brand, and Charles H. Barnett

Contact Author:
Christopher Woodall, cwoodall@fs.fed.us,
651-649-5141

About the Authors

Christopher W. Woodall is a research forester with the Forest Inventory and Analysis (FIA) program, Northern Research Station, St. Paul, MN.

Mark N. Webb and Jeff Settle are forest resource analysts with Indiana's Department of Natural Resources, Forestry Division.

Susan J. Crocker is a research forester with FIA, Northern Research Station, St. Paul, MN.

Brett J. Butler is a research forester with FIA, Northern Research Station, Amherst, MA.

Ron J. Piva is a forester with FIA, Northern Research Station, St. Paul, MN.

Dacia M. Meneguzzo is a research forester with FIA, Northern Research Station, St. Paul, MN.

Charles H. (Hobie) Perry is a research soil scientist with FIA, Northern Research Station, St. Paul, MN.

Barry T. (Ty) Wilson is a research forester with FIA, Northern Research Station, St. Paul, MN.

Mark H. Hansen is a research associate, University of Minnesota, St. Paul, MN.

Mark A. Hatfield is a forester with FIA, Northern Research Station, St. Paul, MN.

Gary J. Brand is a programmer, University of Nevada-Las Vegas.

Charles J. Barnett is a forester with FIA, Northern Research Station, Newtown Square, PA.

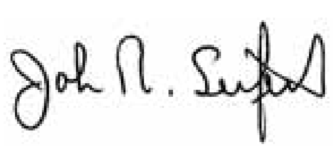
Foreword

We welcome you to the latest results of our statewide forest inventory of Indiana. The inventory is conducted as a cooperative program 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 sixth inventory show Indiana's 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's forests have expanded to more than 4.75 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. In fact, the Bio-Crossroads Report shows that hardwood timber and associated industries represent Indiana's largest agricultural sector, supporting $9 billion of economic activity each year. Every thousand acres of forest land directly supports 12 manufacturing jobs in the primary and secondary wood-using industry.

While Indiana's forests continue to expand, there are concerns. Regeneration of some shade-intolerant species such as oaks 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 8.2 million cubic feet of volume per year, partially attributed to the emerald ash borer, a nonnative insect accidentally introduced into Michigan that has spread to other states. There are a growing number of invasive plant species outcompeting native vegetation for sunlight and nutrients. 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 latest results of Indiana's forest inventory, and I hope 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 Seifert, State Forester

Contents

Highlights

On the Plus Side

Statewide forest land area continues to increase at a steady rate, slowly approaching 5 million acres.

The total aboveground biomass of forest trees across Indiana is tremendous – nearly a quarter of a billion tons.

Indiana possesses an extremely diverse array of forest tree species with dozens of forest types statewide.

Since 1950, the average cubic foot volume of growing-stock trees on timberland has nearly tripled.

Forest growth exceeds volume losses from mortality, harvest, and land use change combined.

Tree mortality has stabilized at sustainable levels across the State.

The ratio of tree volume removal from Indiana's forest land base (through either mortality or land use change) compared to total tree volume has nearly halved since the 1950s.

For every acre of forest land converted to nonforest, about 5 new acres of forests were added across the State.

Tree crowns across Indiana are on average healthy with minor levels of dieback.

The growing-stock volume on Indiana's timberland has nearly quadrupled since the 1950s.

The volume of sawtimber on Indiana's timberland might reach 40 billion board feet (International ¼-inch log rule) by 2013.

Problem Areas

Indiana's forests are a maturing resource that will eventually experience density and age-related changes.

The forest land base of Indiana is highly fragmented due to agriculture and development.

Despite the diverse array of native plant species in the understory of Indiana's forests, growing numbers of invasive plant species are outcompeting native vegetation.

The average parcel size of privately owned forest land in Indiana continues to decrease with indications that these holdings will be changing owners.

The wildlife habitat provided by dead and downed woody debris is relatively sparse across the State.

Recent ash tree mortality (1999-2003 to 2004-2008), partially attributable to the emerald ash borer, resulted in a loss of 8.2 million cubic feet of volume per year.

Since 2005, there has been a 20-percent decrease in industrial roundwood harvested and processed in Indiana, substantially affecting numerous primary and secondary forest product economies.

Issues to Watch

If bioenergy markets develop in Indiana there may be increased harvest activity in direct competition with traditional forest product industries along with increased harvest utilization rates that may impact forest sustainability (decreased coarse woody debris).

Tree species composition of Indiana's forests continues to evolve as oak species are slowly supplanted by species such as yellow-poplar.

Forest reflections bring color to the autumn. Photo used with permission of Indiana Dept. of Natural Resources.

Levels of ozone (air pollutant) damage to Indiana's trees have decreased during the past few years, although ozone continues to occur and should be monitored.

The emerald ash borer continues to spread across Indiana killing more and more trees.

The atmospheric deposition of sulfur and nitrogen oxides continues to negatively affect forest soil quality and hence tree development (uncompacted live crown ratio).

Given the tremendous gains in growing-stock volume in larger diameter classes for economically important tree species (e.g., yellow-poplar and oaks), the regeneration of these species should be monitored to ensure future sustainability.

The management of forests to maximize carbon sequestration may be more complex than timber management due to fluctuating carbon credit markets and consideration of all carbon pools in forests (e.g., soil organic carbon, dead wood, and belowground stocks).

Peaceful serenity greets visitors to the hardwood forest. Photo used with permission of Indiana Dept. of Natural Resources.

Background

Forests protect our watersheds. Photo used with permission of Indiana Dept. of Natural Resources.

A Beginners Guide to Forest Inventory

What is a tree?

We know a tree when we see one and we can agree on some common tree attributes. Trees are perennial woody plants with central stems and distinct crowns. In general, the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service defines a tree as any perennial woody plant species that can attain a height of 15 feet at maturity. In Indiana, the problem is deciding which species should be classified as shrubs and which should be classified as trees. A complete list of the tree species measured in this inventory can be found in "Indiana's Forests 2008: Statistics and Quality Assurance," on the CD in the inside back cover pocket of this bulletin.

What is a forest?

We know what a forest is, but where does the forest stop and the prairie begin? It's an important question. Often, the gross area of forest land or rangeland determines the allocation of funding for certain State or Federal programs. Forest managers want more land classified as forest land and range managers want more land classified as prairie, but the line has to be drawn somewhere.

FIA defines forest land as land at least 10 percent stocked by trees of any size or formerly having had such tree cover and not currently developed for nonforest uses. The area with trees must be at least 1 acre in size, and roadside, streamside, and shelterbelt strips of trees must be at least 120 feet wide to qualify as forest land.

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

From an FIA perspective, there are three types of forest land: timberland, reserved forest land, and other forest land. In Indiana, approximately 98 percent of forest land is timberland and 2 percent is reserved forest land.

- Timberland is unreserved forest land that meets the minimum productivity requirement of 20 cubic feet per acre per year at its peak.

- Reserved forest land is land withdrawn from timber utilization through legislation or administrative regulation.

- Other forest land is commonly found on low-lying sites with poor soils where the forest is incapable of producing 20 cubic feet per acre per year at its peak.

In Indiana's inventories before 1998, only trees occurring on timberland plots were measured. Therefore, we cannot report volume on other components of forest land for those inventories. The new annual inventory system facilitates the estimation and reporting of volume on all forest land, not just timberland. Because these annual plots have been remeasured upon completion of the second annual inventory, we are now able to report current growth, removals, and mortality on all forest land. However, trend reporting since the 1950s may be limited here to timberland.

Where are Indiana's forests and how many trees are in Indiana?

Indiana's forests dominate the landscape of southern Indiana and are comprised primarily of oak/hickory forest types (Fig. 1). Indiana's forest land contains approximately 2.2 billion live trees that are at least 1 inch in diameter at breast height (d.b.h., 4.5 feet above the ground). We do not know the exact number, because only a sample of trees was measured, roughly 1 out of every 78,000 trees, or a total of 28,066 trees. These trees were measured on a total of 1,408 forest plots. For information on sampling errors, see the CD, "Indiana's Forests 2008: Statistics and Quality Assurance" at the back of this bulletin.

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.

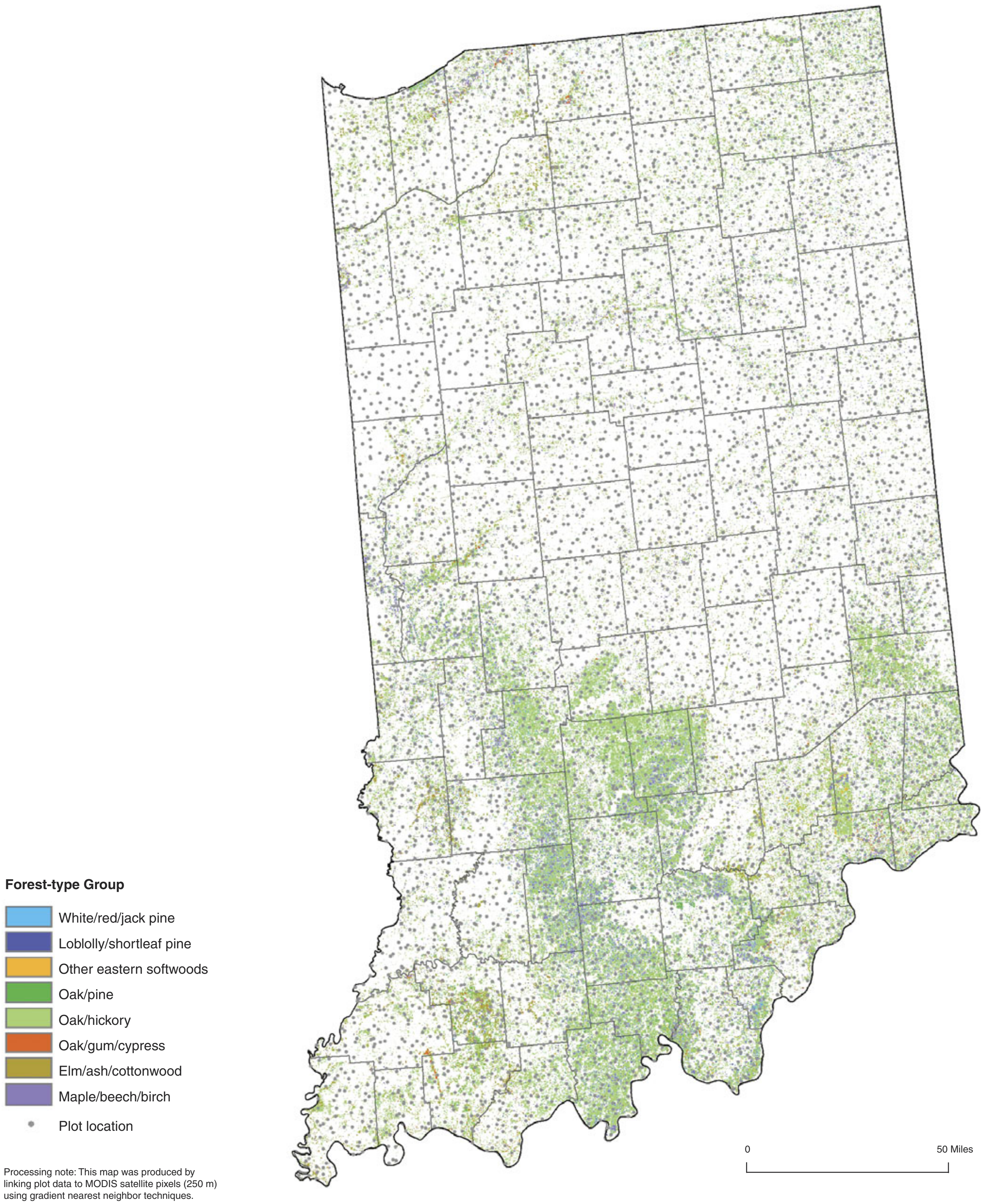


Figure 1.—Distribution of forest land by forest-type group, Indiana, 2004-2008.

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 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 this 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 volumes. FIA reports sawtimber volumes in International 1/4-inch board foot scale as well as Doyle rule. To convert to the Scribner board foot scale, see Smith (1991).

How much does a tree weigh?

Building on previous work, the U.S. Forest Service's Forest Products Laboratory developed estimates of specific gravity for a number of tree species (U.S. For. Serv. 1999). These specific gravities were applied to estimates of tree volume to determine merchantable tree biomass (the weight of the bole). To estimate live biomass, we have to add in the stump (Raile 1982), limbs, and bark (Hahn 1984). We do not currently report the live biomass of roots or foliage.

Forest inventories report biomass as 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 zero percent moisture content. On average, 1 ton of oven-dry biomass is equal to 1.9 tons of green biomass.

How do we estimate all the forest carbon pools?

FIA does not measure the carbon in standing trees, let alone carbon in belowground pools. FIA roughly assumes that half the biomass in standing live/dead trees consists of carbon. The remaining carbon pools (e.g., soil, understory vegetation, belowground biomass) are modeled based on stand/site characteristics (e.g., stand age and forest type).

How do we compare data from different inventories?

Data from new inventories are often compared with data from earlier inventories to determine trends in forest resources. For comparisons to be valid, the procedures used in the two inventories must be similar. As a result of FIA's ongoing efforts to improve the efficiency and reliability of the inventory, several changes in procedures and definitions have occurred since Indiana's inventory in 1998. Although these changes will have little effect on statewide estimates of forest area, timber volume, and tree biomass, they may significantly affect plot classification variables such as forest type and stand-size class. Some of these changes make it inappropriate to directly compare annual inventories completed in 2003 and 2008 with those published before then.

A word of caution on suitability and availability…

FIA does not attempt to identify which lands are suitable or available for timber harvesting, particularly since such suitability and availability are subject to changing laws, economic/market constraints, physical conditions, adjacency to human populations, and ownership objectives. The classification of land as timberland does not necessarily mean it is suitable or available for timber production.

Nor is it safe to assume that forest owners plan regular harvests or intend to harvest at all. In response to FIA's National Woodland Landowner Survey, only one in six of landowners, owning 75 percent of Indiana's private forest land, stated that they intend to harvest saw logs or pulpwood over the next 5 years. Many of Indiana's private landowners own forest land for its aesthetic value. Although most family forest owners in Indiana plan to do relatively little with their forest land in the near future, one in every 8 acres is owned by someone who plans to either transfer their land to an heir or sell it within the next 5 years.

Thus, forest inventory data alone are inadequate for determining the area of forest land available for timber production. Additional factors, like the previously mentioned social trends, need to be considered when estimating the timber base.

Forest Features

Young regenerating hardwood forest. Photo used with permission of Indiana Dept. of Natural Resources.

Forest Area

Background

Trends in forest area are often an early indicator of future forest resource trends. Fluctuations in area may indicate changing land use or forest health conditions. Monitoring these changes provides information essential for management and decisionmaking.

What we found

Following a trend found in the 1967 inventory, forest land area continues to increase at a steady rate reaching a current estimate of approximately 4.75 million acres (Fig. 2). At the county level, gains in the percentage of forest land area per total county land area have been fairly consistent since 1950 across all areas of Indiana (Fig. 3). When we examine changes in county-level forest land percentages between 1998 and 2008, there appears to be no spatial pattern to either gains or losses (Fig. 4). Twelve counties gained more than 5 percent in forest land area while eight counties lost more than 5 percent over a period of 10 years.

What this means

At the state level, Indiana's forest land area has been gradually increasing since 1967. The number of counties with increases in forest land area over the past 10 years exceeds those with losses. There is no spatial pattern to county-level forest land changes, indicating an absence of concentrated risks to Indiana's forest land base. Given the relatively large sampling errors associated with the inventory at sub-state scales, care should be given to monitoring forest land area changes at these scales especially given the impact that land use change has on all of Indiana's forest resources.

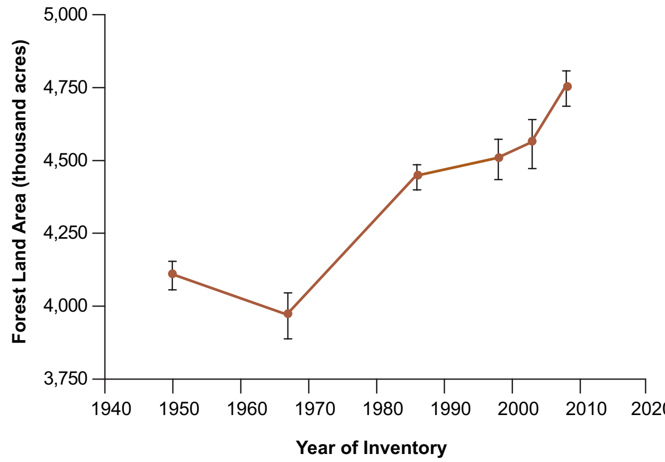


Figure 2.—Total forest land area and associated sampling errors, Indiana, 1950-2008.

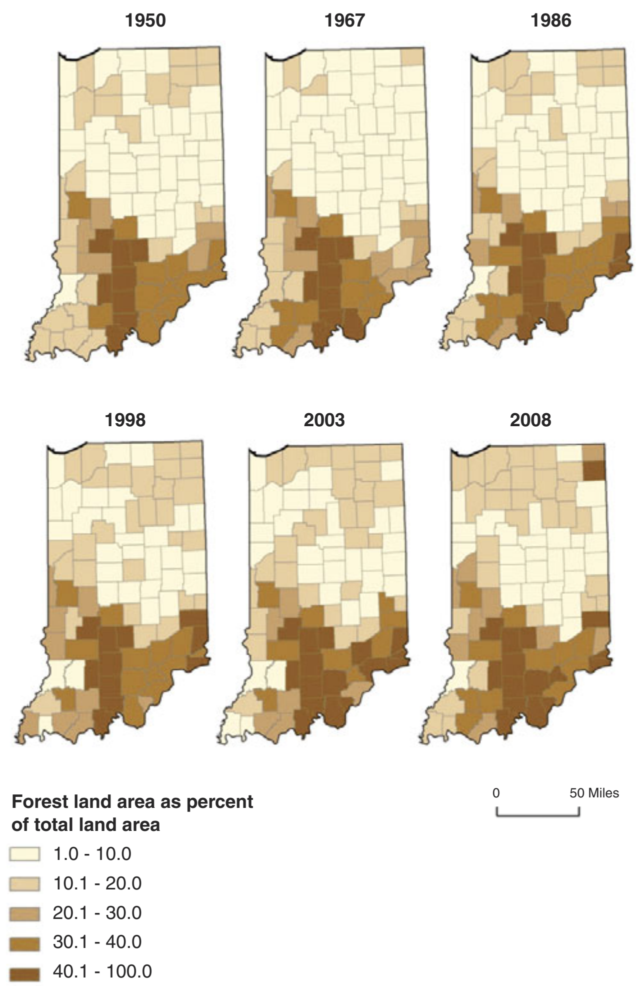


Figure 3.—County-level forest land area as a percent of total land area for completed statewide inventories, Indiana, 1950-2008.

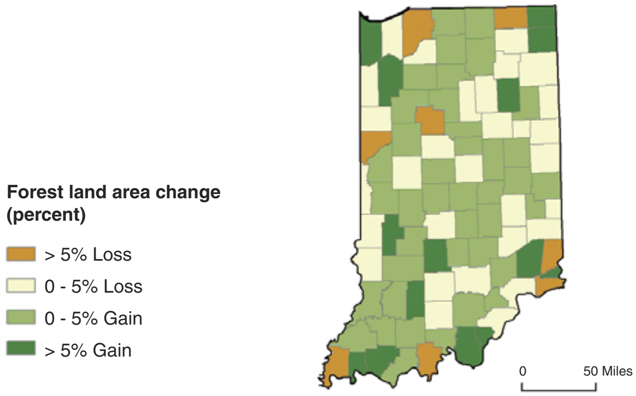


Figure 4.—Change in forest land area as a percentage of total land area by county between 1998 and 2008, Indiana.

Land Use Change

Background

Indiana's land base is not static through time; instead, the use and condition of each acre of Indiana's land ebbs and flows. Although Indiana's forest land area may appear stable through time, in reality it represents the "net" difference between additions and diversions of forest land. Just as one acre of forest land may be converted to a suburban development, another acre of agricultural land may revert to forest land. Assessing trends in land use and inferring effects on forest resources are critical to holistically monitoring the sustainability of statewide forest resources.

What we found

Most (92 percent) forest land in 1999-2003 remained in the forest land condition in 2004-2008 (Fig. 5). Only an estimated 80,000 acres of forest land diverted to nonforest in 2004-2008, while about 385,000 acres of nonforest reverted to forest. The average annual removals of growing-stock volume on timberland can be either classified as a harvest removal or other removals, which include both forest land diverted to nonforest and forest land re-classified as "reserved." The ratio of average annual harvest to average annual other removals was relatively static between 1999-2003 and 2004-2008 at 4.0:1.0 (Figs. 6A, B). However, the level of total removals decreased by approximately 40 percent from 2003 to 2008. The specific forest-type groups that had the highest conversion from a forest land use between 1999-2003 and 2004-2008 were oak/hickory at more than 40,000 acres followed by elm/ash/cottonwood at approximately 15,000 acres (Fig. 7).

What this means

Examining the matrix of Indiana's land use changes over the past 10 years indicates that Indiana has a rather stable forest land base. Indeed, many acres of Indiana's forest land were converted to nonforest uses. However, Indiana's total forest land base has continued to steadily increase as the result of nonforest land reverting to forest land use over the past 10 years. For every acre of forest land lost to nonforest conversion, approximately 5 more new acres were added to the forest land base. The loss of growing

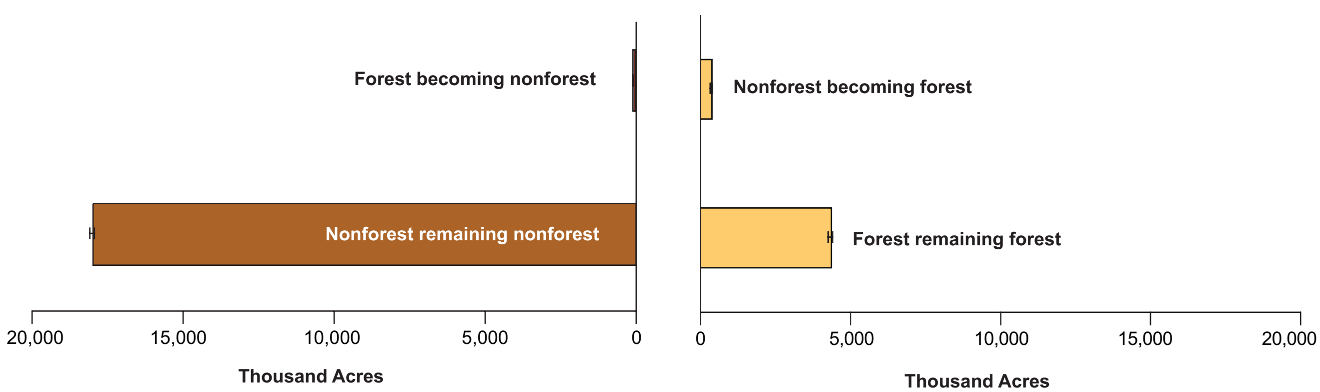


Figure 5.—Land use status and change, Indiana, 1999-2003 to 2004-2008.

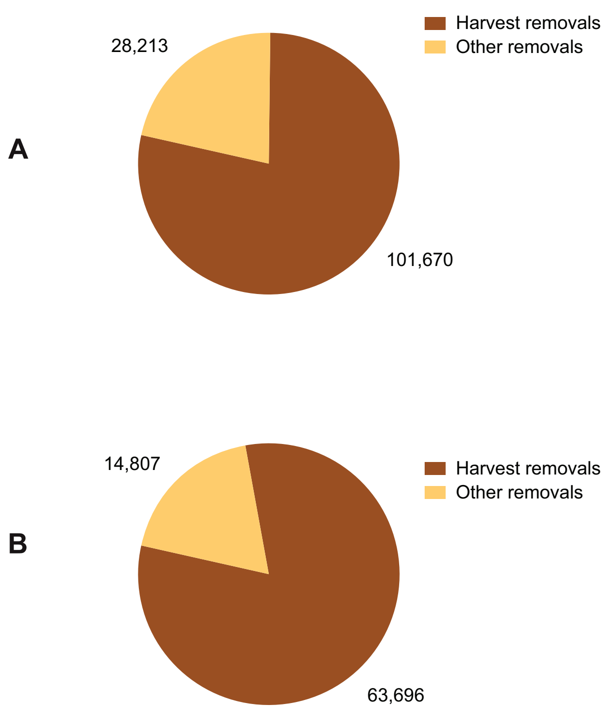


Figure 6.—Average annual removals of growing-stock volume (thousand cubic feet) on timberland by "harvest" and "other," Indiana, (A) 1998 to 1999-2003, (B) 1999-2003 to 2004-2008.

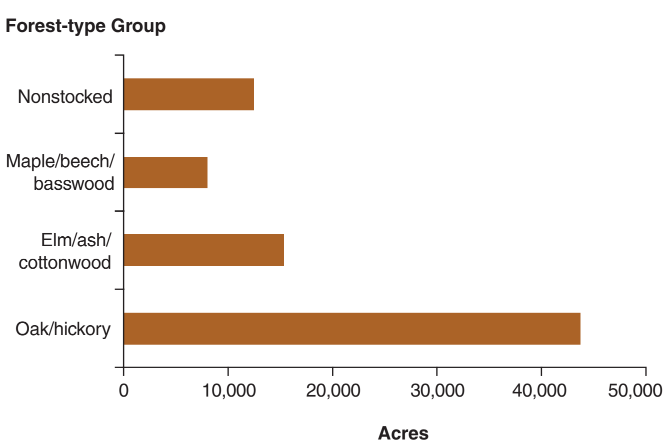


Figure 7.—Total acres of forest land in 1999-2003 by forest-type group that changed to a nonforest land use in the measurement period 2004-2008, Indiana (Note: sampling errors all exceed 100 percent).

stock volume due to land use conversion was just a fraction of the utilization of growing stock through harvest. The most common forest types across Indiana, such as oak/hickory, demonstrated some of the highest rates of forest diversions. Given the consistent increase in the State's total forest land area and reasonable fluctuations in Indiana's land use change matrix, the conservation of Indiana's forest land area appears to be successful.

Whose Woods Are These?

Background

From the Hoosier National Forest in the southern part of the State to a family with a few acres outside of Gary, forest ownership varies dramatically across Indiana (Figs. 8, 9). These ownership patterns are important because it is the owners who ultimately control the forest resources and ultimately decide if forests will stay forests and if so, if and how they will be managed. This dominant, most diverse, and dynamic group of owners is the one we understand the least – families, individuals, and other unincorporated groups that we collectively refer to as "family forest owners." By understanding more about these owners, we can better help them meet their needs, and in so doing, help conserve the forests for generations to come.

What we found

A total of 218,000 family forest owners control 75 percent of the forest land in Indiana. To better understand who these people are, why they own forest land, and how they use it, the Forest Service conducts the National Woodland Owner Survey (Butler 2008). According to the results of this survey, the average size of the forested holdings of these owners is 16 acres (Fig. 10), a reduction of 27 percent since 1993. The primary reasons for owning forest land are related to aesthetics, privacy, and the land as part of their home (Fig. 11). Although timber production is not a major ownership objective, 51 percent of the family forest land is owned by people who have commercially

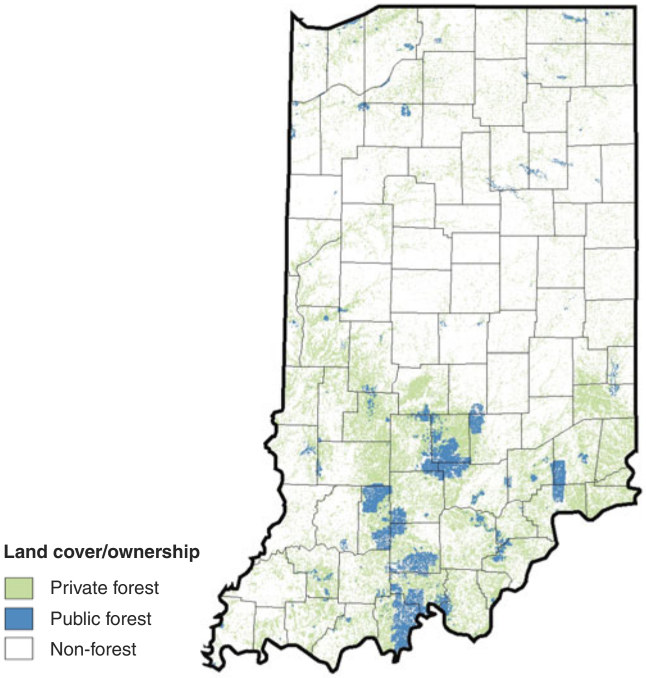


Figure 8.—Private and public forest owners in Indiana.

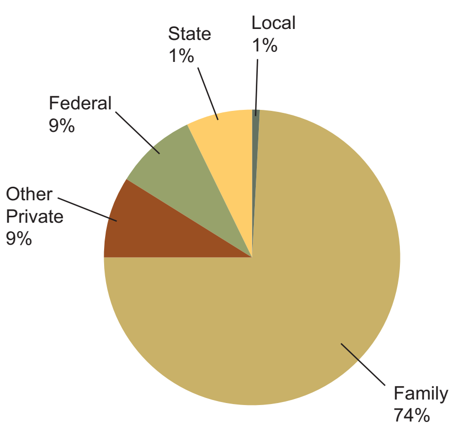


Figure 9.—Distribution of forest land by public and private ownership, Indiana, 2004-2008.

harvested trees. Less than 10 percent of the land is owned by people who have a written management plan, and less than a third of these owners have received forest management advice. The owners' major concerns are related to family legacy, property taxes, and trespassing. Although most family forest owners plan to do little or nothing with their land in the next 5 years, 1 in 3 acres is owned by someone who plans to harvest firewood, 1 in 6 by someone who plans to harvest timber, and 1 in 8 by someone who plans to pass the land onto heirs or sell it.

What this means

The average parcel size is decreasing and much land will soon be changing hands. Family legacy is a major ownership objective: passing land on is a major planned activity, but family legacy is also a major concern. Landowner turnover is something that is perpetually happening, but it is also a critical juncture for the owners and the land. What can be done to help the landowners and the land? It is clear that timber production is not on the forefront of landowners' minds, but it is also clear that many landowners are not adverse to harvesting and other activities in the woods. How can natural resource professionals better communicate with family forest owners and help them better manage their woods? As Indiana's forest is diverse, so too are the people who own it. It is important to provide programs that meet the landowners' needs. General statistics are good for a broad overview, but we need to better understand the different types of owners, their attitudes, and their behaviors, as well as effective and efficient ways of communicating with them (www.engaginglandowners.org).

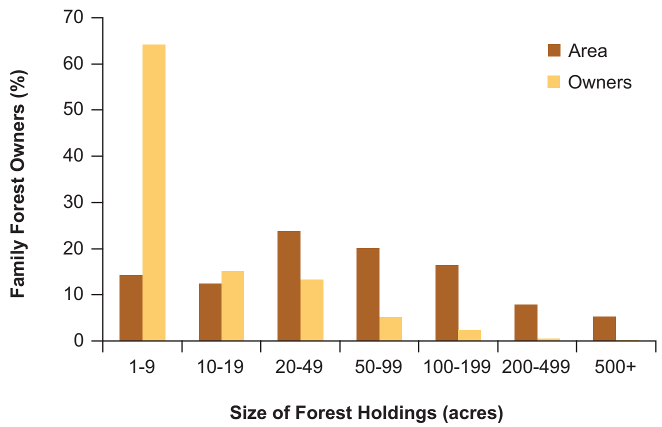


Figure 10.—Area and number of family forests in Indiana by size of forest landholdings, Indiana, 2004-2008.

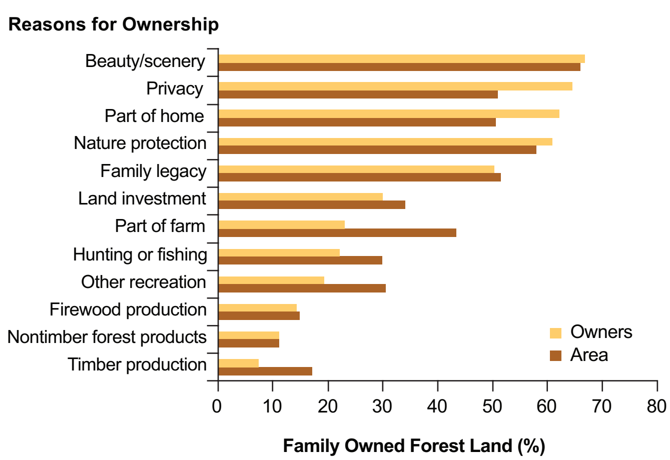


Figure 11.—Percentage by area and number of family forests in Indiana by reason for owning forest land, Indiana, 2004-2008. (Note: Numbers include landowners who ranked each objective as very important (1) or important (2) on a seven-point Likert scale. Categories are not exclusive.)

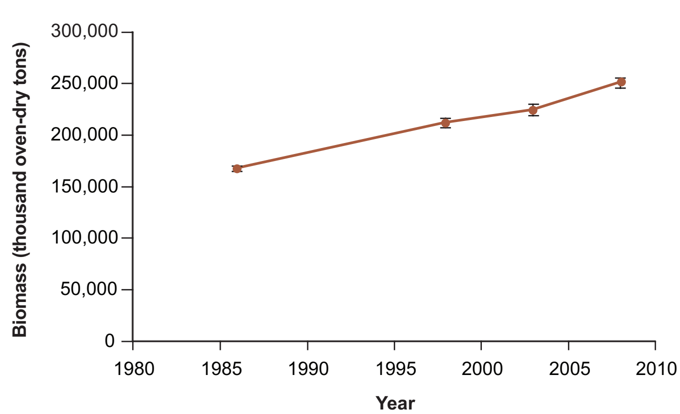


Figure 12.—Live-tree and sapling biomass (oven-dry tons) on timberland, Indiana, 1986 and 2004-2008.

Forest Biomass

Background

As with measures of Indiana's forest acreage, measuring total biomass and its allocation among stand components, e.g., small-diameter trees, limbs, stumps, helps us understand the components of a forest stand and the resources available for different uses (e.g., wildlife habitat, carbon sequestration, or biofuels).

What we found

The quantity of live biomass on timberland has increased at a steady rate since 1986, reaching a total of about a quarter of a billion oven-dry tons (Fig. 12). Most of the forest biomass is in growing-stock tree boles (62 percent) followed by growing-stock tree stumps, tops, and limbs (22 percent), and non-growing-stock tree boles (8 percent) (Fig. 13). Although the distribution of forest biomass across Indiana is highly correlated with occurrence of forest area, the largest quantities of forest biomass can be found in the highlands of south-central Indiana (Fig. 14).

What this means

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 the carbon cycles and future wood availability. Given the increasing demand to manage forest biomass components for both carbon and bioenergy uses, the monitoring of Indiana's forest biomass becomes even more critical.

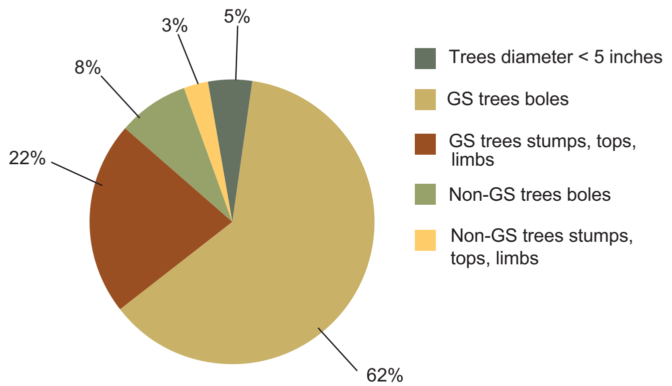


Figure 13.—Forest biomass on timberland by tree component, Indiana, 2004-2008. (Note: GS refers to growing-stock trees while Non-GS refers to non-growing-stock trees greater than 5.0 inches d.b.h.).

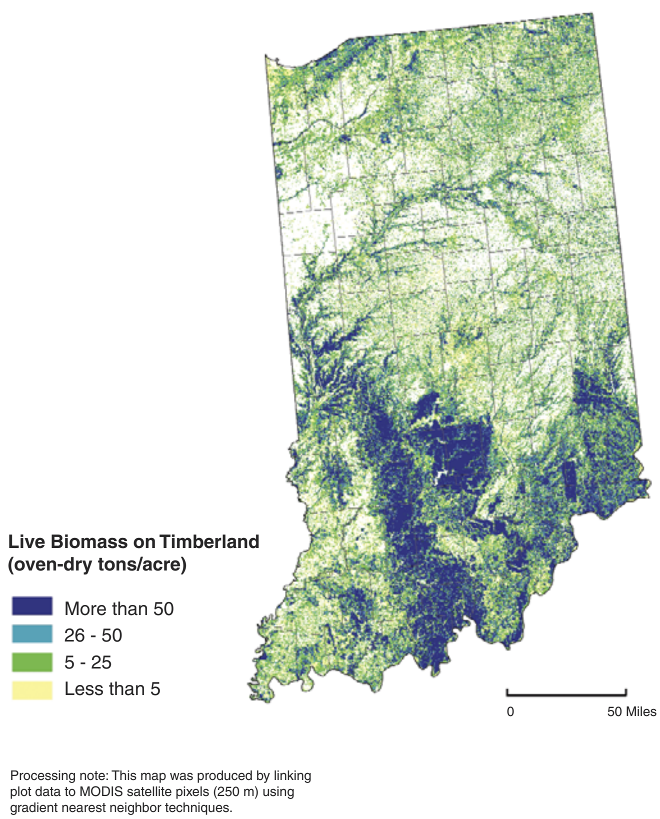


Figure 14.—Distribution of live-tree biomass on timberland, Indiana, 2004-2008.

Tree Species Composition

Background

Forest composition is constantly evolving. Influenced by the presence or absence of disturbances such as timber management, recreation, wildfire, prescribed burning, extreme weather and invasive species, the current state of species composition reflects historical and environment trends. As a result, the composition of species in a forest is an indicator of forest health, growth, succession, and need for stand improvement, i.e., management. Knowledge of the distribution of species allows for the measurement and prediction of change.

What we found

In terms of the total number of trees statewide on forest land in 2004-2008, sugar maple was by far the most numerous species with more than 350 million trees (Fig. 15). American elm and black cherry were second and third, respectively. There were no oak or hickory species in the top 12. In terms of the total statewide live-tree volume on forest land, yellow-poplar and sugar maple both dominated the State with more than 1 billion cubic feet (Fig. 16). Numerous oak and hickory species were represented in the top 12 tree species in volume of live trees. For several tree species, there has been tremendous change in growing-stock cubic foot volume on timberland; pin oak, yellow-poplar, red maple, and green ash have doubled their volumes since 1986 (Fig. 17A). In contrast, mockernut hickory and black willow lost roughly 75 and 30 percent of their growing-stock volume on timberland since 1986, respectively (Fig. 17B).

What this means

As evidenced by inventory results, the species composition of Indiana's forests is constantly evolving with some species increasing their dominance while others wane. Although oak/hickory species dominate the State in terms of total volume, they are not represented in the top species according to tree counts, indicating a maturing forest resource with sparse regeneration. This

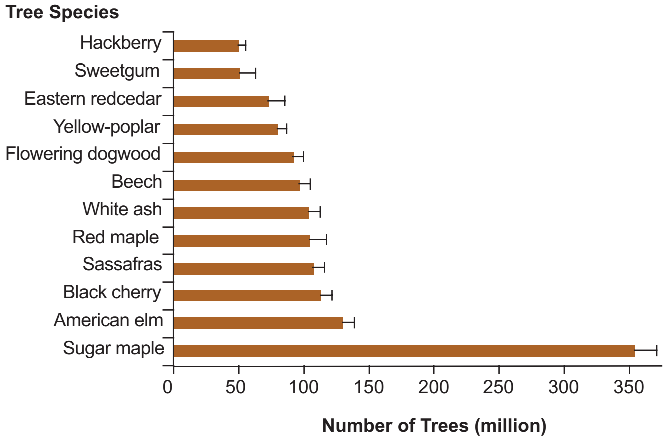


Figure 15.—Top 12 tree species in terms of number (million) of live trees on forest land, Indiana, 2004-2008.

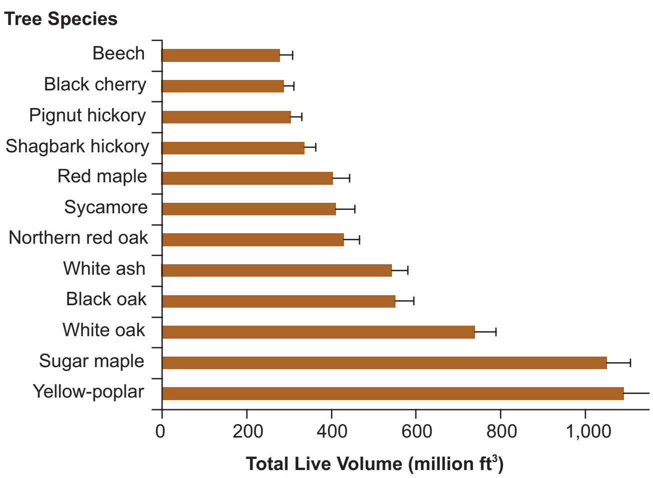


Figure 16.—Top 12 tree species in terms of volume (million cubic feet) of live trees on forest land, Indiana, 2004-2008.

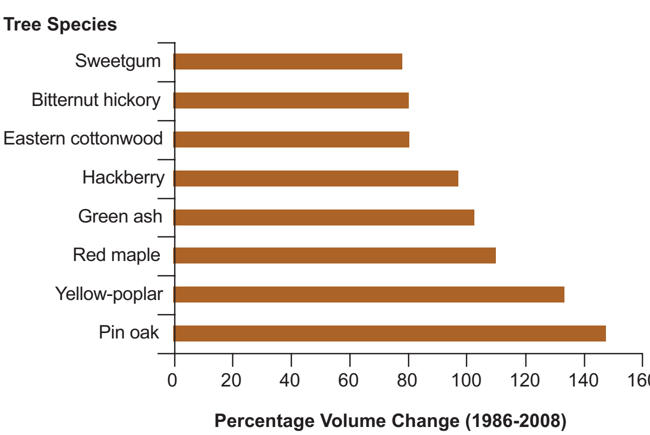


Figure 17A.—The top eight species in terms of percent (A) gain or (B) loss in growing-stock volume between 1986 and 2004-2008 for tree species with at least 25 million cubic feet statewide total volume on timberland in 1986, Indiana.

was further evidenced by mockernut hickory demonstrating the greatest percentage loss in volume statewide. Indiana possesses a great diversity of tree species that will undoubtedly fill niches vacated by other species as forest ecosystems continue to evolve through the decades. Tree species such as yellow-poplar and red maple stand ready to fill voids left by Indiana's maturing oak/hickory forests.

How Thick are The Woods?

Background

The density of a forest indicates the current phase of stand development and has implications for diameter growth, tree mortality, and yield. Density is typically measured in terms of number of trees or basal area per unit area. Relative density, a measure of a forest's current stocking of trees per unit area relative to a maximum (Woodall et al. 2005), represents the degree of tree occupancy required to fully utilize the growth potential of the land.

What we found

The density of Indiana's forests has continued to increase since the first forest inventory in 1950. The number of growing-stock trees per timberland acre continues to decrease, reaching a current statewide average of about 400 trees per acre (Fig. 18). In contrast, the average volume of growing-stock trees on timberland continues to increase, reaching a current statewide average close to 1,900 cubic feet per acre (Fig. 19). The relative density of trees on forest land is not equally distributed across Indiana: the south-central forests are the most highly stocked with lower stocking levels in northern Indiana (Fig. 20).

What this means

The dynamics between the number of trees per acre and average volume per acre presents evidence of a maturing

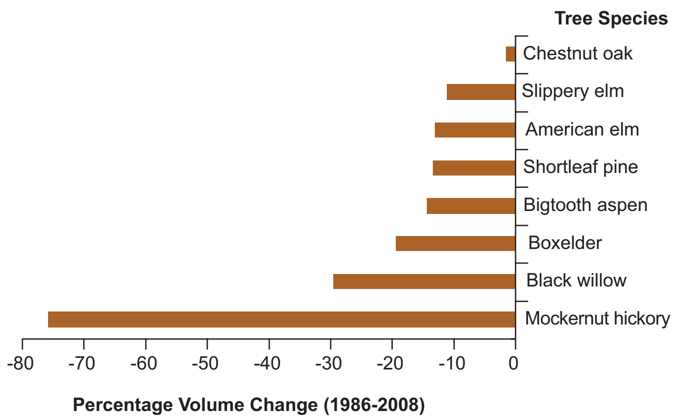


Figure 17B.—The top eight species in terms of percent (A) gain or (B) loss in growing-stock volume between 1986 and 2004-2008 for tree species with at least 25 million cubic feet statewide total volume on timberland in 1986, Indiana.

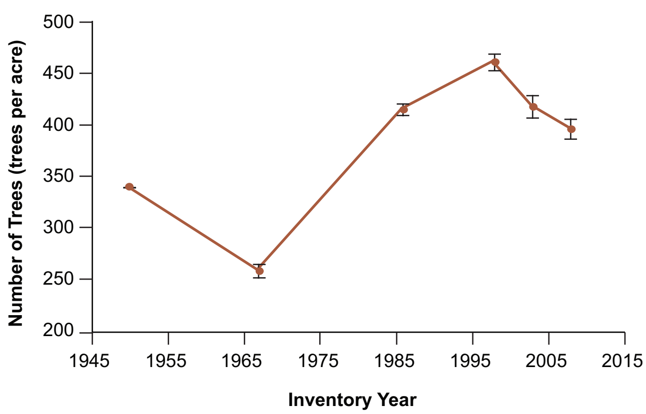


Figure 18.—Average number of growing-stock trees per acre on timberland in Indiana, 1950-2008.

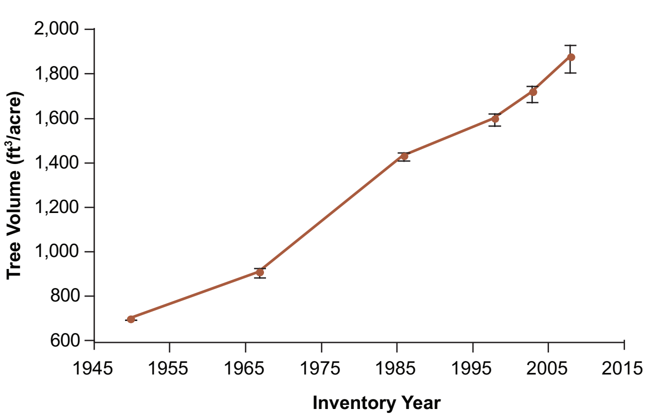


Figure 19.—Average net growing-stock volume per acre of timberland in Indiana, 1950-2008.

forest resource across Indiana. Unless disturbances (i.e., tree mortality/removal) occur, whether human-induced or natural, it should be expected that this trend will continue until stands reach a state of senescence. Since 1950, the average cubic foot volume of growing-stock trees on timberland has nearly tripled, representing tremendous stewardship and conservation of Indiana's forest resources. However, many of Indiana's forests have reached relative densities far in excess of full stocking and well into zones of density-induced mortality. It should be expected that as the relative density of Indiana's forests continues to increase that stand stagnation issues (e.g., lack of regeneration and mortality of mature/overstory trees) will arise.

Forest Growth: Upward and Onward

Background

A stand's capacity for growth, i.e. for trees to increase in volume, is an indication of the overall condition of the forest and more specifically of tree vigor, forest health, and successional stage. Forest growth is measured as average annual net growth, where net growth is equivalent to gross growth minus mortality. Average annual net growth represents an average for the annual change in volume between the two most recent inventories, 1999 to 2003 and 2004 to 2008 for this report.

What we found

The average annual net growth of growing-stock trees on Indiana's timberland has increased steadily since 1967, reaching a current zenith of approximately 325 million cubic feet per year (Fig. 21). Yellow-poplar, other eastern soft hardwoods, and hard maple were the top three species groups in terms of average annual net volume growth; yellow-poplar had growth in excess of 50 million cubic feet per year statewide (Fig. 22). The average annual net growing-stock growth on timberland as a percent of total

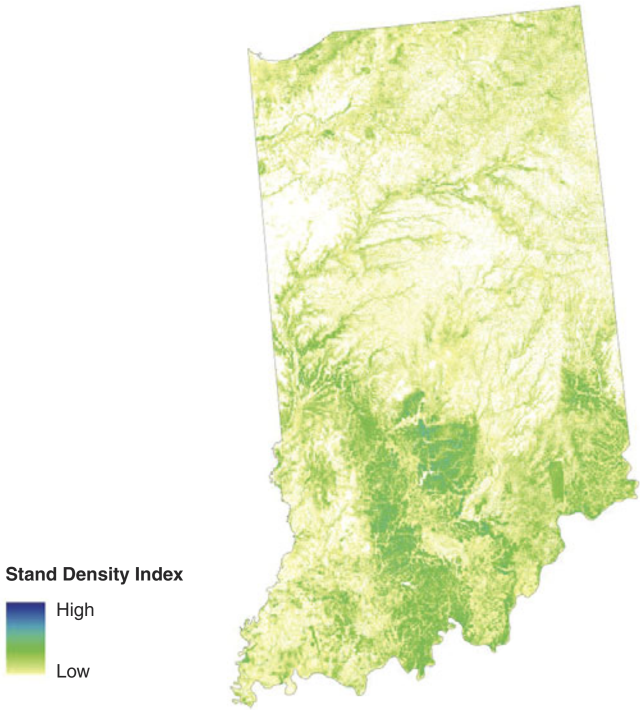


Figure 20.—Relative density of forest land in Indiana, 2004-2008.

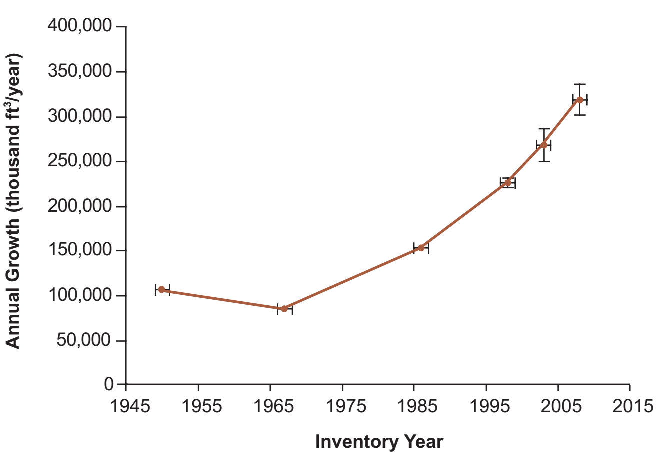


Figure 21.—Average annual net growth of growing stock on timberland acreage in Indiana, 1950-2008.

growing-stock volume reveals almost all species groups are below 0.05 (Fig. 23). Basswood, yellow-poplar, and black walnut were the top three species in terms of average annual net volume growth per total species group volume with a 4- to 5-percent increase in its total volume per year.

What this means

The net growth of Indiana's forests continues to increase at a steady rate indicating an overall sustainable resource. Many of the economically desirable tree species, such as oaks, walnuts, and hickories, continue to accrue tremendous yearly growth. However, when annual growth is viewed relative to the total growing-stock volume on timberland, many tree species are increasing their total statewide volumes at faster rates than oaks and hickories. Other red oaks are currently increasing their total volumes at approximately 3.5 percent per year while yellow-poplar is increasing its statewide volumes in excess of 5 percent per year. Given the disparities in species growth rates, it should be expected that oaks and hickories will eventually not be in the top 10 in terms of total statewide average annual net growth.

Tree Mortality: What Grows Up, Eventually Comes Down

Background

Forest health, vigor, and rate of accretion and depletion are all influenced by tree mortality. Mortality can be caused by insects, disease, adverse weather, succession, competition, fire, old age, or human or animal activity, and is often the result of a combination of these factors. Tree volume lost as a result of land clearing or harvesting is not included in mortality estimates. Growing-stock mortality estimates represent the average cubic foot volume of sound wood in growing-stock trees that died each year as an average for the years between inventories, 1999 to 2003 and 2004 to 2008.

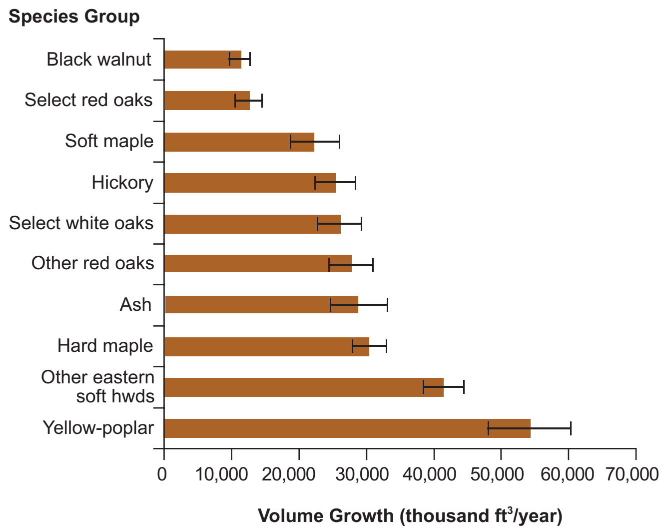


Figure 22.—Top 10 species groups in terms of average annual net growing-stock volume growth on timberland in Indiana, 2004-2008.

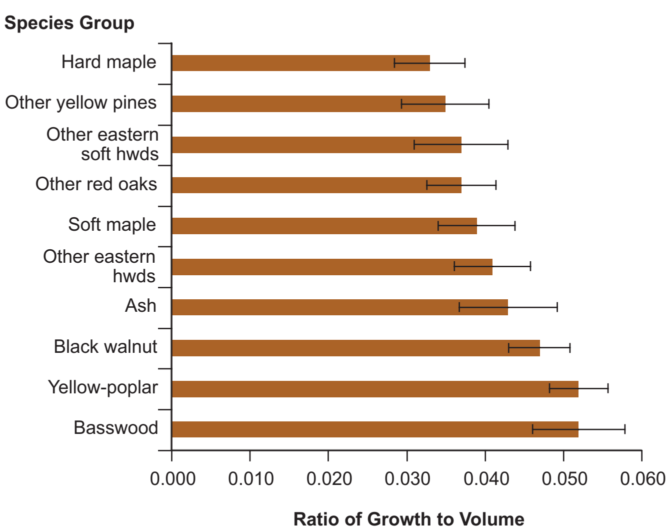


Figure 23.—Top 10 species in terms of average annual net volume growth expressed as a percent of total growing-stock volume on timberland in Indiana, 2004-2008.

What we found

The average annual growing-stock volume mortality on Indiana's timberland has leveled off since 1998 indicating a decade of stable forest mortality (Fig. 24). In terms of total statewide average annual mortality, the "other eastern soft hardwoods" species group had the greatest mortality in excess of 20 million cubic feet (Fig. 25). Other species groups with notable average annual mortality loss were ash and hickory. Another metric indicative of mortality is total growing-stock volume mortality on timberland as a percent of the total statewide growing-stock volume on timberland. The cottonwood/aspen species group had the highest mortality ratio, in excess of 0.2, indicating a yearly loss of approximately 2 percent of the total statewide volume (Fig. 26). All other species groups had mortality ratios below 0.02.

What this means

The levels of tree mortality across Indiana have stabilized over the last decade. Mortality is a natural process in forest stands as they develop and change over time. Because no single species group has lost more than 2.5 percent of its total growing-stock volume on timberland per year, it appears that no single species is suffering from poor health or substantial decline. Tree mortality is a crucial component of overall forest health and thus should be monitored into the future.

Tree Removals

Background

Trees are removed from timberland to meet a variety of management objectives or land use changes. Changes in the quantity of growing stock removed help to identify trends in land use change and forest management. Because removals are generally recorded on a limited number of plots, the estimates for removals show greater variance than those for growth, mortality, or area. Like forest growth, the rate at which trees are removed represents the average

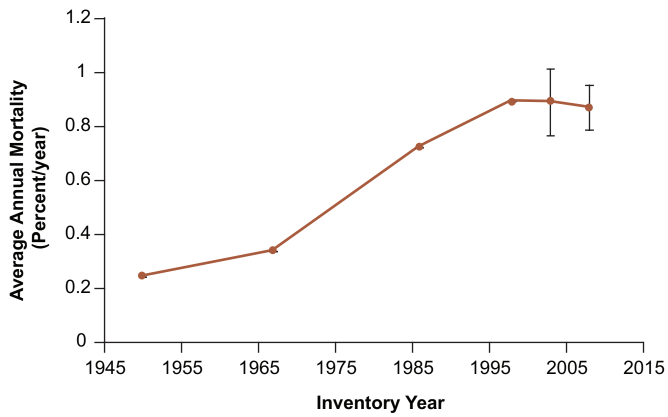


Figure 24.—Average annual net growing-stock volume mortality by total statewide growing-stock volume on timberland in Indiana, 1950-2008.

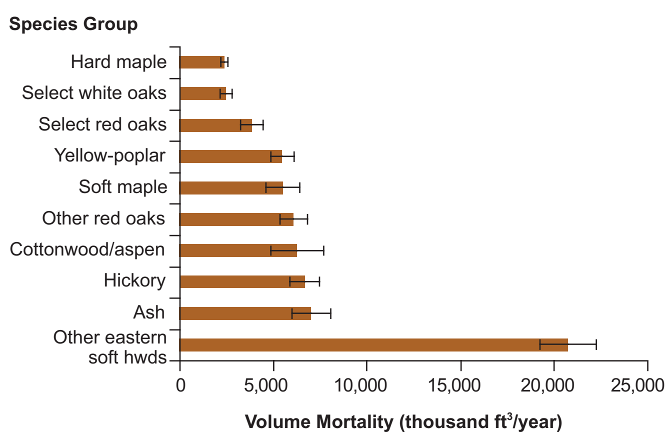


Figure 25.—Top 10 species groups in terms of average annual net growing-stock volume mortality on timberland in Indiana, 2004-2008.

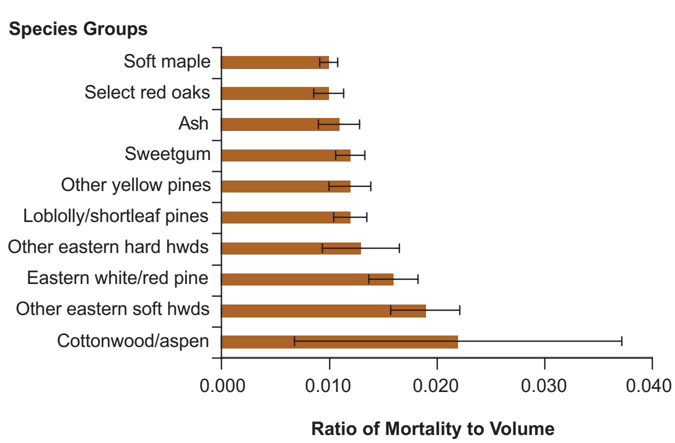


Figure 26.—Top 10 species in terms of average annual net growing-stock volume mortality as a percent of total growing-stock volume on timberland in Indiana, 2004-2008.

annual growing-stock removals that occurred between 1999-2003 and 2004-2008.

What we found

Since 1967 there has been a gradual trend toward decreasing growing-stock removals on Indiana's timberland (Fig. 27). Average annual growing-stock removals as a percent of total statewide volumes was approximately 1.8 between 1950 and 1967. Between 2004 and 2008, this same ratio decreased dramatically to approximately 0.9. Most of the removals were focused on other eastern soft hardwoods, hard maple, select white oaks, and other red oaks species groups; all of these groups had removals in excess of 8 million cubic feet per year (Fig. 28). Average annual growing-stock removals as a percent of total statewide volumes indicated that basswood, other eastern hardwoods, select white oaks, and other red oaks had the highest rate of removals relative to total statewide volumes, although only a little over 1 percent per year (Fig. 29).

What this means

Removal rates are indicative of both harvest and land use change. The rates of removal for all species groups (about 1 percent per year or less) are far below that of mortality (less than 2 percent per year). In addition, net growth typically averages greater than 3 percent for common species groups. From a statewide viewpoint, it appears as though removals are in balance with forest growth and mortality such that total volumes continue to increase. However, this may not be the case at small scales (e.g., county) or for specific species (e.g., shortleaf pine). In these cases, removal rates should be monitored and evaluated on a case-by-case basis.

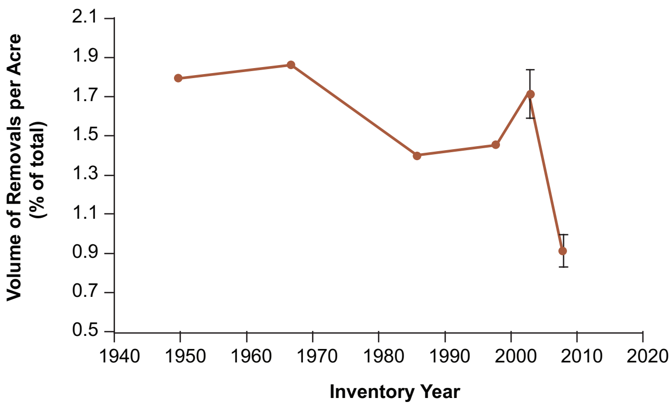


Figure 27.—Average annual removals of growing stock as a percent of total statewide growing-stock volume on timberland in Indiana, 1950-2008.

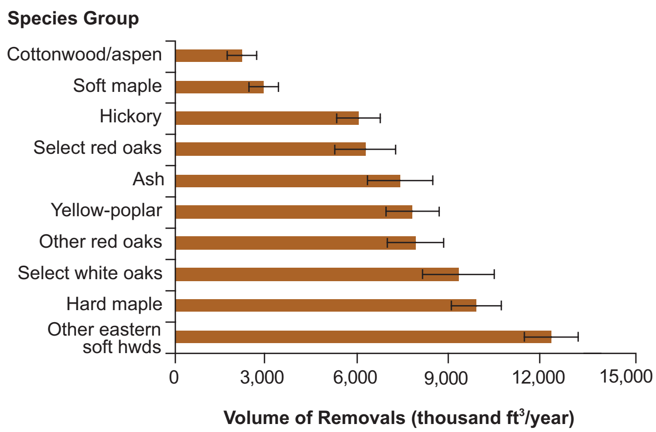


Figure 28.—Top 10 species groups in terms of average annual net growing-stock volume removals per acre of timberland in Indiana, 2004-2008.

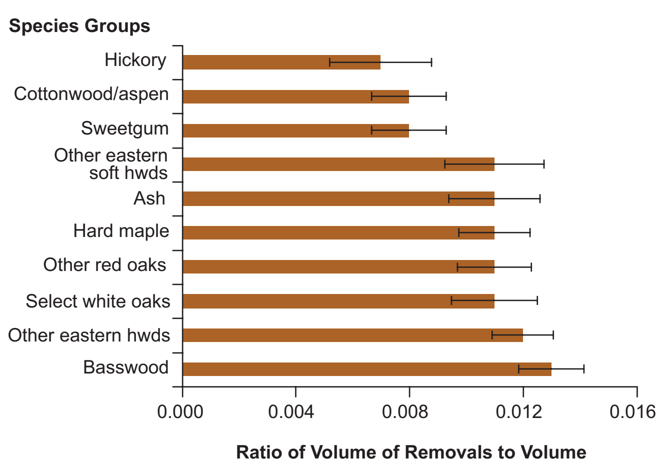


Figure 29.—Top 10 species in terms of average annual net volume removals as a percent of total growing-stock volume on timberland in Indiana, 2004-2008.

Forest Patterns

Background

The fragmentation of forest land areas continues to be a major ecological issue worldwide. Fragmentation is the process by which contiguous tracts of forest land are broken down into smaller, more isolated forest patches surrounded by nonforest land uses such as agriculture or urban development. Furthermore, fragmentation results in a loss of interior forest conditions and an increase in edge habitat, which has many negative effects on the remaining vegetation and interior forest dwelling wildlife species, including the loss of native species and increased populations of nonnative invasive species.

What we found

National Land Cover Dataset (NLCD) imagery from 2001 (Vogelmann et al. 2001) was reclassified to create a six-class land cover map of Indiana (Fig. 30). Using this map, we characterized forest pixels according to their location in relation to developed edges, or edges due to urban development, agriculture, or barren land uses. Environmental differences at the forest edge, also referred to as edge effects, can penetrate a forest patch for tens of meters (Collinge 1996). A commonly used threshold for edge effects is 100 to 300 ft, or approximately 30 to 90 m, after which interior forest conditions begin (Riemann et al. 2009). Using the high end of 90 m, we classified forest pixels as being within 90 m of a developed edge or greater than 90 m from a developed edge (Fig. 31). According to this analysis, more than half (58%) of Indiana's forest land is subject to edge effects and lacks interior forest conditions.

What this means

Overall, forest makes up approximately one-fifth of Indiana's land base. How this forest land is arranged across the landscape affects ecological processes. Based on the map pixel analysis, more forest was classified as edge than interior forest, indicating that the forest land in Indiana is

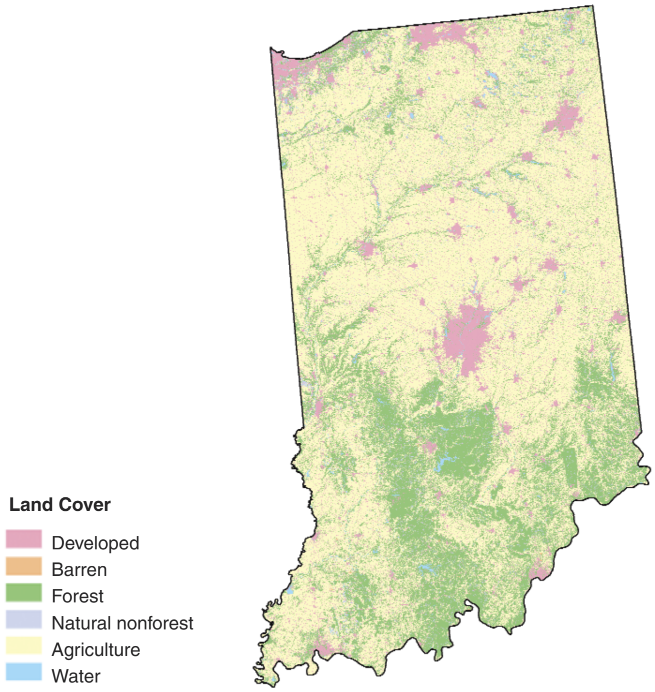


Figure 30.—Indiana land cover derived from National Land Cover Dataset 2001.

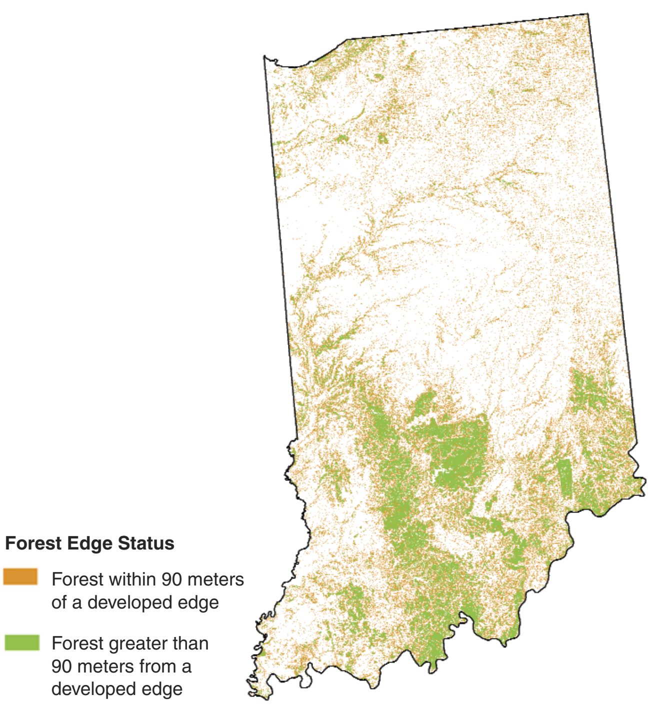


Figure 31.—Map of forest edge status derived from National Land Cover Dataset classification, Indiana, 2001.

heavily fragmented. Almost all fragmentation is due to agriculture and development (Figs. 30 and 31). The majority of the interior forest land is in the southern half of the State while other areas with interior conditions can be found along major rivers. These areas of continuous forest habitat are critical for maintaining biodiversity and healthy populations of native plants and wildlife. On the other hand, the remaining forest patches containing mostly edge habitat are highly susceptible to invasion by nonnative invasive species, resulting in a loss of native species in addition to other negative effects.

Snags

Background

Standing dead trees (snags) are important indicators of wildlife habitat, structural diversity, past mortality events, and carbon storage. The number and density of such trees, together with decay classes, species, and sizes, define the snag resource across Indiana's forests.

What we found

Between 2004 and 2008, FIA collected data on standing dead trees of numerous species and sizes in varying stages of decay. According to the inventory data, the greatest number of the estimated 53 million snags were present in the oak/hickory forest-type group, the most predominant in Indiana (Fig. 32). Among the most common standing dead species were sassafras, American elm, red elm, white ash, sugar maple, white oak, and black oak. Sassafras and American elm dominated other species, comprising 28 percent of all dead trees (Fig. 33). The majority of snags were between 5 and 6.9 inches in d.b.h. (Fig. 34). That is, the numbers of smaller diameter snags substantially exceeded those of larger diameter. Compared to larger dead trees, snags of smaller diameter tended to have less advanced decay; a decay class of three was most prevalent across standing dead trees of all sizes.

What this means

Among possible reasons for occurrence of snags in Indiana forests are diseases and insects, weather damage, fire, flooding, drought, and competition. The dominance of sassafras and American elm snags in particular might be accounted for by diseases such as Nectria canker (of fungal origin) and Dutch elm disease. Additionally, normal forest maturation dynamics may be responsible for large mortality rates in the population of these two species. Smaller trees and certain early-successional species suffer competition-induced deaths, ensuring gap succession (creation of small openings through tree mortality), which is an important part of a mature forest. Once dead, snags provide areas for foraging, nesting, roosting, hunting perches, and cavity excavation for wildlife, from primary colonizers such as insects, bacteria, and fungi to birds, mammals, and reptiles. The Indiana bat (*Myotis sodalis*), one of only two species designated as state and federally endangered species, roosts primarily in the cavities and under exfoliating bark of snags of many hardwood species abundant in the oak/hickory forest type.

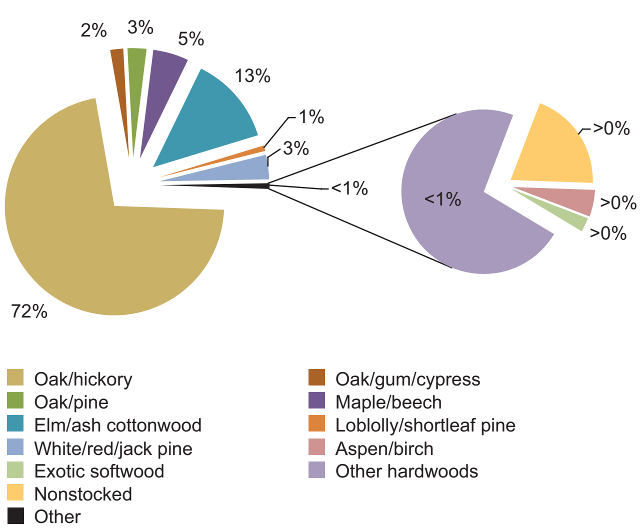


Figure 32.—Distribution of standing dead trees by forest-type group, Indiana, 2004-2008.

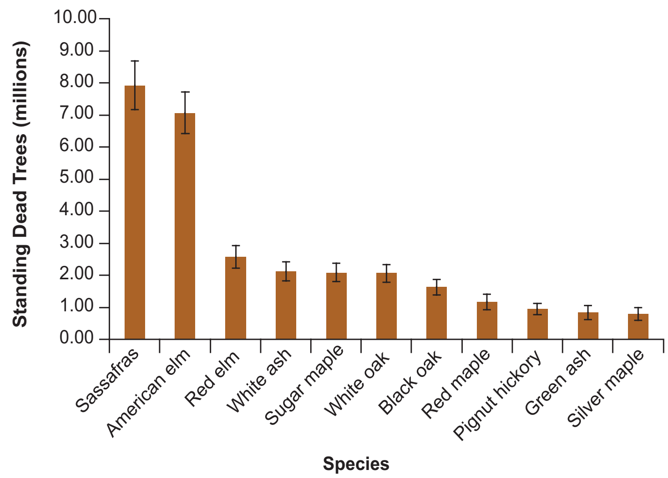


Figure 33.—Number of standing dead trees for the 11 most common standing dead tree species, Indiana, 2004-2008.

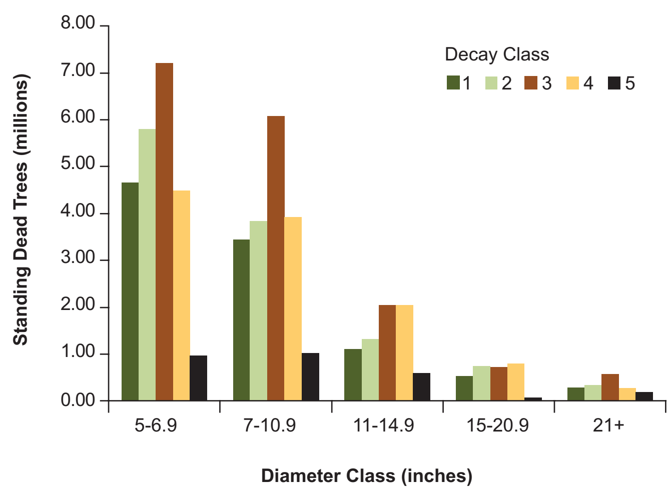


Figure 34.—Distribution of standing dead trees by decay and diameter classes for all dead trees in Indiana, 2004-2008 (decay class 1= least decayed, decay class 5 = most decayed).

Forest Indicators

Towering trees reach for sunlight. Photo used with permission of Indiana Dept. of Natural Resources.

Crown Conditions

Background

Crown condition is an indicator of general tree health. Vigorous tree growth is associated with full, dense crowns (Schomaker 2003). Conversely, sparse crowns suggest poor growth conditions resulting from disturbances such as disease, insect activity, and adverse weather, or from unfavorable site conditions such as nutrient deficiency, overcrowding, and moisture stress or excess. Three components of crown condition are crown density, crown dieback, and sapling crown vigor. Crown density is an estimate of crown fullness and represents the amount of foliage, branches, and reproductive structures that block light through the crown (U.S. For. Serv. 2007a). Dieback is a measure of twig and branch mortality within the crown. Sapling crown vigor is an estimate of the crown condition and health of saplings. Crown vigor is based on estimates of crown ratio, dieback, and condition of foliage (U.S. For. Serv. 2007a).

What we found

The frequency distribution of crown dieback in Indiana's tree crowns is dominated by the 0- to 5-percent class (Fig. 35). This represents a very low level of crown dieback. From 1999-2003 to 2004-2008, the frequency distribution of crown dieback was stable. The frequency distribution of tree crown density across Indiana is normally distributed around 36 to 45 percent (Fig. 36). Crown density percentages of this level are reasonably healthy, although there has possibly been a slight shift toward less dense crowns over the last 10 years. The crown vigor of tree saplings for both oak/hickories and all other hardwoods is dominated by healthy crowns with no apparent differences between the two species groups (Fig. 37).

What this means

The overall health of tree crowns across Indiana appears stable, as indicated by low levels of crown dieback and moderate levels of crown density. Because the condition of

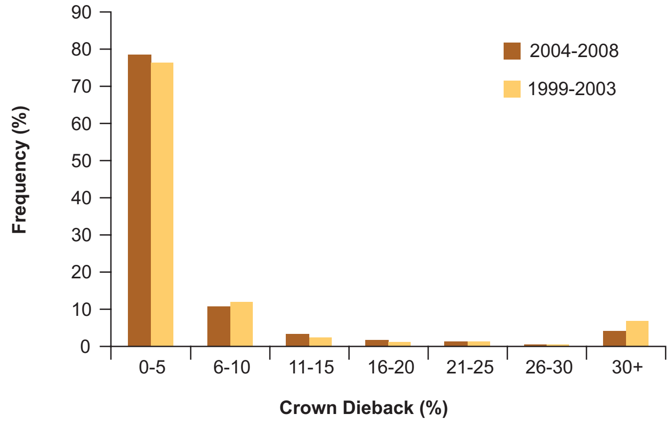


Figure 35.—Crown dieback frequency distribution, Indiana, 1999-2003 and 2004-2008.

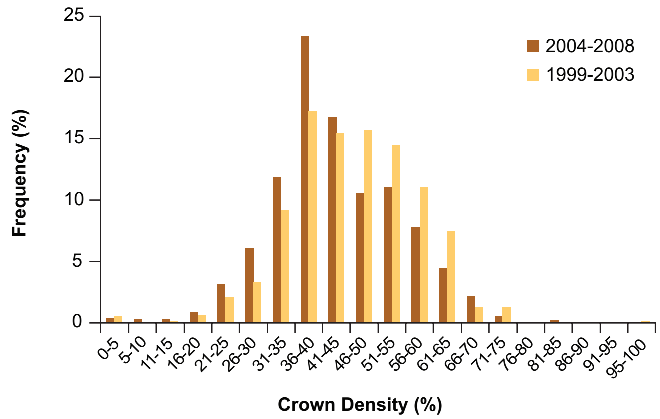


Figure 36.—Crown density frequency distribution, Indiana, 1999-2003 and 2004-2008.

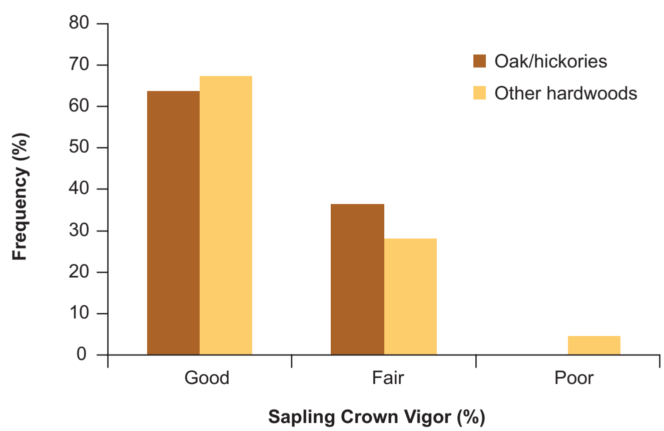


Figure 37.—Crown sapling vigor for oaks/hickories and all other hardwoods, Indiana, 2004-2008.

tree crowns is often the first indicator of impending forest health issues, a logical conclusion may be drawn that Indiana's individual tree health is good. Given the relatively sparse tree crown sample size, specific conclusions on individual species or infrequent species groups cannot be made. Despite the lack of any large-scale forest health crisis, the condition of Indiana's tree crowns should continue to be monitored to assess effects of smaller scale forest health issues (e.g., emerald ash borer and oak decline) on Indiana's total forest land area.

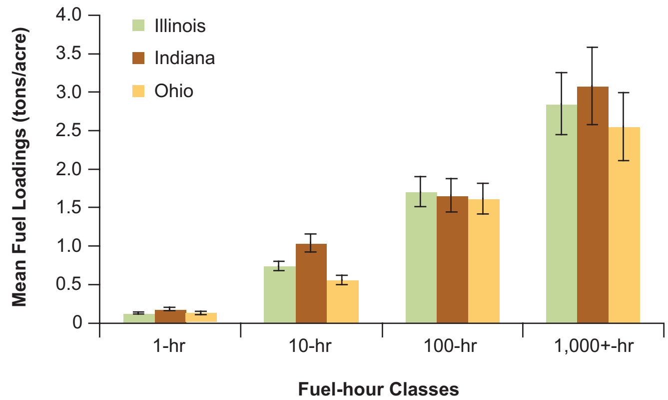


Figure 38.—Estimates of mean fuel loadings by fuel-hour class on forest land for Indiana, Illinois, and Ohio, 2003-2006.

Down Woody Materials

Background

Down woody materials, including fallen trees and branches, fill a critical ecological niche in Indiana's forests. They provide valuable wildlife habitat in the form of coarse woody debris and contribute to forest fire hazards via surface woody fuels.

What we found

The fuel loadings and subsequent fire hazards of dead and down woody material in Indiana's forests are relatively low and commensurate with the neighboring states of Illinois and Ohio (Fig. 38). The size distribution of coarse woody debris (diameter larger than 3 inches) is overwhelmingly dominated (73 percent) by pieces less than 8 inches in diameter (Fig. 39A). Moderately decayed coarse woody pieces (decay classes 2 and 3) constituted 75 percent of the decay class distribution (Fig. 39B). The carbon stocks of coarse woody debris appear to increase with increasing standing live-tree basal area (BA) on Indiana's forest land to a peak of nearly 2.5 tons/acre of carbon in fully stocked stands (Fig. 40). The ground cover provided by coarse woody debris generally increases as standing live-tree basal area increases to a peak of over 800 square feet/acre (approximately 2 percent coverage of 1 acre) in fully stocked stands (Fig. 41).

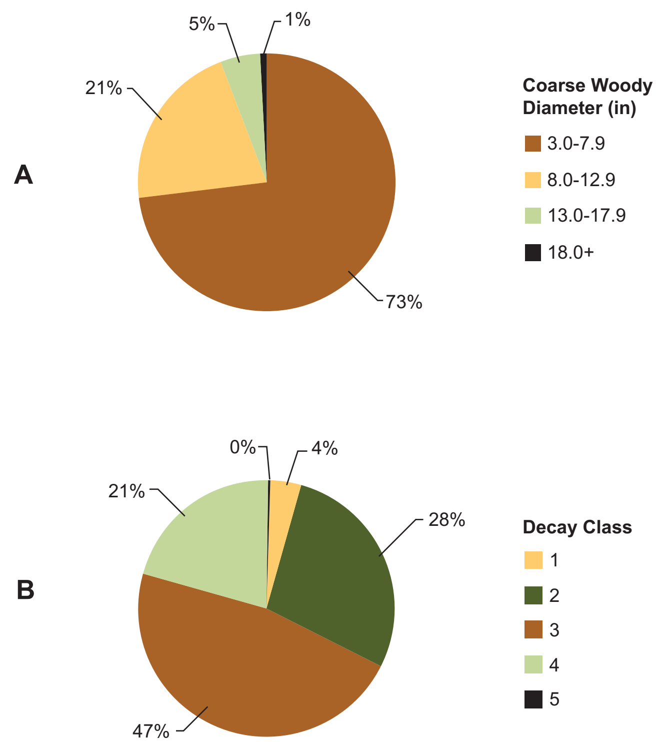


Figure 39.—Mean distribution of coarse woody debris (pieces per acre) by (A) large-end diameter and (B) decay class, Indiana, 2003-2006.

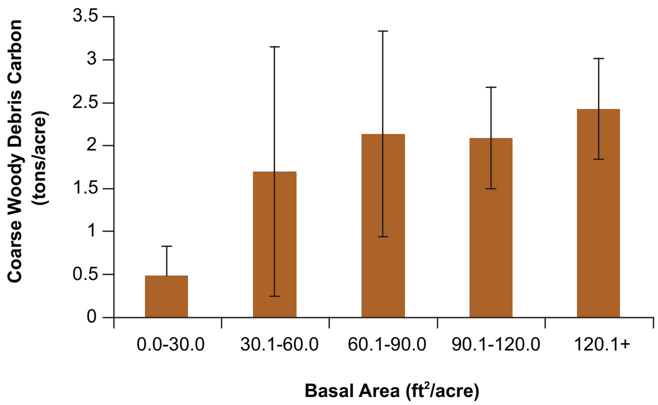


Figure 40.—Estimates of mean coarse woody debris carbon stocks by stand live-tree basal area on forest land, Indiana, 2003-2006.

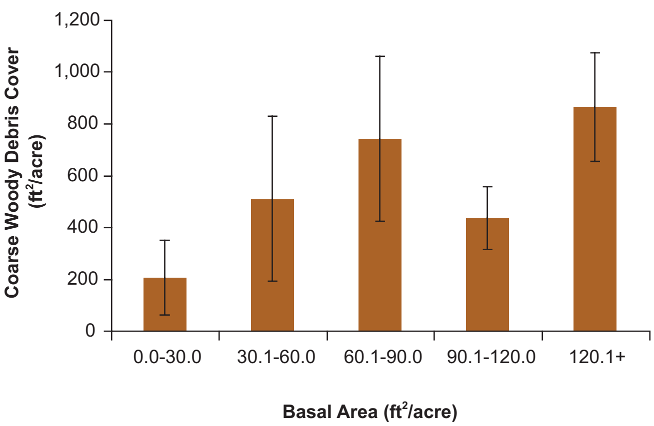


Figure 41.—Estimates of mean coarse woody debris ground cover by stand live tree basal area on forest land, Indiana, 2003-2006.

What this means

The fuel loadings of downed woody material can be considered a forest health hazard only in times of drought or in isolated stands with excessive tree mortality. The ecosystem services (e.g., habitat for fauna or shade for tree regeneration) provided by down woody materials exceeds any negative forest health aspects. The population of coarse woody debris across Indiana consists mostly of small pieces that are moderately decayed. Due to this, coarse woody debris constitutes a small, albeit important carbon stock across Indiana's forests. Compared to the last annual inventory, the population of down woody materials in Indiana's forests appears stable and provides valuable ecosystem services.

Ozone Damage

Background

Ozone is a naturally occurring component of both the upper and lower atmosphere. Ground-level ozone pollution results largely from industrial processes and automotive engines (U.S. For. Serv. 2007b). As a result, ozone levels are often higher in and downwind of major industrial and urban centers, and in warm temperatures. Elevated concentrations of ground-level ozone can adversely affect forested landscapes, causing direct foliar injury and reduced photosynthetic activity (Coulston et al. 2004). Prolonged exposure to high levels of ozone reduces tree growth, weakens tree defenses (increasing vulnerability to insects and disease), and may lead to changes in forest composition, regeneration, and productivity. Plant response to ozone is monitored using bioindicator plants (biomonitoring) that exhibit increased sensitivity to ambient levels of pollution (Coulston et al. 2003). The use of bioindicator plants provides an indirect measure of air quality, identifying conditions that are favorable for the occurrence of ozone injury.

What we found

Biosite index values can vary widely over individual years due to varying ozone concentrations and distribution across forest landscapes. The yearly trend in biosite index values has decreased for Indiana's forests since the late 1990s and early 2000s (Fig. 42). When comparing 1999-2003 and 2004-2008 for individual bioindicator plants, the same trend emerges, decreasing ozone damage (Fig. 43). Most bioindicator plants had half as much damage in 2004-2008 than in 1999-2003. Blackberry and sweetgum still had the highest levels of damage in 2004-2008. Mean plant injury, a gauge of the relative number of plants that showed any level of ozone damage, decreased substantially from 1999-2003 to 2004-2008; blackberry had about a two-thirds reduction in mean plant injury (Fig. 44).

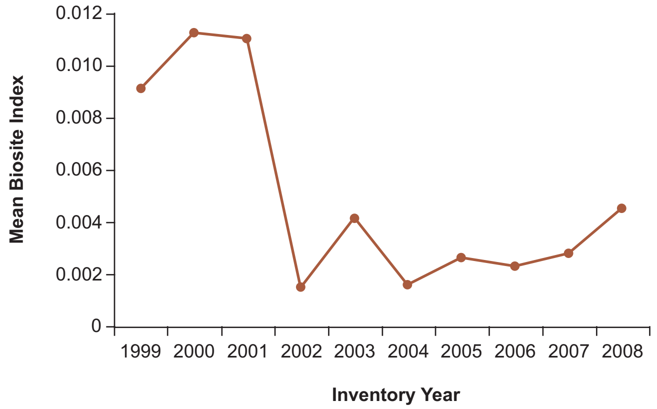


Figure 42.—Mean biosite index (unitless ratio of number of bioindicator plants with ozone damage by total number of sampled plots) for Indiana by inventory year, 1999-2008.

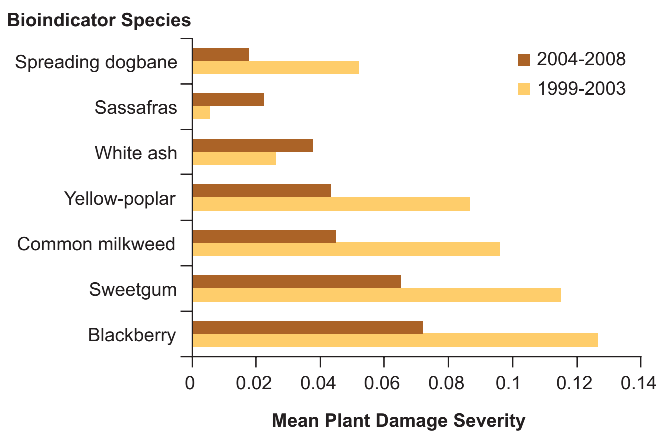


Figure 43.—Mean plant damage severity (unitless ratio of ozone damage, 1 being complete damage) by bioindicator species, Indiana, 1999-2003 and 2004-2008.

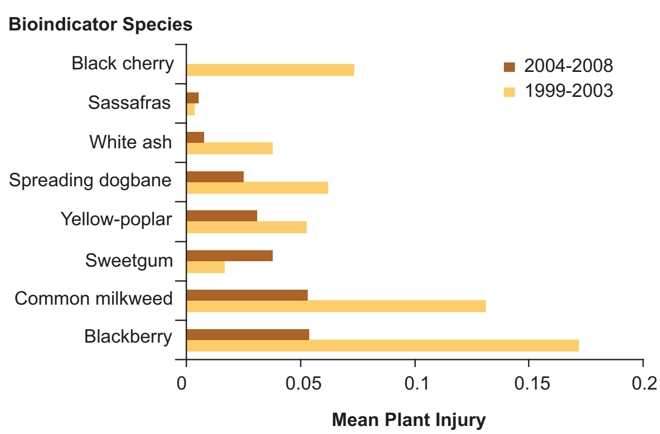


Figure 44.—Mean plant injury severity (unitless ratio of number of plants injured by total plants sampled), Indiana, 1999-2003 and 2004-2008.

What this means

The potential appears to have decreased for ambient ozone concentrations to negatively affect Indiana's forests. Various aspects of the ozone indicator survey program, whether the biosite index or plant damage severity ratings, all showed substantial declines over the past 5 years. There is still a potential for some growth reductions or mortality from ozone damage, especially if wind patterns, industrial emissions, or drought patterns change; however, this risk is much less than witnessed in prior reporting periods.

Emerald Ash Borer

Background

The emerald ash borer (EAB) (*Agrilus planipennis*), a wood-boring beetle native to Asia, was identified in Indiana during the spring of 2004, 2 years after its initial North American discovery. In North America, EAB has only been identified as a pest of ash and all native species of ash appear to be susceptible to it (McCullough and Usborne 2008). Trees and branches as small as 1 inch in diameter have been attacked, and while EAB may prefer stressed trees, healthy trees are also susceptible (Cappaert et al. 2005). In areas with a high density of EAB, tree mortality generally occurs 1 to 2 years after infestation for small trees and 3 to 4 years for large trees (McCullough and Usborne 2008). Artificial spread mediated by human transportation of infested ash materials has increased EAB establishment over long distances. Initially limited to a single northeastern county, EAB has spread across most of Indiana. By the end of 2008, EAB was confirmed in 21 counties, including in the Hoosier National Forest (Fig. 45). EAB is considered generally infested in 10 northeastern counties and intermittently infested throughout the rest of the State.

What we found

Indiana's forest land contains an estimated 146.6 million ash trees (greater than 1 inch in diameter) that account for

766.5 million cubic feet of volume. Ash is present on approximately 2.4 million acres or over half of Indiana forest land (Fig. 46). Rarely the most abundant species in a stand, ash generally makes up less than 25 percent of the total live-tree basal area. Distributed throughout most of Indiana, ash is concentrated in the southern half of the State and in the northeastern corner (Fig. 47). An average acre of Indiana forest land contains seven ash trees.

In ash-dominant forest types (those forest types in which ash makes up at least 15 percent of total species composition), sugar maple, black cherry, American elm, and yellow-poplar are the major components, along with white ash, on upland sites (Fig. 48A). Lowland ash-dominant forest types are primarily composed of sugar maple, green ash, and American elm sawtimber and saplings, and green ash, hackberry, and boxelder poletimber (Fig. 48B).

Ash mortality was recorded across much of Indiana forest land (Fig. 49). On average, mortality of live ash trees totaled 616,000 trees per year between 2004 and 2008, resulting in a loss of 8.2 million cubic feet of volume per year. Ash mortality occurred in 43 percent of all counties and 38 percent of counties quarantined by the end of 2008. In most counties, ash mortality accounted for less than 50 percent of total mortality (Fig. 49). One major exception was Marion County, in which ash mortality represented 100 percent of total mortality; Marion County has been under quarantine since EAB was first detected there in 2006 (Figs. 45 and 49).

What this means

Due to its ability to cause extensive decline and mortality of ash, as evidenced by the tens of millions of dead trees left in the wake of infestation, EAB represents a significant threat to Indiana's ash resource. Although ash yellows disease is present in Indiana, EAB is likely to be the largest contributor to ash mortality throughout the State. Those counties that are not quarantined, but that have a moderate amount of ash mortality may indicate areas of low EAB density that are currently unidentified; these counties also are good candidates for increased survey efforts. Ash mortality and the continued identification of new EAB infestations will have a large impact on the future makeup of Indiana's forests. Species composition and forest structure will likely change 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. Additionally, efforts to slow the spread of EAB will be improved by discontinuing the transportation of firewood.

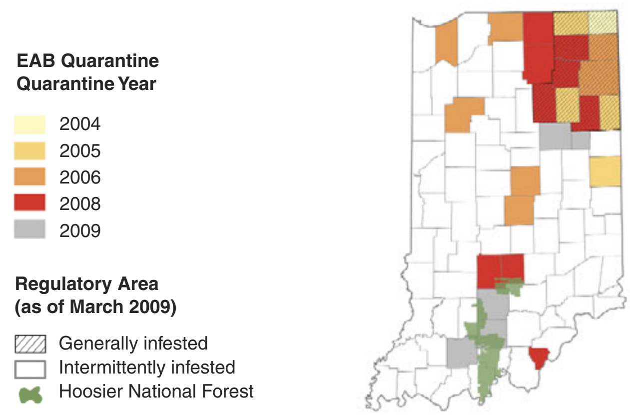


Figure 45.—EAB quarantine boundaries by year and regulatory area, Indiana, 2004-2009.

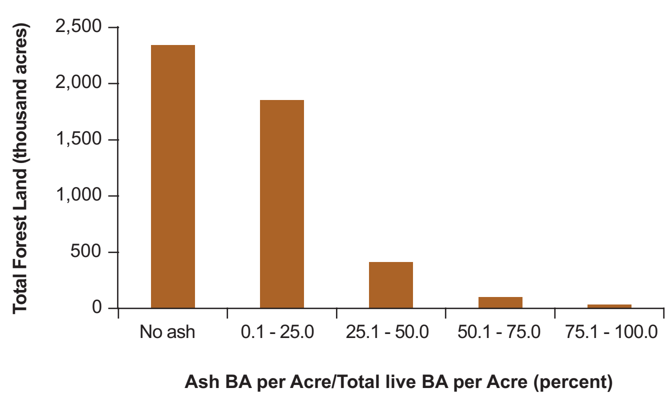


Figure 46.—Distribution of forest land by live ash basal area as a percent of total basal area, Indiana, 2004 to 2008.

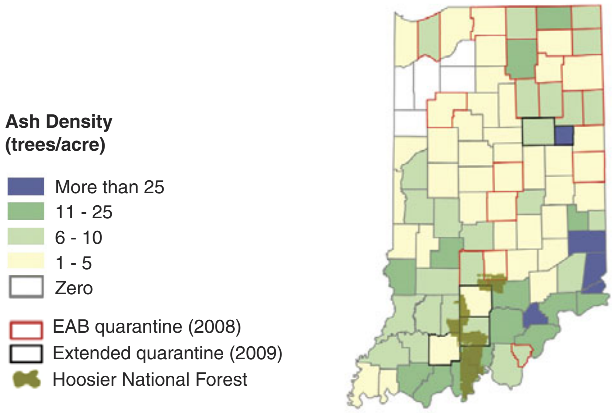


Figure 47.—Ash density (trees per acre) on forest land by county land, Indiana, 2004 to 2008.

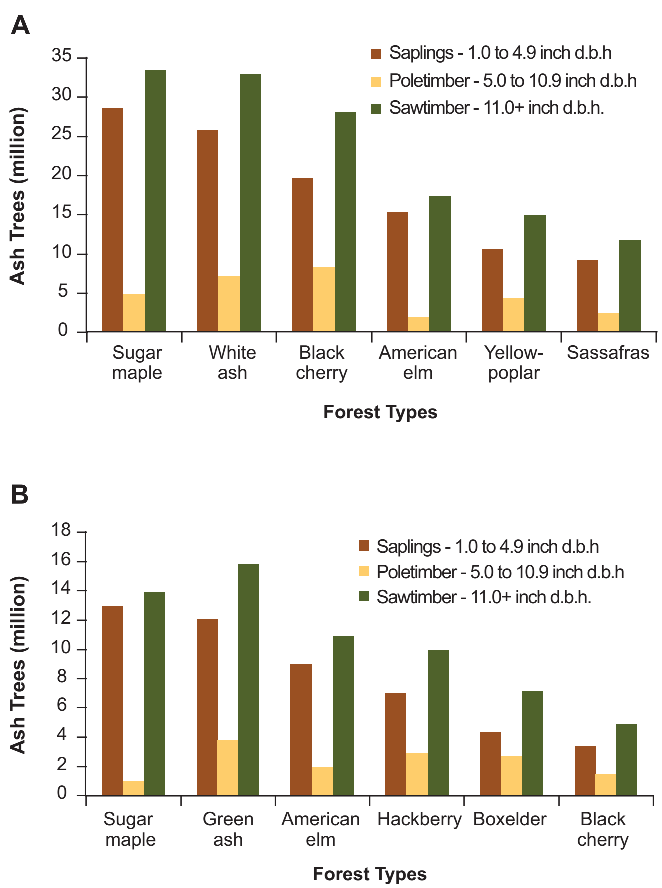


Figure 48.—Number of ash trees for ash-dominated forest types (where ash accounts for at least 15 percent of stand basal area) by major species and stand-size class, upland (A) and lowland (B), Indiana, 2004 to 2008.

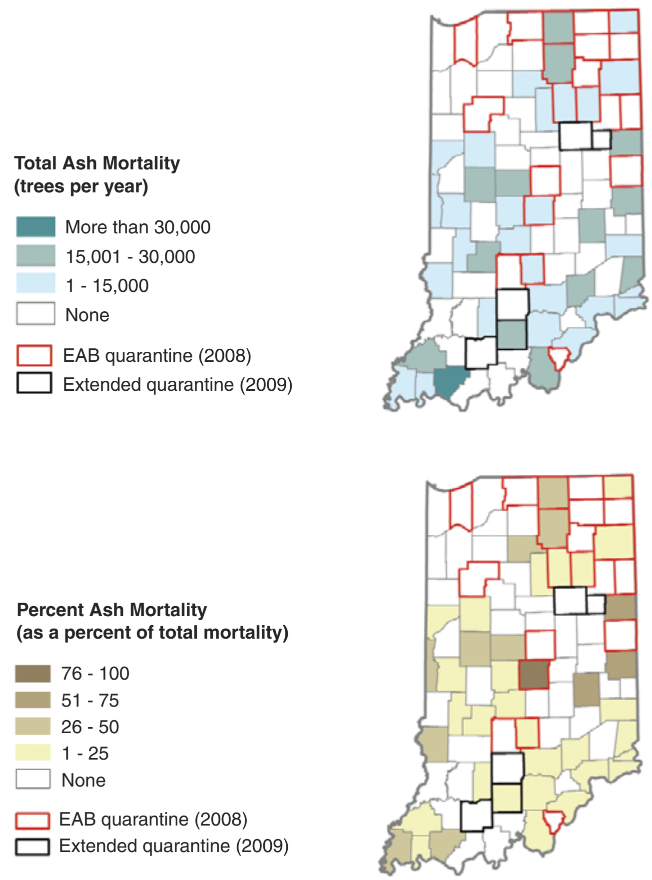


Figure 49.—Total ash mortality (trees per year) and percent ash mortality on forest land by county, Indiana, 2004 to 2008.

Soils

Background

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

What we found

The calcium:aluminum ratio in the soil is an important predictor of several measures of crown vigor, and the effect varies across tree species. The uncompacted live-crown ratio is determined by dividing the live-crown length by the actual tree length. Larger values are associated with healthier trees; low values of this ratio can be related to self pruning and shading from other tree crowns, but other reasons include defoliation due to dieback and loss of branches due to breakage or mortality. The calcium:aluminum ratio is a significant predictor of the uncompacted live-crown ratio (Fig. 50), but this effect varies across tree species. For example, the live-crown ratio of red maple goes down with increasing aluminum (decreasing calcium:aluminum ratio), but the live-crown ratio of sugar maple appears to be unaffected (Fig. 51). Similar results are observed in measurements of crown density: increasing amounts of aluminum generally lead to lower crown density (Fig. 52). Here again, the effect varies across species. In fact, the crowns of some species are densest at lower calcium:aluminum ratios or even optimal at middle values (Fig. 53).

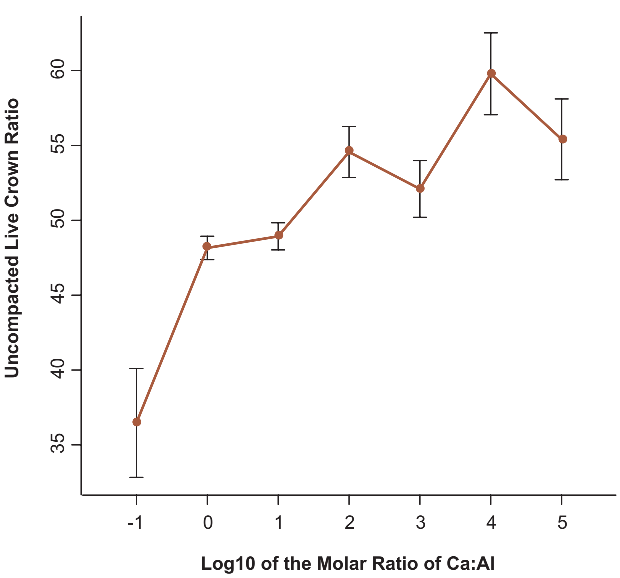


Figure 50.—Uncompacted live-crown ratio is significantly related to the amount of calcium and aluminum in the soil. Error bars represent one sampling error (66%).

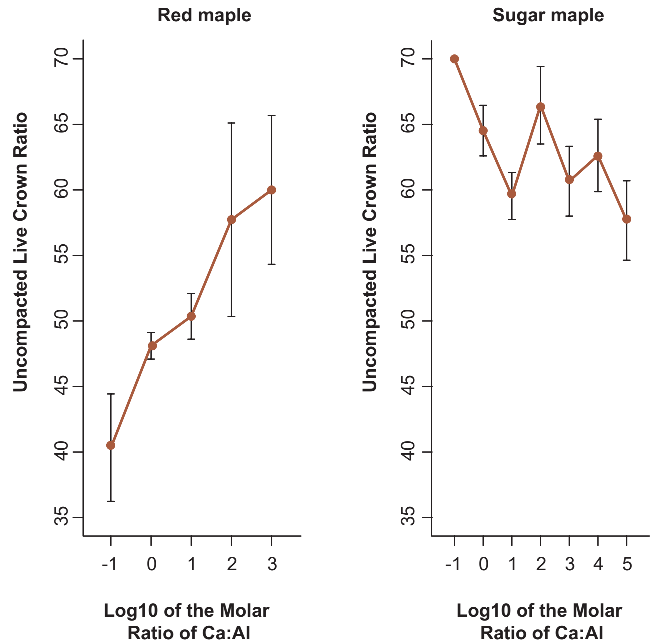


Figure 51.—The effect of calcium and aluminum on the uncompacted live-crown ratio varies by species. Error bars represent one sampling error (66%).

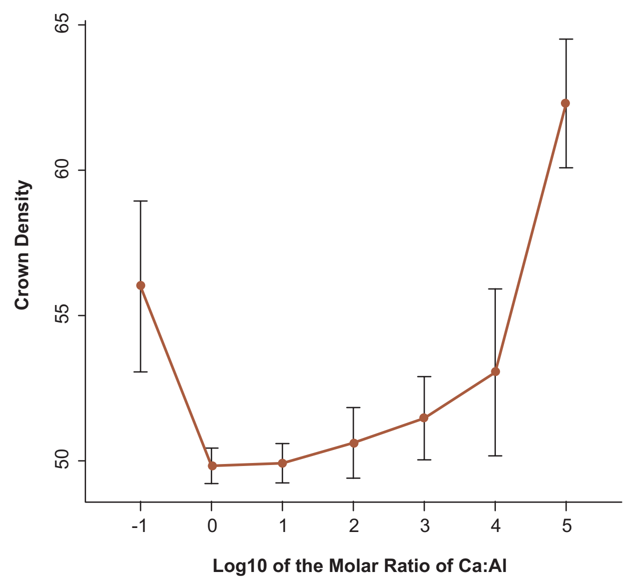


Figure 52.—Increasing amounts of aluminum (falling Ca:Al ratios) generally lead to lower crown density. Error bars represent one sampling error (66%).

What this means

Tree species occupy different niches in the landscape, which provides a competitive advantage for colonization, growth, and reproduction. Atmospheric deposition of different compounds changes the soil substrate through additions or removals of nutrients and pollutants. These changes in the soil influence the ability of existing trees to thrive and reproduce in their current locations, as well as the ability of other trees to colonize new landscapes. It is important to document and understand natural and anthropogenic processes in the soil because they profoundly influence the current forest and success of future forest management plans.

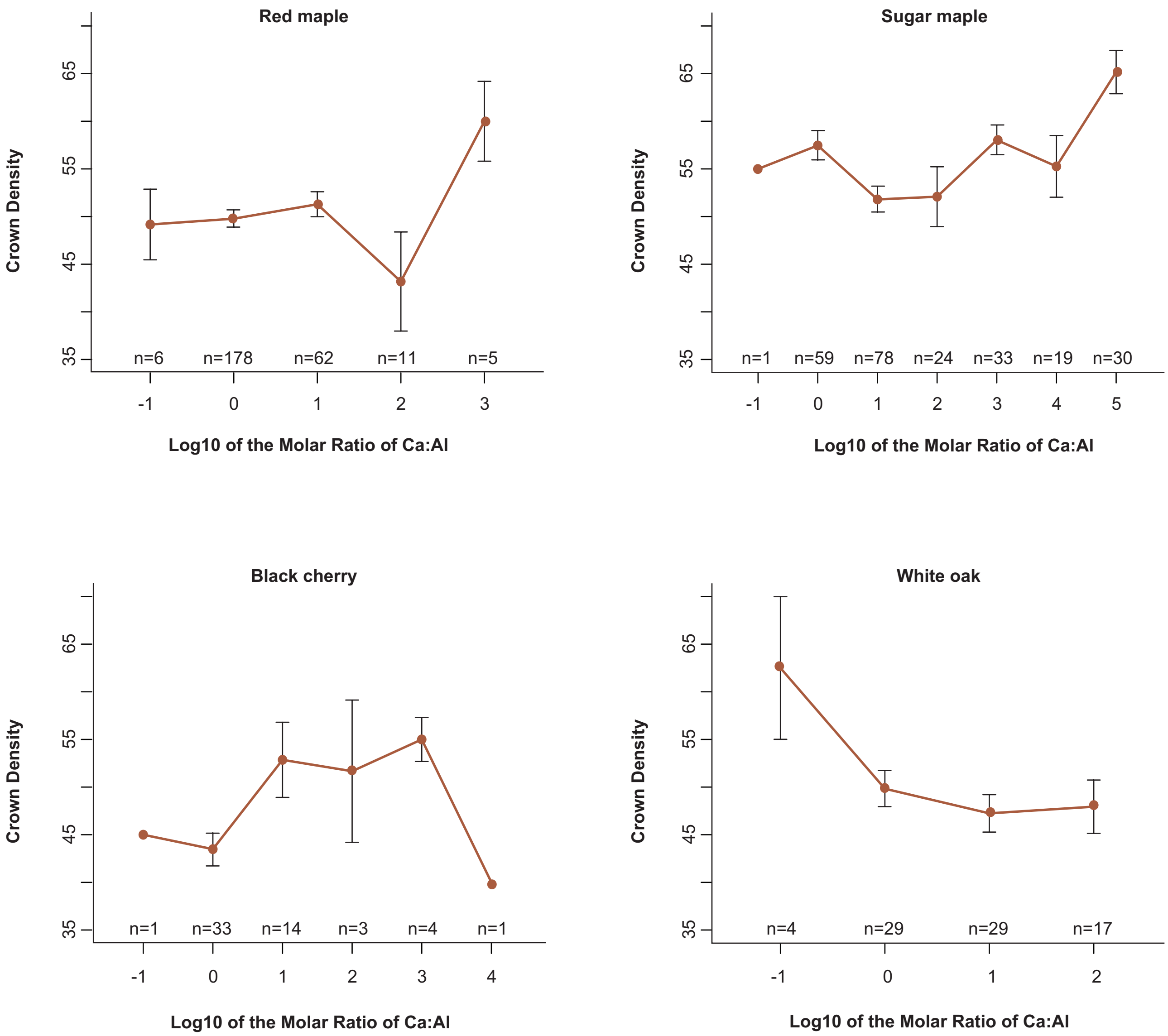


Figure 53.—The effect of calcium and aluminum on crown density varies by species. Error bars represent one sampling error (66%).

Understory Vegetation: Diversity and Nonnative Invasive Plants

Background

The diversity and abundance of vascular plants (possessing water- and sap-conducting tissues) are important indicators of forest ecosystem health. The total species composition of forest stands often reflects chronic stresses such as site degradation, climate change, and pollution. Such disturbances may lead to an increase in opportunistic species, including nonnative invasive plants. Inhibiting and outcompeting native plant species, nonnative invasive plants adversely affect the structure and function of ecosystems all over the country including Indiana. During the inventory, FIA assessed understory vegetation in two ways. First, it collected data on all vascular plants on subplots in Phase 3 (P3) plots in 2001-2008, approximately 1/16th of the total forested plots in Indiana. Secondly, it evaluated presence/absence and estimated percent cover for the 23 most common nonnative invasive plant species in the Midwest on all Phase 2 (P2) forested plots sampled during summer months in 2007-2008.

What we found

During 2001-2008, FIA identified all vascular plants on subplots in P3 plots in Indiana. The inventory found an average of 46 species on each plot and a total of 468 species of vascular plants representing 99 families and 263 genera (Fig. 54). Accounting for nearly 38 percent of the taxa, the sunflower (*Asteraceae*), grass (*Poaceae*), rose (*Rosaceae*), sedge (*Cyperaceae*), and legume (*Fabaceae*) were the most dominant families. Major genera included *Carex* (21 taxa), *Quercus* (9), *Galium* (7), and *Symphyotrichum* (7). Common forbs present were Clayton's sweetroot (*Osmorhiza claytonii*), Jack in the pulpit (*Arisaema triphyllum*), and fragrant bedstraw (*Galium triflorum*). Most widespread vines included Virginia creeper (*Parthenocissus quinquefolia*) and roundleaf greenbrier (*Smilax rotundifolia*). Northern spicebush (*Linderera benzoin*) and flowering dogwood (*Cornus florida*) were the most abundant shrubs.

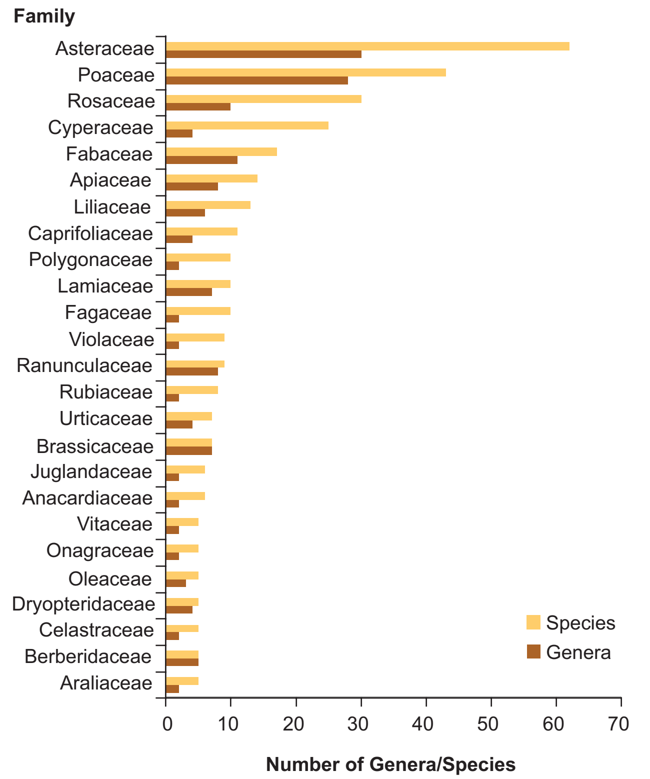


Figure 54.—Number of genera and species on P3 plots for the top 25 vascular plant families, Indiana, 2001-2008.

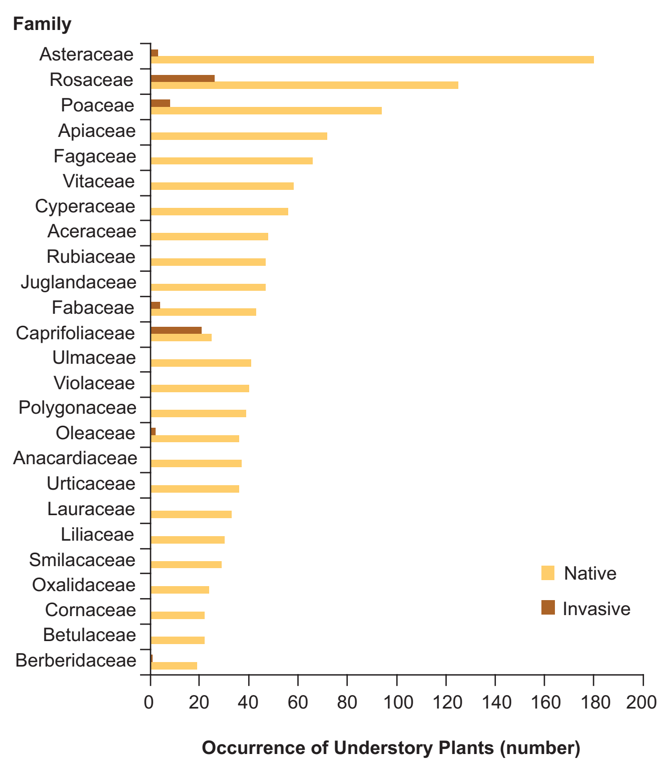


Figure 55.—Occurrence of understory plants on P3 plots for the top 25 vascular plant families, Indiana, 2001-2008.

The prevalence in numbers did not translate directly into prevalence in occurrence, however, with the sunflower, rose, grass, *Apiaceae*, and *Fagaceae* dominating the list of occurrences (Fig. 55). Eighty-seven percent of all P3 plots measured had at least one invasive species present. Twenty-three nonnative invasive species were found on both P2 and P3 plots (see Table 1 for complete list of invasive species). Among them, the rose and honeysuckle families had the highest proportion of occurrences, with such species as multiflora rose, nonnative bush honeysuckles, Japanese honeysuckle, and garlic mustard being most common. (Fig. 56). The average number of invasive species per plot ranged from as high as seven to as low as one; 62 percent of the plots had either one or two (Fig. 57).

What this means

The forest land of Indiana provides an essential environment for a variety of vascular plant species. Those with the most occurrence, e.g., Virginia creeper (*Parthenocissus quinquefolia*) and roundleaf greenbrier (*Smilax rotundifolia*), Northern spicebush (*Linderera benzoin*) and flowering dogwood (*Cornus florida*), are associated with the oak/hickory forest type, which predominates in Indiana. The distribution of vascular species within this and other types depends on the differences in elevation, topography, and soil composition, i.e., spatial parameters. Temporal variations, both seasonal and long term, also affect the diversity and composition of vascular species. In addition, the current forests of Indiana have developed in response to both natural (such as fire, wind, floods) and human (such as land clearing for agriculture, livestock grazing, timber harvesting, and development) disturbance. These factors have contributed to the fragmentation of Indiana's forested landscape, creating a diverse understory. This diversity might be jeopardized by a few nonnative invasive species introduced into the State. Invasive plants are good competitors in their new environments due to a number of characteristics. Early maturation, rapid reproduction, effective and aggressive mechanisms of their spread all lead to their proliferation, often at the expense of the number and abundance of native plant species. The reduction in diversity may result in a reduction in the value and health of Indiana's forests.

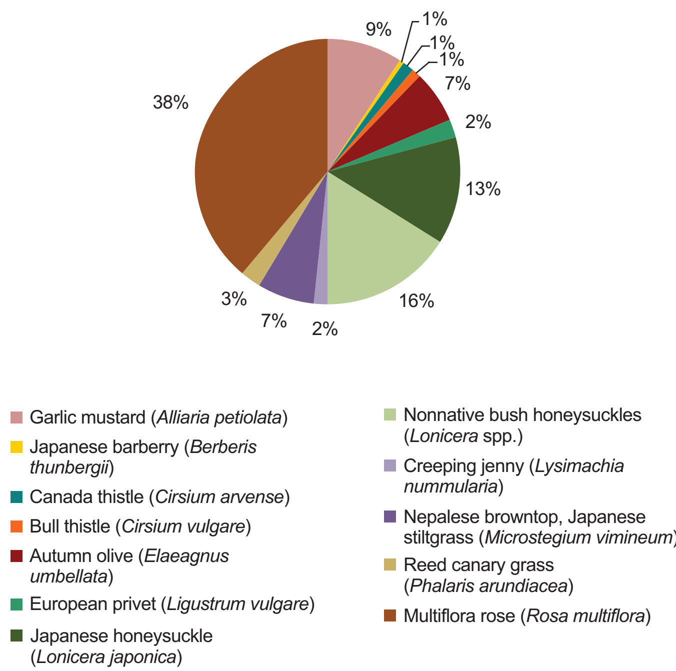


Figure 56.—Percent occurrence of top 12 nonnative invasive plants observed on P2 and P3 plots (n=155), Indiana, 2001-2008.

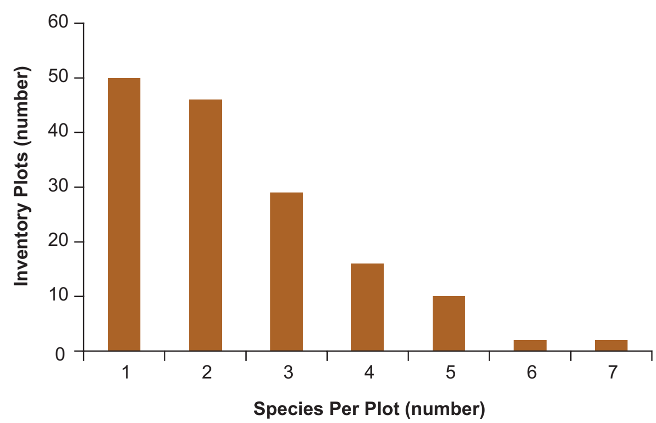


Figure 57.—Distribution of the top 10 nonnative invasive understory plants observed on P2 and P3 plots (n=155), Indiana, 2001-2008.

Table 1.—List of nonnative invasive plants surveyed on P2 plots in Indiana, 2007

Common Name	Genus species
Multiflora rose	*Rosa multiflora*
Creeping Jenny	*Lysimachia nummularia*
Nonnative bush honeysuckles	*Lonicera* spp.
Japanese honeysuckle	*Lonicera japonica*
European privet	*Ligustrum vulgare*
Spotted knapweed	*Centaurea stoebe*
Garlic mustard	*Alliaria petiolata*
Autumn olive	*Elaeagnus umbellate*
Russian olive	*Elaeagnus angustifolia*
Canada thistle	*Cirsium arvense*
Bull thistle	*Cirsium vulgare*
Japanese barberry	*Berberis thunbergii*
Common barberry	*Berberis* spp.
Reed canary grass	*Phalaris arundiacea*
Japanese stiltgrass	*Microstegium vimineum*
Dame’s rocket	*Hesperis matronalis*
Oriental bittersweet	*Celastrus orbiculatus*

Forest Economics

Fine-quality hardwood logs await the sawmill. Photo used with permission of Indiana Dept. of Natural Resources.

Growing-Stock Volume

Background

Growing-stock volume is the amount of sound wood in live, commercial tree species; trees must be at least 5 inches in d.b.h. or greater and free of defect. This measure has traditionally been used to ascertain wood volume available for commercial use. Estimates of the volume of growing stock are important considerations in economic planning and evaluations of forest sustainability.

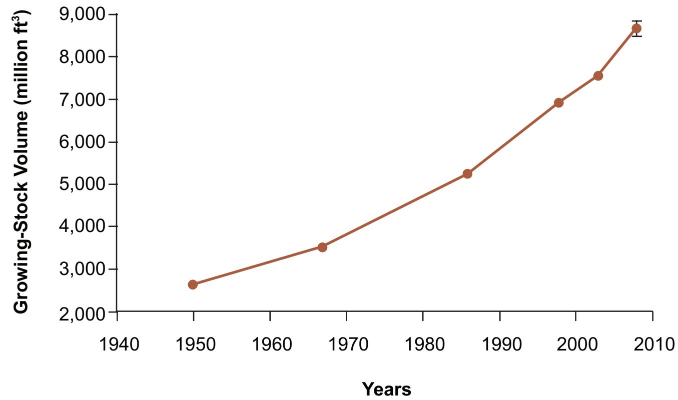


Figure 58.—Total growing-stocking volume (millions cubic feet) on timberland, Indiana, 1950-2008.

What we found

The total growing-stock volume on Indiana's timberland continues to increase at a steady rate, nearly quadrupling since 1950 to a current statewide estimate of nearly 9 billion cubic feet (Fig. 58). Many economically important species groups, such as red oak, yellow-poplar, maples, and hickories, continue to increase (Fig. 59). White oak growing-stock volumes have remained fairly static since 1998. When we view changes in growing-stock volume by selected species groups and d.b.h. classes, we see that hard maple has made some of its greatest gains in smaller diameter classes (Fig. 60 A,B). In contrast, yellow-poplar has shown some of its greatest volume gains in larger diameter classes.

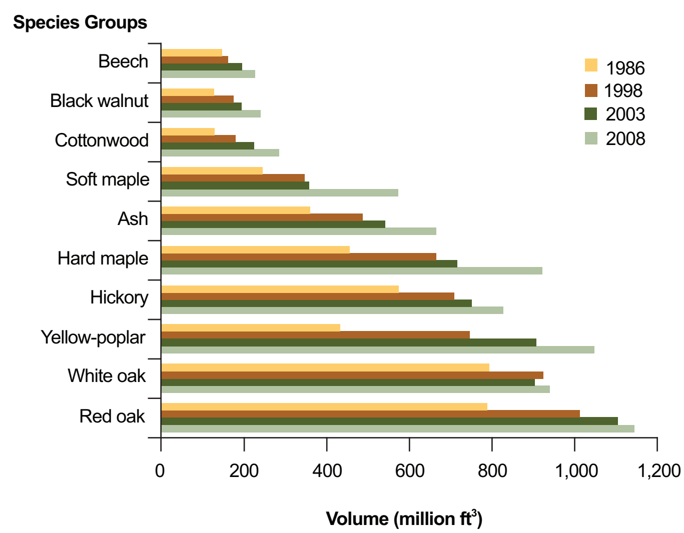


Figure 59.—Total growing-stock volume on timberland by selected species groups, Indiana, 1986-2008.

What this means

Since Indiana's earliest statewide inventory in 1950, the growing-stock volume of economically critical species groups on timberland has continued to increase. Given that 79 million cubic feet of roundwood from Indiana's forests was utilized in Indiana's mills in 2008, the nearly nine billion cubic feet of growing-stock volume is sufficient volume to supply Indiana's wood product industry for nearly 114 years at current levels. Although volumes continue to increase, for a number of critical tree species the primary volume gains are found in larger tree diameters. Sustainability issues (e.g., regeneration) of mature forest stands containing economically vital tree species should be monitored into the future.

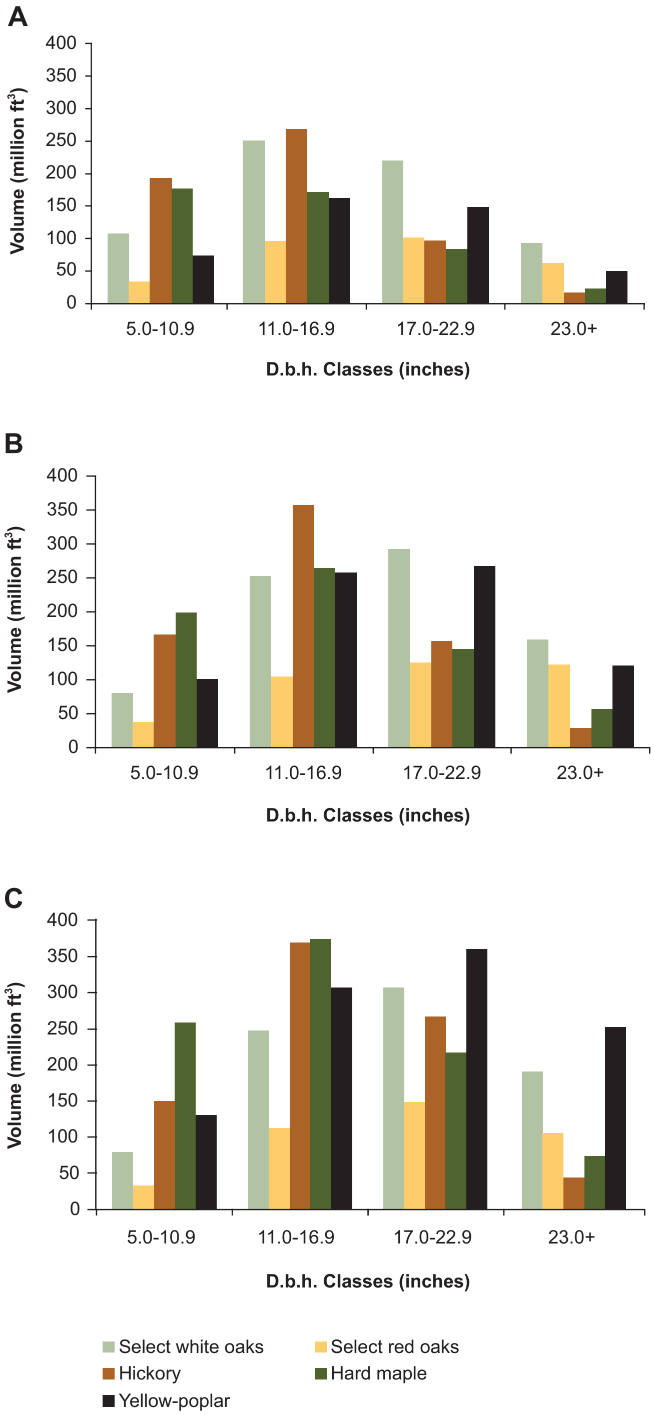


Figure 60.—Growing-stock volume of selected hardwood species groups by 6-inch d.b.h. classes on timberland, Indiana, 1986 (A), 1998 (B), and 2003-2008 (C).

Sawtimber Volume

Background

Sawtimber trees are live trees of commercial species that contain either one 12-foot or two noncontiguous 8-foot logs that are free of defect. Hardwoods must be at least 11 inches d.b.h. and softwoods must be 9 inches d.b.h. to qualify as sawtimber. Sawtimber volume is defined as the net volume of the saw log portion of live sawtimber, measured in board feet, from a 1-foot stump to minimum top diameter (9 inches for hardwoods and 7 inches for softwoods). Estimates of sawtimber volume, expressed as board feet (International ¼-inch rule), are used to determine the monetary value of wood volume and to identify the quantity of merchantable wood availability.

What we found

Total statewide board foot volume of sawtimber on timberland continued to increase to approximately 35 billion board feet (Fig. 61). Given the current rate of sawtimber growth, it should be expected that Indiana's total sawtimber volume might reach 40 billion board feet by 2013. Most hardwood species of economic interest have demonstrated tremendous gains in sawtimber volume on timberland since 1998 (Fig. 62). Yellow-poplar, ash, and hard maples all had nearly a 40-percent increase in their total sawtimber volumes since 1998. Select red and white oaks had much lower increases in total statewide volumes of approximately 4 percent since 1998. Since 1967, the average annual net growth of sawtimber with respect to total statewide sawtimber has increased steadily; average annual mortality has increased only slightly every year and statewide removals have decreased (Fig. 63).

What this means

Sawtimber volume resources on Indiana's timberland have increased steadily since 1967, despite ongoing sawtimber mortality and removals. This statewide dynamic indicates forest health issues (i.e., stand development mortality and pests/diseases) and harvesting (i.e., removals) have been a

Figure 61.—Volume of sawtimber on Indiana's timberland, 1950 to 2004-2008.

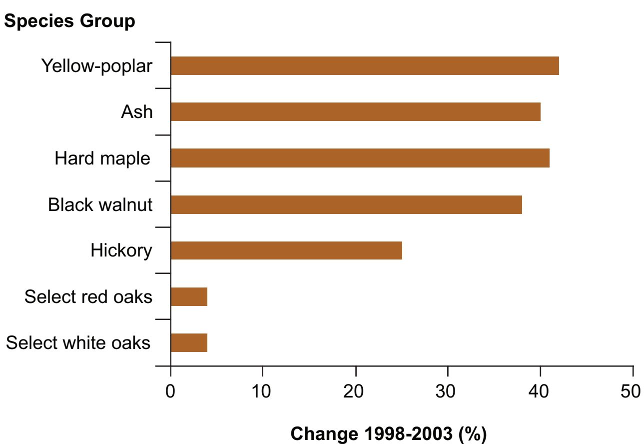


Figure 62.—Percent change in total sawtimber volume on timberland for selected hardwood species in Indiana, 1998 to 2004-2008.

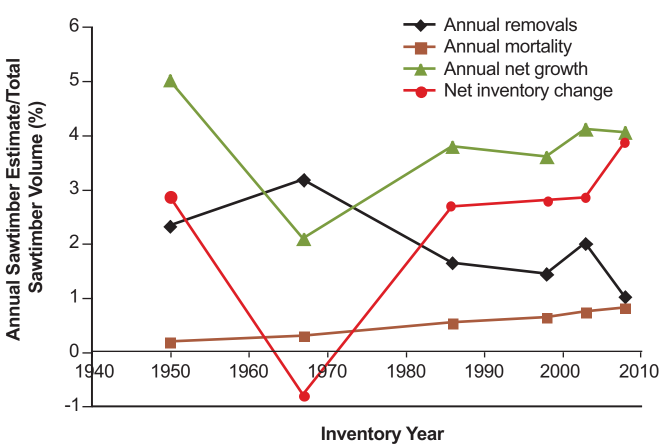


Figure 63.—Total average annual removals, mortality, net growth, and net inventory change as a percent of total sawtimber on Indiana's timberland, 1950 to 2004-2008.

stable, sustainable component of forest ecosystems. If current trends were to continue into the future, one would expect increasing sawtimber volumes into the foreseeable future. Important caveats to this hypothesis are scale and stochastic events. Utilization of sawtimber resources may be unsustainable at smaller scales requiring continued monitoring. Additionally, unforeseen forest health events (e.g., storms or EAB) could drastically alter the course of Indiana's accruing sawtimber volumes.

Sawtimber Quality

Background

The economic value of Indiana's sawtimber lies not only in its absolute amount (volume) but also in its quality. The high quality of hardwood sawtimber across Indiana indicates its value and supports Indiana's reputation of being a leading hardwood producer.

What we found

Although grading techniques have changed since previous inventories, it would appear that Indiana's forest has had major increases in total volumes of high quality sawtimber in recent decades. The net volume of grade one sawtimber has steadily increased since 1986, both in terms in absolute volume (5.9 billion board feet) and as a percentage of all graded sawtimber in Indiana (Fig. 64). In 1986, the volume of grade 1 sawtimber as a percentage of all graded sawtimber was 8 percent; by 2004-2008 it had increased to 25 percent. Although there have been fluctuations in the proportions of other grades since 1986, the general trend has been increasing volumes of higher grades. In absolute terms, grades 1 and 2 sawtimber totaled nearly 16.5 billion board feet in 2008, compared to nearly 8 billion in 1998 and almost 5 billion in 1986. On a species-specific basis, important hardwood species have all had increases in sawtimber volumes for grades 1 and 2 since 1986 (Fig. 65). Black walnut has had more than a 200-percent increase in grade 1 sawtimber volume since 1998.

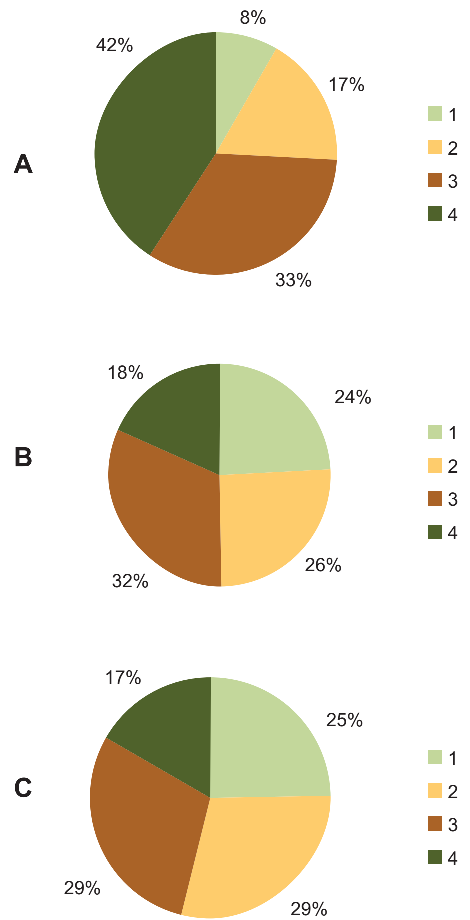


Figure 64.—Distribution of sawtimber volume on timberland by tree grade, Indiana, 1986 (A), 1998 (B), and 2004-2008 (C).

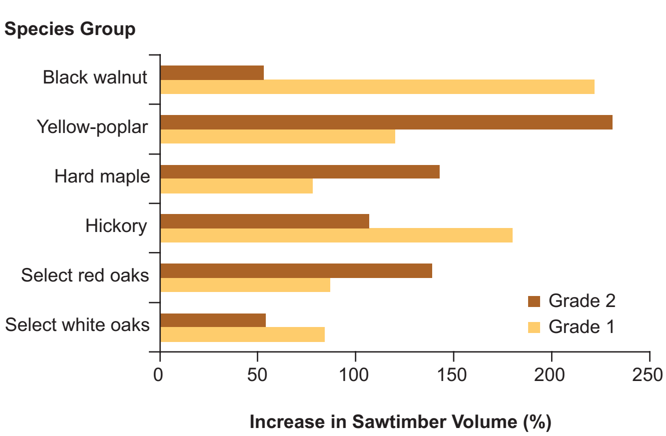


Figure 65.—Percent increase in sawtimber volume (grades 1 and 2) for selected hardwood species groups on timberland in Indiana between 1998 and 2004-2008.

What this means

The quality of Indiana's sawtimber has been increasing for decades, with substantial increases in the amount of higher grade sawtimber. This increase in sawtimber grades has not been limited to only a few species; rather, it has been well distributed across many economically important tree species. The substantial increase in higher grade sawtimber volumes for commercially important hardwood species is most likely due to the individual tree growth increasing the sawtimber volume and increasing tree grades, a synergistic interaction. Overall, it appears that Indiana's sawtimber resource has been sustainably developed in recent decades with substantial increases in quality and subsequent market value.

Carbon Futures

Background

Increasing forest ecosystem carbon stocks represent the best opportunity to increase CO_2 sequestration and thus mitigate increasing atmospheric CO_2 levels, which are primarily due to the burning of fossil fuels. The FIA program does not directly measure forest carbon stocks in Indiana. Instead, a combination of empirically derived carbon estimates (e.g., standing live trees) and models (e.g., soil organic carbon based on forest type) is used to estimate Indiana's forest carbon stocks. Estimation procedures are detailed by Smith et al. (2006).

What we found

Aboveground live trees represent the largest forest ecosystem carbon stock in Indiana at more than 120 million tons, followed by soil organic components at 80 million tons and live tree belowground stocks at 30 million tons (Fig. 66). The majority of Indiana's forest live and dead tree carbon stocks are found in stands aged 41 to 80 years (Fig. 67). The value of Indiana's aboveground live-tree carbon stocks on forest land has

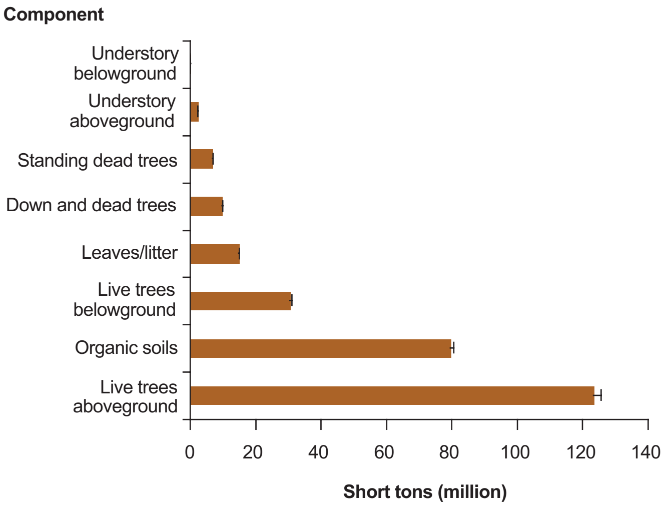


Figure 66.—Estimated total carbon stocks by forest ecosystem component, Indiana, 2004-2008.

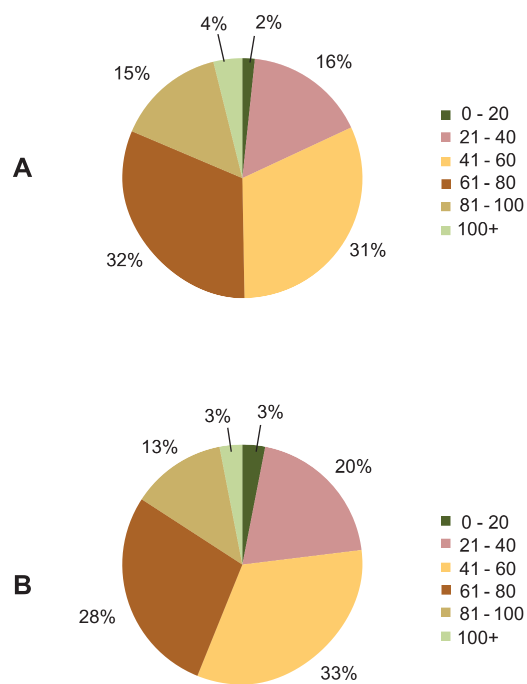


Figure 67.—Carbon on forest land by (A) standing live tree and (B) standing dead tree components by stand age class, Indiana, 2004-2008.

varied tremendously based on average yearly market values of metric tonnes of CO_2 on the Chicago Climate Exchange (Fig. 68).

What this means

Given the tremendous increases in Indiana's live-tree volume and biomass on forest land over the past 25 years, it should be expected that forest management for carbon credit trading could be a viable economic alternative to other management options (e.g., harvesting) given established carbon markets. Managing Indiana's forest carbon stocks is not as simple as maximizing live-tree growth due to the importance of other carbon stocks such as soil organic components and belowground carbon stocks. While there are opportunities to rapidly increase carbon stocks in moderate-aged, well-stocked stands, management impacts on non-live tree carbon stocks need to be identified. Finally, given the relatively recent development of carbon markets, extreme variability in carbon credit prices and verification requirements should be expected and included in forest stand management guidelines when managing for carbon sequestration.

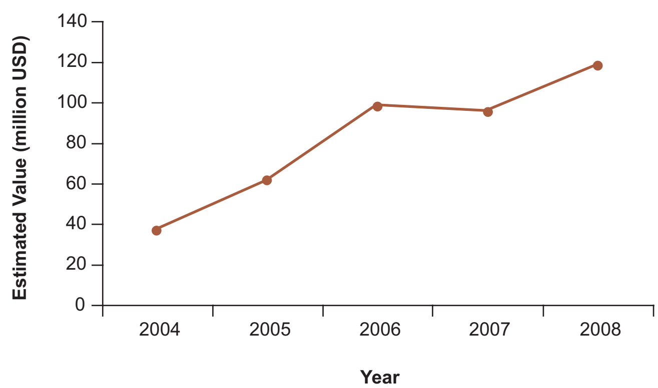


Figure 68.—Annual estimates of the value (million USD) of Indiana's standing live aboveground forest land trees based on average annual Chicago Climate Exchange market value for CO_2 by year.

Timber Products

Background

Forest harvest produces a stream of income shared by timber owners, managers, marketers, loggers, truckers, and processors. Almost 9,000 people, with a payroll of $220 million, are employed by primary wood harvesters and processors in Indiana (Bratkovich et al. 2004). To better manage the State's forests, it is important to know the species, amounts, and locations of timber being harvested.

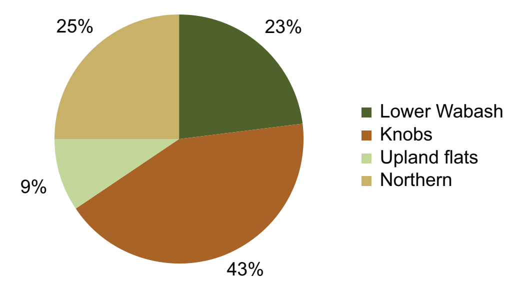


Figure 69.—Proportion of industrial roundwood production by FIA survey unit, Indiana, 2008.

What we found

In 2008, a mill survey was conducted to estimate the amount of industrial roundwood harvested and processed at Indiana's primary wood-processing mills: 79 million cubic feet of industrial roundwood was harvested from Indiana in 2008. This was an estimated 20-percent decrease from 2005. Ninety percent of the industrial roundwood harvested came from the southern third of Indiana (Fig. 69). Red oaks accounted for 22 percent of the harvest, followed by yellow-poplar (17 percent) and white oaks (14 percent) (Fig. 70). All softwoods combined made up less than 1 percent of the volume harvested. Saw logs accounted for 86 percent of the total harvest, with other minor products – handles, veneer logs, pulpwood, cooperage, mine timbers, posts, cabin logs, and excelsior/shavings – making up the rest (Fig. 71). Ninety-three percent of industrial roundwood production came from growing-stock sources; limbwood and dead trees accounted for most of the remainder. Ninety percent of the industrial roundwood harvested was processed by Indiana mills. The industrial roundwood harvest left 21 million cubic feet (6 percent) of growing-stock material on the ground as logging residue.

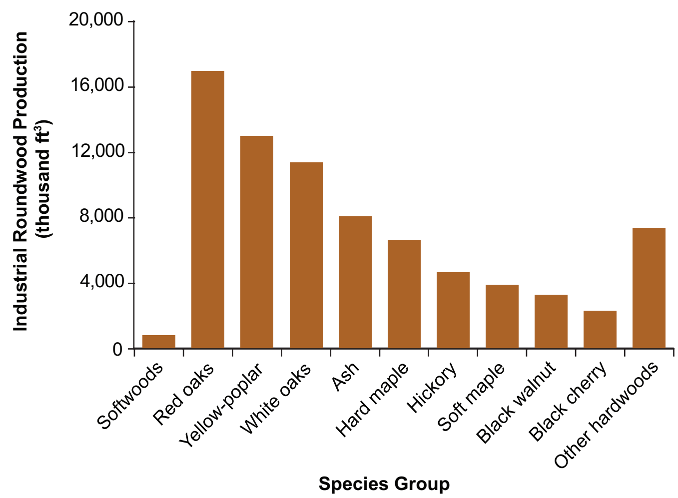


Figure 70.—Industrial roundwood production by species group, Indiana, 2008.

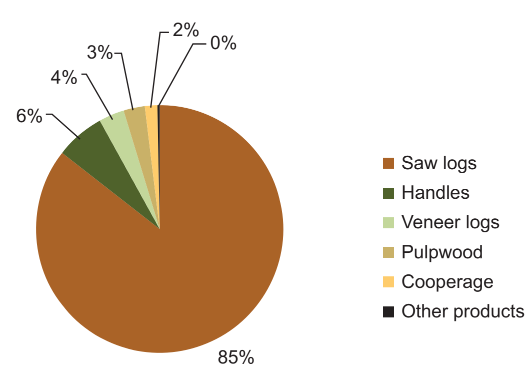


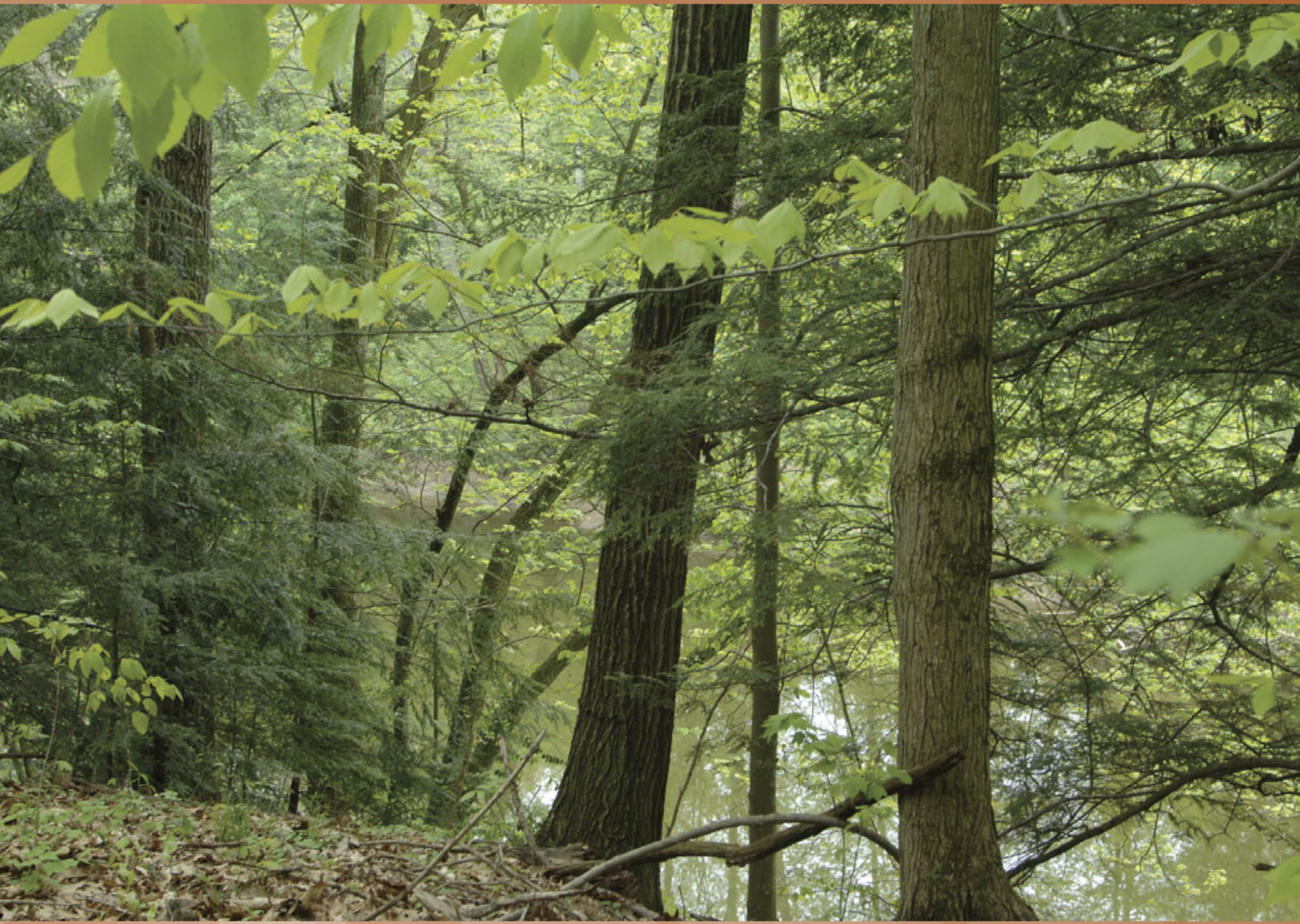
Figure 71.—Proportion of industrial roundwood production by end-product use, Indiana, 2008.

What this means

The 20-percent decrease in industrial roundwood production is the result of the poor economy and the collapse of the housing construction industry. Mills that remained in operation reduced production, while other mills idled or permanently closed. As the economy begins to recover, mills will begin to increase production or re-open.

Biomass fuel products will provide the opportunity to better utilize forest biomass. Saw logs account for almost 90 percent of the industrial roundwood produced in Indiana, which means that the upper portions of trees are largely left on the ground as logging residue. A biomass fuel industry will provide the potential to utilize these logging residues. Most of the logging residue is confined to the southern third of the State. In the northern two-thirds of Indiana, industrial roundwood harvests and the associated logging residues alone are too scattered to support biomass fuel projects. But, small, localized biofuel facilities could provide additional markets for wood material from better management of small woodlots and other traditionally, nonforest land areas, and areas that are limited in the number of industrial wood-using mills.

Data Sources and Techniques



Lakeside trees help prevent bank erosion. Photo used with permission of Indiana Dept. of Natural Resources.

Forest Inventory

Information on the condition and status of forests in Indiana was obtained from the Northern Research Station's Forest Inventory and Analysis (NRS-FIA) program. Previous inventories of Indiana's forest resources were completed in 1950 (Hutchison 1956), 1967 (Spencer 1969), 1986 (Smith and Golitz 1988, Spencer et al. 1990), 1998 (Schmidt et al. 2000), and 2003 (Woodall et al. 2005). Data from Indiana's forest inventory can be accessed electronically at: http://www.nrs.fs.fed.us/fia/.

Since the 1998 inventory, several changes in FIA methods have improved the quality of the inventory. The most significant change between inventories has been the shift from periodic to annual inventory. Historically, FIA inventoried each state on a cycle that averaged about 12 years. However, the need for timely and consistent data across large geographical regions along with national legislative mandates resulted in FIA implementing an annual inventory program. Annual inventory was initiated in Indiana in 1999.

With the NRS-FIA annual inventory system, approximately one-fifth of all field plots are measured each year. The entire inventory is completed every 5 years. NRS-FIA reports and analyzes results using a moving 5-year average. For example, NRS-FIA generates inventory results for 1999 through 2003 or for 2004 through 2008.

Other significant changes between inventories include implementing new remote-sensing technology, a new field-plot configuration and sample design, and gathering additional remotely sensed and field data. The use of new remote-sensing technology allows NRS-FIA to use classifications of Multi-Resolution Land Characterization (MRLC) data and other remote-sensing products to stratify the total area of Indiana and to improve estimates.

New algorithms were used for the 2008 inventory to assign forest type and stand-size class to each condition observed on a plot. These algorithms are being used nationwide by FIA to provide consistency from state to state. As a result, changes in forest type and stand-size class will reflect actual changes in the forest and not changes due to differences between algorithms. The list of recognized forest types, groupings of these forest types for reporting purposes, models used to assign stocking values to individual trees, definition of nonstocked (stands with a stocking value of less than 10 percent for live trees), and names given to the forest types changed with the new algorithms. As a result, comparisons between the published 2008 results and those published for the prior inventory may be invalid. Contact NRS-FIA for additional information on the algorithms used in both inventories.

Sampling Phases

The 2008 Indiana inventory was conducted in three phases. Phase 1 (P1) uses remotely sensed data to obtain initial plot land-cover observations and to stratify land area in the population of interest to increase the precision of estimates. In phase 2 (P2), field crews visit the physical locations of permanent field plots to measure traditional inventory variables such as tree species, diameter, and height. In phase 3 (P3), field crews visit a subset of P2 plots to obtain measurements for an additional suite of variables associated with forest and ecosystem health. The three phases of the enhanced FIA program as implemented in this inventory are discussed in greater detail in the sections that follow.

Phase 1

Aerial photographs, digital orthoquads (DOQs: digitally scanned aerial photograph), and satellite imagery are used for initial plot measurement via remotely sensed data and stratification. P1 plot measurement consists of observations of conditions at the plot locations using aerial photographs or DOQs. Analysts determine a digitized geographic location for each field plot and a human interpreter assigns the plot a land cover/use. Lands satisfying FIA's definition of forest land include commercial timberland, some pastured land with trees, forest plantations, unproductive forested land, and reserved, noncommercial forested land. In addition, forest land requires minimum stocking levels, a 1-acre minimum area, and a minimum bole-to-bole width of 120 feet with continuous canopy. Forest land excludes wooded strips and windbreaks less than 120 feet wide and idle farmland or other previously nonforest land that currently is below minimum stocking levels. All plot locations that could possibly contain accessible forest land are selected for further measurement via field crew visits in P2.

Phase 2

P2 of the inventory consisted of the measurement of the annual sample of Indiana field plots. Current FIA precision standards for annual inventories require a sampling intensity of one plot for approximately every 6,000 acres. FIA has divided the entire area of the United States into nonoverlapping hexagons, each of which contains 5,937 acres (McRoberts 1999). This array of plots is designated the Federal base sample and is considered an equal probability sample; its measurement in Indiana is funded by the Federal Government with the State of Indiana providing additional funding to increase the base sample intensity. Since 2006, the sample intensity of P2 plots in Indiana has been doubled to one plot per 3,000 acres. The total Federal base sample of plots was systematically divided into five interpenetrating, nonoverlapping subsamples or panels. Each year, the plots in a single panel are measured; panels are selected on a 5-year, rotating basis (McRoberts 1999). For estimation purposes, the measurement of each panel of plots can be considered an independent systematic sample of all land in a state.

Before visiting plot locations, field crews consult county land records to determine the ownership of plots and then seek permission from private landowners to measure plots on their lands. The overall P2 plot layout consists of four subplots. The centers of subplots 2, 3, and 4 are located 120 feet from the center of subplot 1. The azimuths to subplots 2, 3, and 4 are 0, 120, and 240 degrees, respectively, from the center of subplot 1. The center of the new plot is located at the same point as the center of the previous plot if a previous plot existed at the same location. Trees with a d.b.h. of 5 inches or larger are measured on a 24-foot-radius (1/24 acre) circular subplot. All trees 1 to 4.9 inches in diameter are measured on a 6.8-foot-radius (1/300 acre) circular microplot located 12 feet east of the center of each of the four subplots. Seedlings [trees less than 1 inch d.b.h. and at least 6 inches tall (softwood species) or 12 inches tall (hardwood species)] are counted but not individually measured on this same microplot. Forest conditions on the four subplots are recorded. Factors that differentiate forest conditions are changes in forest type, stand-size class, land use, ownership, and density. Each condition that occurs anywhere on any subplot is identified, described, and mapped if the area of the condition meets or exceeds 1 acre in size. Field crews determine the location of the geographic center of the center subplot using geographic positioning system (GPS) receivers. They record condition-level observations that include land cover, forest type, stand origin, stand age, stand-size class, site-productivity class, history of forest disturbance, and land use for every condition (major land use or forest stand at least 1 acre in size) that occurs on the plot. They also record information on condition boundaries when multiple conditions are found on a plot. For each tree, field crews record a variety of observations and measurements, including condition, species, live/dead status, lean, diameter, height, crown ratio (percent of tree height represented by crown), crown class (dominant, codominant, suppressed), damage, and decay status. Office staff use statistical models based on field-crew measurements to calculate values for additional variables, including individual-tree volume, per unit area estimates of number of trees, volume, and biomass by plot, condition, species group, and live/dead status. Details of the data collection procedures used in P2 are available at http://www.nrs.fs.fed.us/fia/data-collection/.

Phase 3

The third phase of the enhanced FIA program focuses on forest health. P3 is administered by the FIA program with consultation from other Forest Service programs, other Federal agencies, state natural resource agencies, universities, and the FHM program. The FHM program consists of four interrelated and complementary activities: detection, evaluation and intensive site-ecosystem monitoring, and research on monitoring techniques. Detection monitoring consists of systematic aerial and ground surveys designed to collect baseline information on the current condition of forest ecosystems and to detect changes from those baselines over time. Evaluation monitoring studies examine the extent, severity, and probable causes of changes in forest health identified through the detection monitoring surveys. Intensive site-ecosystem monitoring studies regionally specific ecological processes at a network of sites located in representative forested ecosystems. Research on monitoring techniques focuses on developing and refining indicator measurements to improve the efficiency and reliability of data collection and analysis at all levels of the program.

The ground-survey portion of the detection monitoring program was integrated into the FIA program as P3 in 1999. The P3 sample consists of a 1:16 subset of the P2 plots with one P3 plot for about every 95,000 acres. P3 measurements are obtained by field crews during the growing season and include an extended suite of ecological data: lichen diversity and abundance, soil quality (erosion, compaction, and chemistry), vegetation diversity and structure, and down woody material. The incidence and severity of ozone injury for selected bioindicator species also are monitored as part of an associated sampling scheme. All P2 measurements are collected on each P3 plot at the same time as the P3 measurements. Additional information on the collection procedures used in P3 is available at http://www.nrs.fs.fed.us/fia/topics/.

P3 variables are selected to address specific criteria outlined by the Montreal Process Working Group for the conservation and sustainable management of temperate and boreal forests and are based on the concept of indicator variables. Observations of an indicator variable represent an index of ecosystem functions that can be monitored over time to assess trends. Indicator variables are used in conjunction with each other, P2 data, data from FHM evaluation monitoring studies, and ancillary data to address ecological issues such as vegetation diversity, fuel loading, regional air-quality gradients, and carbon storage. The P2 and P3 data of the enhanced FIA program are a primary source of reporting data for the Montreal Process Criteria.

Stratified Estimation

The combination of natural variability among plots and budgetary constraints prohibits measurement of a sufficient number of plots to satisfy national precision standards for most inventory variables unless the estimation process is enhanced using ancillary data. Thus, the land area is stratified by using remotely sensed data to facilitate stratified estimation. NRS-FIA uses canopy density classes to derive strata. Canopy density information was obtained from the 2001 National Land Cover Database (NLCD). The NLCD 2001 canopy density layer for the United States was produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium (http://www.mrlc.gov/). The layer characterizes subtle variations of forest canopy density as a percentage estimate of forest canopy cover (0-100) within every 30 m pixel over the United States. The method employed to map canopy density for NLCD 2001 is described in detail in Huang et al. (2001).

The current strata categorization was optimized for the entire Northern FIA region. Using plot location information (center of the center subplot), a percent canopy density value was assigned to each plot. Plots were then aggregated into one of the five strata based on the center of the center subplot. The percent canopy cover stratification scheme consists of five groupings: (1) 0-5, (2) 6-50, (3) 51-65, (4) 66-80, and (5) 81-100. These groupings were based on observed natural clumping of pixel values. If there were not enough plots in each of these classes to create strata, then collapsing rules were used to combine classes until sufficient sample sizes were obtained.

In addition to the classification of every pixel into one of the five canopy strata, every pixel was assigned to an ownership stratum. In Indiana, ownership layers, derived from the Protected Areas Database (PAD—http://www.protectedlands.net/) and the Indiana Spatial Data Portal (http://gis.iu.edu/website/isds/index.htm) were used to classify pixels into four ownership classes: (1) national forest, (2) inland census water, (3) other public, and (4) private. The largest ownership class, based on pixel counts, was private ownership at more than 39 million acres. Every pixel was also assigned to a county based on pixel center location.

Stratified estimation requires two tasks. First, each plot must be assigned to a single stratum. Next, the proportion of each detailed stratum must be calculated (TM land-cover classification, ownership, and county group delineation). The first task is accomplished by assigning each plot to the stratum assigned for the pixel containing the center of the center subplot. The second task is accomplished by calculating the proportion of pixels in each stratum. The population estimate for a variable is calculated as the sum across all strata of the product of each stratum's observed proportion (from P1) and the variable's estimated mean per unit area for the stratum (from P2).

Field plot measurements are combined with P1 estimates in the data compilation and table production process. However, other tabular data can be generated at the Forest Inventory and Analysis Data Center Web page at http://www.fia.fs.fed.us/tools-data/. For additional information, contact Program Manager, Forest Inventory and Analysis, Northern Research Station, 1992 Folwell Avenue, St. Paul, MN 55108 or John Seifert, State Forester, Indiana Department of Natural Resources, Division of Forestry, 402 West Washington Street, Room W296 Indianapolis, IN 46204-2739.

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 randomly selected families and individuals who own forest land in Indiana. For additional information about the NWOS, visit: www.fia.fs.fed.us/nwos.

Timber Products Output Inventory

This study was a cooperative effort of the Division of Forestry of the Indiana Department of Natural Resources (INDNR) and the Northern Research Station (NRS). 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, Indiana Division of Forestry personnel visited all "known" primary wood-using mills within the State. Completed questionnaires were sent to NRS for editing and processing. As part of data editing and processing, all industrial roundwood volumes reported on the questionnaires were converted to standard units of measure using regional conversion factors. Timber removals by source of material and harvest residues generated during logging were estimated from standard product volumes using factors developed from logging utilization studies previously conducted by NRS.

Mapping Procedures

Maps in this report were constructed using (1) categorical coloring of Indiana's counties 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, or (3) colored dots to represent plot attributes at approximate plot locations.

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The second full annual inventory of Indiana's forests reports more than 4.75 million acres of forest land with an average volume of more than 2,000 cubic feet per acre. Forest land is dominated by the white oak/red oak/hickory forest type, which occupies nearly a third of the total forest land area. Seventy-six percent of forest land consists of sawtimber, 16 percent contains poletimber, and 8 percent contains sapling/seedlings. The volume of growing stock on timberland has been rising since the 1980s and currently totals more than 8.5 billion cubic feet. The average annual net growth of growing stock on forest land from 2004 to 2008 is approximately 312 million cubic feet per year. This report includes additional information on forest attributes, land use change, carbon, timber products, forest health, and statistics and quality assurance of data collection.

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

DVD Contents

Indiana's Forests 2008 (PDF)

Indiana's Forests 2008: Statistics and Quality Assurance (PDF)

Indiana Inventory Database (CSV file)

Indiana Inventory Database (MS Access file)

Field guides that describe inventory procedures (PDF)

Database User Guides (PDF)

http://www.nrs.fs.fed.us